Virtual Organization Simulation for Operational Management

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***Abstract*—This paper presents concept of the Decision Support System (DSS) for operational management of the Virtual Organizations (VO). It supports the VO manager by the VO rescheduling tool and a simulation of possible future performances of the VO. The embedded scheduler, which is also used for the simulations, is built upon multi-agent technology. The DSS is designed as a component of the VO management toolkit. If interconnected to the other toolkit components it utilizes up-to-date operational data. Otherwise, it may be operated as a stand-alone application. The DSS concept is proved by a research prototype.**

I. Introduction

In business-to-business e-commerce, collaborating partners (often former competitors) may act as a single company and thus to create a more competitive whole (Browne in [1]). Virtual Organization (VO) is an example of such joint company concept.

The Decision Support System is a tool for supporting VO operational and strategic management by a what-if analysis based on a simulated (re)scheduling and (re)configuration of VO plan and schedule. The simulation provides various possible scenarios of alternative futures influenced by defined occurrences to the VO performance. Through them the simulation allows verifying and comparing various configurations and their robustness, discovering possible bottlenecks and preparing potential adaptations of the VO configuration and the schedule.

The DSS concentrates on decision making process of the resource allocation in the VO management. A resource is something which enables the process operation. The characteristics of resources are that they are limited and their quantity is nonnegative [2]. Examples of resources are e.g. material or capacity of a plant. The distributed resource allocation is one of the basic problems studied in multi-agent systems [2]. The DSS utilizes the multi-agent technology for reallocation to optimize the VO schedule.

The DSS works with distributed resources reallocation and thus the specific features of the VO structure must be taken into account. They are mainly:

- *VO members*. They are autonomous, self-oriented and distributed.
- *Limited access to information*. VO manager has no access to the partners' internal information. The VO manager is limited only to information provided by members.
- *Already concluded contracts*. Withdrawing from a contract or changing the concluded details is limited by the contract and the affected member's willingness.

II. Virtual Organization – Related Concepts

The VO is a specific form of a network organization. It is formed from autonomous and mutually independent units that collaborate as a single company towards the customer. After the mission of the collaboration is fulfilled the organization is dissolved [3]. Collaboration in such organizations allows individual units to concentrate to their core competencies. Other features of such kind of collaboration are sharing risk with partners and use of information technology for the organization coordination [4].

Behind a VO there could be a stable network or cluster of entities that intend to repetitive cooperate. Such network is created to support its members in the VO formation and operation [5]. According to Faisst, the background network may be formed by big enterprises to clarify their organizational structure or to create a network of suppliers. On the other hand, the network may also be formed by business units to cover all the business aspects and opportunities that they cannot satisfy on their own [5]. The network may be also created and supported by a subject like state agencies that do not participate in the network or in network formed VOs.

A. Virtual Organization Lifecycle

During whole VO lifecycle, its manager is provided with VO management tools. In case of VO created by some form of a cluster, such cluster may support the VO management as well. The life-cycle of the VO consists of several phases. Number of slightly different VO lifecycles has been already presented (e.g. Fischer has extended the creation phase [6]; all of them build upon these basic three phases:

- *Creation phase*, which is the first phase after discovering a business opportunity. During this phase the VO is created: the VO task is defined, VO team is formed and then the VO is initiated.

- *Operation phase*,which contains all the value-adding processes of the VO. The operation of the VO is under control of the VO management. In some cases there is a need for an adaptation of the VO, e.g. initiation of new VO members. The adaptation is under control of VO management but it may be supported by tools primarily used during the VO creation phase.
- *Dissolution phase*, which finalizes and evaluates the VO operation and it potentially opens future cooperation. When the task of the VO is accomplished the VO operation may be evaluated. The evaluation concentrates e.g. to get information about reputation of individual members and their ability to collaborate with other members of the VO that is to be dissolute.

B. Power of the Virtual Organization Manager

Despite many similarities between VO and real organizations, there are significant differences that must be taken into account. One of them is the power of the organization manager. In case of a standard common organization, the manager has access to all internal data of subordinate units and is allowed to control the profit of each unit as well as its schedule in order to optimize the profit of the whole organization (although the profit of the single unit may be decreased). Besides their private goals all the units share one common goal, which is given by the organization manager. To optimize it, the manager has the right to assign tasks to inferior units without asking them about willingness to accept the tasks.

On the other hand, members of the VO are obliged by the concluded contract. They give access only to such information that they contracted to provide or they accept to provide. In the VO, processes of planning and scheduling are interconnected yet divided into two partially independent hierarchical levels:

- *VO manager level*, where optimization of the whole VO takes place, and
- *VO members' level*, where optimization of members' profits takes place.

