Smart Enterprise: Multi-Agent Solution for Holonic Enterprise Resource Management

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Abstract — Holonic enterprises are considered as one of the new types of networking organizations used to increase business efficiency. In practice this requires to introduce a new type of management stimulating the “interpreneurial” approach, active interaction between actors to make coordinated and effective decisions on resource allocation, both within the individual project team and between the teams. In this paper we propose the concept of holonic enterprise based on the principles of leadership management and describe the multi-agent system for supporting decision making to maximize productivity of knowledge based resources. The system is called “Smart Enterprise” and combines top-down project planning with real time on-line bottom-up communication with employees. This provides more coordinated, flexible and efficient resource scheduling in case of unexpected events, which are an inevitable reality when the environment changes. The functionality and architecture of Smart Enterprise system is described, and its usage of ontology and multi-agent technology is presented.

Keywords — holon, actor, ontology, project management, multi-agent technology, resource scheduling, real time

I. INTRODUCTION

The challenges of the global economics associated with the growing complexity of business, a priori uncertainty and high dynamics of supply and demand make businesses look for new approaches to increase the efficiency of the modern project-based enterprises. Modern management science considers bureaucracy as the main obstacle for efficiency in organizations, in particular because of loss of content of tasks in the hierarchical lines of communication, ignorance of personal knowledge and employee talent. [1-2]. The solution requires a paradigm change by shifting from centralized, monolithic, hierarchical top-down structures to talent-driven networked organizations that are based on the principles of inter-subjective communication and negotiations between actors. [3].

However, most attempts to achieve this type of organization have failed, because of lack of systems to make interactions grow efficiently to larger organizations. Prevent a complexity disaster [10] an intelligent system is required that can operate in real time and constantly communicate with employees on all levels to obtain relevant information to coordinate the decisions on resource allocations.

The paper presents new approach to organize holonic enterprises and describes Smart Enterprise as a suitable candidate for overcoming the problem.

II. NEW APPROACH TO ENTERPRISE MANAGEMENT

Many modern companies oriented to the success and achieving long-term results, begin to develop internal culture of “interpreneurship” stimulating the appearance of the entrepreneurial spirit in usual daily routines; and pursues integration of personal entrepreneurial skills and enterprise resources [4]. This promotion of entrepreneurial mindset governs a wide range of relevant issues:

- stimulation & encouragement of new ideas from all levels in the organization,
- reduction or removal of barriers for collaboration between employees in different departments,
- recognition of the role of knowledge in the project management,
- acknowledgement of learning through trial and error and failures,
- provision of required resources,
- result oriented teamwork,
- development of a reward systems that promotes the best results,
- and, of course, support of the top management.

This approach breaks the existing bureaucratic stereotypes in the company management and results in designing networked organizations and implementing the principles of organizational democracy which could be based on ideas of holonic enterprises [5]. The organization of such enterprise can be explained as a multi-level network of business centers that can self-organize on virtual market of Parent Company, similar to the way businesses organize themselves within nations. The main features of such enterprises are given in TABLE I.

In this paradigm traditional managers (administrators) are replaced by talented leaders (actors) that form the interdisciplinary teams, in which the top-down instructions are replaced by goal oriented discussions to identify the most advantageous and coordinated decisions.

<table>
<thead>
<tr>
<th>TABLE I. THE CHARACTERISTICS OF HOLONIC ENTERPRISES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional enterprise</td>
</tr>
<tr>
<td>Centralization of functions</td>
</tr>
</tbody>
</table>

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III. MODEL OF HOLONIC ENTERPRISE

A. The Structure of Holonic Enterprise

The key elements of holonic enterprise structure are business centers (BC) that work as an autonomous virtual companies operating in the internal market of the parent company (MC) for projects implementation. This means that the organizational hierarchy is only used to illustrate affiliations by specialty of skills, not reference of authority. Let’s consider the structure of our company Smart Solutions as an example.

The structure of the company includes the BCs responsible for the projects in the corresponding domains (aerospace, factory, trucks, mobile services, railways, supply chain networks).

Knowledge centers (KC) act as resource pools for projects implementation. As knowledge is the key resource for success, the name appropriately reflects this relationship. They become a “home” for professional community of employees, where the level of qualification of employees is determined. Competencies profiles are designed, salary is assigned and individual trajectory of competencies development are created. The KC of the company includes:

- Analytics Center (AC) including analysts working on the proposals for government and commercial customers, gathering and specifying requirements, responsible for sales, marketing, advertising and development of contacts;
- Development Center (DC) including the platform developers, solution architects, programmers, testers and technical writers;
- Project Management Center (PMC) including business centers leaders, project managers and coordinators;

In this structure PMC is the operational “think tank”, that monitors the projects throughout their development cycle – literally from idea to implementation.

The AC is responsible for preparative work until the contract is signed, whilst DC is responsible from the contract is signed until the delivery of results.

### TABLE II.
THE EXAMPLES OF VPS ASSESSMENT FOR KEY TASKS EXECUTION RESULTS

<table>
<thead>
<tr>
<th>Task description</th>
<th>Expected results</th>
<th>Virtual shares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Searching for a new customer and preparing an initial letter</td>
<td>The letter attracted customer interest and resulted in signing the contract</td>
<td>50 - 150</td>
</tr>
<tr>
<td>Selecting a tender for</td>
<td>The tender is won and it helps to</td>
<td>150 - 350</td>
</tr>
</tbody>
</table>

B. Operations of Holonic Enterprise

A new BC is created on the base of the first project in the new domain or sector of application. From the very beginning the BC has its own profit and loss reports and usually requires an initial investment from the parent company.