Inner planning and optimization on the members' level is out of control of the Virtual Organization manager, who is responsible for optimization of the whole Virtual Organization. Planning and scheduling over the Virtual Organization members are much more difficult than planning and scheduling over an organization under central control. It requires advanced negotiation about the individual members' obligations.

C. Workflows in Virtual Organization

Specific of workflow management in VO is a distribution of the managed organization and therefore integration of the heterogeneous and autonomous workflow management systems or interfaces to them (Grefen in [7]).

Jun Yan et al. discuss weaknesses (mainly architectural limitations) of conventional workflow management systems for distributed workflows. Discovered weaknesses are: poor performance, lack of reliability, limited scalability, user restriction, and unsatisfactory system openness. In case described by Jun Yan et al. both data and control are distributed [8]. On the other hand as the workflow management of VO is oriented to the central point represented by the VO manager, the centralized aspects should be taken into account. Such aspect could be supported in some way by centralized technologies as well as the distributed aspects by distributed technologies. For a domain of VO some extension in inter-organizational support are required but the overall workflow concept is sufficient for VO requirements (Mohan in [9]).

D. Multi-agent Systems in the Domain of Virtual Organizations

In case of decentralized workflow it is suitable to use genuinely decentralized technology to support decentralized manner of the workflow (Jun Yan in [8]). Multi-agent technology, which is naturally distributed, seems to be promising to support such distributed environment of VO. Approaches to workflow management technologies vary from "viewing workflows as extended transactions" to "autonomous agent-based workflow implementation" (Dittrich in [10]).

Multi-agent system is a technology of distributed artificial intelligence; it is based on agents, independent autonomous software or hardware units, which may operate in cooperative as well as competitive environment [11]. In the VO domain the agents are mainly employed as representatives or models of individual partners or e.g. their individual work centers—the competency cells. The competency cell is defined by Wiendahl as an independent unit modeling a partner and one of its core competencies [12]. Each of the partners (and so their cells as well) operates with own resources that are not shared among the member's company. Although they collaborate, the VO members do not share all production relevant information they have (e.g. real costs). The multi-agent technology uses various levels of information privacy to model such characteristic of distributed environments [13].

Wiendahl also lists domains for agent application in the VOs [12]:

- *Network design.* Agents are utilized for partner selection, i.e. for identification of suitable partners and negotiation about their involvement in the network.
- *Operation of a network.* Agents are utilized for operational management of the network, i.e. for coordination of processes and process exception handling.
- *Modeling of network.* Agents are utilized for prediction of network future or alternative performance, i.e. for what-if analysis, and bottle-neck identification and removing.

Although modeling and simulation have been used to support production management for a long time, especially for distributed networks (e.g. Virtual Organizations) they become crucial e.g. for optimizing the production plan before the production itself is started [14].

The simulation of the VO as a VO manager tool for the VO optimization is studied e.g. by Osuna, who concentrates to multi-tier abstraction of the whole production process and has their simulation environment M2Value bounded to real enterprise data of simulated partners [14]. Savarimuthu et al provides JBees, the Coloured Petri net based multi-agent

framework for an adaptive and distributed workflow system [15]. In the MS2Value, JBees and in this work described DSS as well, the agents control resources.

In our work we concentrate to the last point of the Wiendahl's list of agent applications in the VO domain, the modeling of a VO. The reason of the model is simulation of the VO performance without influencing performance of the "real" VO during the simulation.

III. Decision Support System for Virtual Organization Management

The DSS has been designed as a component of the Virtual Organization Management toolkit (VOM) [16]. The VOM components support the manager by information about the VO obligations, configuration, up-to-date information performance and state of the work, and monitoring and alerting system for discovering impending deviations as well as simulations of alternative future VO performances. The VOM also contains distributed components located on site of the VO members. These distributed components are configured by the VO manager through a specialized tool for the performance indicators management and they provide another monitoring component with their measurements.

The VO configuration data as well as performance data are collected and analyzed to support the manager in the VO control. One of the features given to the VO manager is a possibility of the VO simulation; such feature is a key service of the DSS. It may be used together with the other toolkit components or as a stand-alone application. Added values of the DSS are the following features:

- *Using latest VO operational data.* Integration with other tools for VO operational management allows the DSS to provide manager with VO simulation based on the latest VO data.
- *Impending deviations alerting.* VO manager is informed whether any milestone is (according to the simulation results) expected not to be kept.
- *Suggestions of local adaptation and alternative VO configurations analyzer.* In case of expected schedule deviations the analyzing part of DSS provides alternative schedule of VO.
- *Murphy generator.* Generator of random deviations (negative as well as positive) of keeping deadlines and abilities to meet an engagement allows proving the VO configuration robustness. Outputs are presented in VO configurations analyzer.
- *Thin client.* Using web interface as system GUI, the DSS may be maintained by any provider e.g. as an on-demand service. In such case DSS users (VO managers) are provided with tools that they could not afford or maintain individually. This support saves VO managers' resources that would be used for maintaining local decision support systems.

A. The Application of DSS

The DSS concentrates on operation phase of the VO lifecycle. It offers user (the VO manager) with various possibilities how to configure and reconfigure VO and its schedule. Manual as well as semi-automated and automated (re)scheduling is supported. The core feature of the system is the what-if analysis based on a future performance simulation. As an input for the simulation the actual state of the VO, which is represented by a VO configuration and schedule, and to be simulated occurrences influencing them are used. The other simulation parameters configure using of the rescheduling, ability to move tasks to the earlier day if necessary and number of configuration rounds. The simulation provides adapted VO configuration how it would have been in case of occurrences injected to the simulation. To keep the causality in the simulation, although known, no information about any defined occurrence is used for the VO optimization before the defined time of its application to the schedule.

The simulation provided by the DSS operates with time constraints of the VO members' resources. There is a schedule defining when and how much of resources should be dedicated to the VO tasks and there are under the DSS investigations. The costs limitations as well as efficiency of the resources utilization are not in the scope of the DSS. To include them into the questions would mean extension of the re-scheduling module by new rules.

The DSS concentrates to one specific VO structure that consists of one VO manager coordinating the VO and team of executive units provided by the other VO members. The other VO structures (e.g. the golf-club) may be simulated as well if the re-scheduling module is configured according the appropriate community structure.

B. DSS Architecture

The DSS consists of various modules that together form a system supporting the VO manager in VO simulations and what-if analyses. The main adding-value feature of the DSS is a what-if analysis. It is provided by the simulation environment, which applies the "ifs" to the simulated VO and presents the "whats". Next to the simulation there is a VO configuration management that allows using up-to-date information about the VO status (only if connected to the rest of the VOM) and manual creation and adaptation of the VO configuration and its schedule. The VO related data are stored in a local repository from that they are provided to the simulation environment. The last main component of the DSS is a management of the DSS users' accounts. This component relates more to the deployment of the system then its value-adding features.

The Fig. 1 presents main modules of the DSS. The DSS main GUI provides personalized access to the system and VO configurations stored in the local repository. Through the main GUI the user selects a configuration and an action that should be applied to it. If connected to the VOMod (a component of the VO management toolkit containing latest operational data of the VO) new VO configuration based

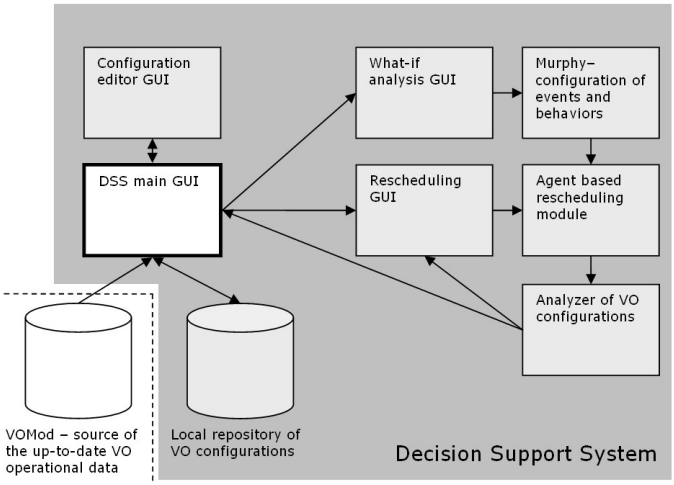

Fig. 1. The DSS architecture

on the data from the VOMod may be created. The existing configuration as well as new (empty) configuration may be manually edited in the configuration editor. The editor contains a feature of validation of syntax as well as semantics of the VO configuration data set. The configuration may be used for semi-automated rescheduling or the simulation based what-if analysis. Both of them uses agent based rescheduling module. The results of a rescheduling or a simulation are evaluated by an analyzer of VO configurations. The Murphy module is utilized for configuration and start up of the simulation for the what-if analysis.

1) The Simulation Environment: The simulation environment is built upon the multi-agent based scheduling and rescheduling system. The what-if analysis is executed by the simulation process, which consists of continuous rescheduling together with applying defined events and occurrences to the schedule. Before the simulation is started the what-if questions are defined in an interface called Murphy. After the simulation completion its results are evaluated in the analyzer. The analyzer presents answers to the what-if questions and is able to give recommendations by its rule-based system.

The scheduling module is based on the multi-agent architectures developed for the intra-enterprise scheduling and coordination of the Extended Enterprises (systems ExPlanTech and ExtraPlanT [17]). To model independent process units within the VO member's company the competency cell concept is employed. In the agent community, there is one agent nominated as a community leader (representing the VO manager) the other agents represent the competency cells of the VO members. Such architecture copies the hierarchical structure of the VO, where there is one VO manager responsible for the VO performance at all and for the realization of the VO task as concluded with the VO customer, and there is a group of other VO members being contracted to provide particular parts of the VO.

One VO member is represented by a group of as much competency cells as much core competencies it provides. Although representing the same VO member, the competency cells do not share their resources. If the resources are shared within a member's company and the VO manager is given such knowledge, the member may be modeled by less number of competency cells. Each group of competencies for that the VO member's resources are shared is provided by one competency cell.

C. Process of the What-if Analysis

The what-if analysis is a part of the decision making process. The analysis is based on the state of the system (VO in this case) as it is and the what-if analysis provides with the state how it could be. The decision making process uses the what-if analysis to generate various possible futures, which are generated according to configured constraints.

The what-if analysis consists of three main processes, which are:

- Process of the Simulation Configuration
- Process of Rescheduling
- Process of the Simulation Evaluation

During the first process the simulation (on that the analysis is based) is configured. Then the simulated rescheduling is executed and finally the simulated run of the VO is evaluated, and suggestions for elimination of the VO weak points are generated. The final decision about the VO schedule and configuration adaptations are up to the VO manager.

1) Process of the Simulation Configuration: The first step of the what-if analysis is definition of the "ifs" for that the analysis has to be provided. During the VO performance the VO manager is informed about realizations of the tasks and according this information the manager adapts the rest of the VO configuration and schedule. In the DSS, sources of deviations of the performance (according to the actual schedule) are represented by the events and behavioral models. The events represent situations influencing the schedule of individual tasks and they are not linked to the concrete VO member. The assignment and reliability of the VO members are modeled by the behavioral models. Events as well as behavioral models are applied to the optimal/acceptable (according to selected criteria) schedule of the task and they are causes of the task deviations in the simulated performance. The deviation may be negative as well as positive e.g. the task may be completed later or earlier than scheduled. They influence start and end dates of the task schedule, and the overall performance.

The events may be distinguished into two categories:

- The first category contains events of impossibility to accomplish the task by the assigned member. In case of such kind of event the VO manager has to look for another VO member to replace the one already assigned to the task.
- The other group of events contains such events that effect start date or end date of the task. In case of such type of event there is no possibility to reassign resources dedicated to affected task. Effect of tasks from the second group must be accepted and the rest of the schedule must be adapted to take their effects into account.

Before the main part of the simulation is started there are behavioral models assigned to the members participating in the VO. The behavioral model is a set of various probability numbers influencing the accuracy with that the member keeps the schedule. There is one model assigned to a member and it is applied to all tasks on that the member participates. Behavioral models of members are mutually independent.

2) Process of Rescheduling: After the simulation is configured the simulated rescheduling is started. The simulation may be provided for whole VO schedule or there may be a defined day that represents a "today" in the simulation. From that point in time the simulation is started. Everything, what is before this date, is assumed to be in the simulated past and therefore it is not influenced by the simulation. Everything else is in the simulated future that is in the scope of the what-if analysis. The simulated rescheduling works as follows:

1) All future schedules are canceled and already assigned resources are moved to the available resources of the related partners and their competency cells.
2) The most critical task is identified in the open list (list of tasks having not assigned all required resources). This task is removed from the open list and operated as the actual task.
3) The most suitable partner is found by CNP to operate the actual task. The best partner from the possible ones is identified according to the scheduling criteria (the earliest delivery date is an example of such criteria).
4) The simulation events representing dropping off resources are applied to the actual task schedule.
5) The behavioral model of the member is applied to the actual task schedule.
6) The simulation events representing variations in task start and/or end date are applied to the actual task schedule.
7) If the assigned partner is not able to fulfill the concluded schedule the algorithm continues by the step 3, where this member (as well as other in this task already failing members) is removed from the list of possible members.
8) The actual task is moved to the close list.
9) If the open list is not empty, the algorithm continues by the step 2.

When the rescheduling is finished the result schedule presents a schedule of the VO how it would be in case of configured deviations. If required, the rescheduling process may be run more than ones; the result schedules may differ due to various events and behavior models are defined by probability coefficients and so they influence the schedule in different manner in each run of the rescheduling. The process of the simulation evaluation, which follows after the rescheduling process, receives a bundle of the rescheduling results as an input.

3) Process of the Simulation Evaluation: After all rounds of simulated rescheduling the results of simulations are evaluated. The simulation analyzer module compares and evaluates the schedules from the simulated VO executions with the original VO schedule. The analyzer results consist of three components:

- Graphic overview of the original and executed schedule.
- Comparison of various schedule details.
- Findings and suggestions of the rule-based system.

The first component provides with a simple graphic overview of the original and final schedule. The second component of the analyzer result concentrates to changes of overall VO start and end dates, if the final schedule (i.e. after the simulated run of the VO) is fully covering all the requests for resources, and if they are provided in an appropriate time. This component also provides with overview of each task schedule and each member involvement. For the tasks their start and end dates are compared as well as an efficiency of the assigned time slot utilization. The member involvement overview presents list of tasks in those they participate and their workload and day load over the all VO. The results of the various details of the schedules comparison are, besides presenting in the system GUI, utilized by the rule based system as well. This system applies set of rules to the uploaded data and in case of positive findings of the weak points of the schedule these findings are presented together with suggestions pre-prepared by the expert.

D. DSS Prototype Deployment

The DSS prototype is developed to be deployed either on user's local computer or server; it may be deployed on third party server as well. Because of it the user interface to the system is implemented as a thin client. The system is developed as a server application using the Tomcat server[1]. In case of deployment on the remote server that server may be maintained e.g. by the cluster from that the VO is created. The DSS functionality may be provided as the on-demand service as well.

IV. Conclusion

In this paper we presented the Decision Support System (DSS) for operational management of a Virtual Organization (VO). The main feature of the tool is a simulation of the possible future of the VO performance. The simulation allows its user (the VO manager) to configure various events and VO members' behaviors that may occur during the VO operation. Such simulation is usable for discovering weak points of the VO schedule and configuration. The user may play with the tool to simulate various negative as well as positive deviations and pre-prepare suitable scenarios for their solving and utilization. The Fig. 2 shows the user interface of the what-if analysis configuration.

The abilities that the VO manager is given to control the VO are limited by manager's power over the VO members. The DSS architecture is designed to reflect these limitations. It may be connected to other system of the VO management toolkit to be provided with latest VO operational data. The DSS system is built upon multi-agent technology; the agents are employed as models of the VO members.

[1]Tomcat homepage: `http://tomcat.apache.org/`

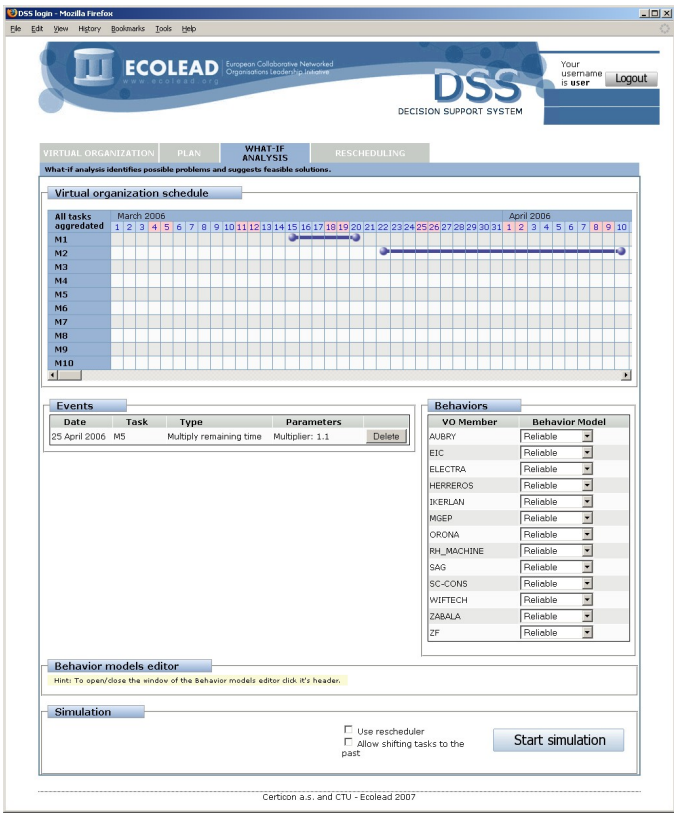

Fig. 2. Sceenshot of the DSS prototype user interface

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