The BC interacts directly with customers and grow from project to project, by gathering domain knowledge and seizing new opportunities. For this reason each business center (BC) is hiring the specialists from KB as well as technology/process knowledge and ready-to-use software components and document templates, best practices etc. to realize the projects. In turn, KB offers and pro-vides the employees to BC, certifies them and monitors their development, growth and success in projects. If the employee is not fully occupied, s/he can receive a new job in other BC’s or participate in establishing a new BC.

By design of organization between BC and KU there exists a conflict that requires negotiations for its resolution in each specific case considering the current company situation: Each BC having specific revenue is interested in obtaining the best specialists, but only for the period that is really required for the tasks execution, to maximize its profit. However, if the main goal of BC is the profit from projects, the goal of KC is the profit from delivery of the resources. This means that the employees, for which KCs are the “homes”, must be properly trained and have the required qualification, otherwise they will not be invited by BCs.

As a result, BC and KC have to negotiate horizontally and agree on the price and terms of specialists, software components and other resources. This is designed to make the projects and resources of the company effective. It is obvious that the more employees are chosen for by BC and work for the specific projects, the more profit is obtained by them and company as a whole and it is only achieved through the internal competition and cooperation on the company market.

In case of such organization each employee has the opportunity to give or receive offer his or her service to any BC negotiating on the jobs and work hours for each project. As a result of the agreements, the payments for employees become variable and can grow unconstrained. Employee’s “home” is also interested in this since it receives the interest for each employee that participates in BC projects.

For the long-term motivation of the employees to reach to final results, we have designed the mechanism of the virtual project shares (VPS) for the employees that reflect the personal creative input into each project and results achieved. VPS are issued by leaders of BC and KC with the view on results (TABLE II.).
In the case of successful task execution, the employee receives a specific amount of VPS in the projects. This is supplemented by the accumulation of the statistics on execution time for the tasks of this type which is used for new tasks estimations and generating recommendations. Finally, each project has the specific sum of shares, which is then normalized and results in participation interest payments for each team member in each project, which helps to allocate bonuses at completing the any stages of each project.

For example, the employee that has successfully implemented the task for organizing an exhibition that resulted in signing a few contracts will receive such “knowledge dividends” for each of these contracts.

As a result all employees may compete and cooperate with each other for success of projects and that motivates the results and increases efficiency of company.

IV. SMART ENTERPRISE SOLUTION: ONTOLOGIES AND MULTI-AGENT TECHNOLOGY FOR MANAGING HOLONIC ENTERPRISES

A. Main Functionality of Smart Enterprise Solution

The proposed solution is designed to support the full cycle of project management, covering resource allocation, scheduling and optimization, rescheduling according to events, coordination with employees and monitoring the execution of tasks in real time.

This requires that the solution takes a wide range of details into account:

- the semantic specifics of the tasks and how they match with the competencies of employees
- reallocates the employees according to the situation and in response to events
- supports employees interaction during decision making in real time project management
- and motivates people to achieve final result.

For this purpose Smart Enterprise solution is developed on the concept of resource-and-demand networks (RDN), uses an explicit ontology and multi-agent system to perform the real-time resource scheduling [6-7].

B. Multi-Agent Technology for Real Time Scheduling of Holonic Enterprise

The multi-agent technology brings the support for real-time decision making into project management by allowing the adaptive rescheduling of the resources when new tasks and unexpected events occur. These disruptions come both from outside the organization or as a result of interaction amongst the team members.

Multi-agent systems are particularly efficient in adaptation of existing schedules, as the update-event triggers the propagation of changes which lead to the new schedule by shifting, reallocating or swapping the operations of other employees. Hereby new project, changes to vacation plans, new tasks, delays, changes in deadlines, execution progress updates, etc. can quickly be incorporated in the schedule.

The principles of by which the multi-agent scheduling platform operates, can be briefly described as follows [8]:

- Each task and employee has its own software agent that receives the requirements, preferences and constraints for the scheduling and has its own individual schedule;
- A task agent begins the scheduling by searching for the required resources in the scene that reflects the current situation in the department, such as which employee is capable of executing particular tasks for the current scheduling horizon;
- If the appropriate employees are busy, the conflict is detected and the negotiations initiated;
- During the negotiations different options are possible: The new task will be moved to a less appropriate resource, the previously occupying task will leave the focal employees schedule or the tasks may rotate to a new order that is acceptable;
- Even after having solved the initial conflicts and established an initial schedule, the pro-actively continue to mine the solution landscape for better solution.

Such approach distinguishes the proposed system from the existing project management systems, in which all tasks and resources are considered as known in advance and, by principle; do not change during execution [9-10]. The key differentiator is that the agents that act on behalf of the orders, projects, tasks, departments, employees, software documents, etc. as illustrated below in TABLE III.

<table>
<thead>
<tr>
<th>Agent name</th>
<th>Agent description</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order</td>
<td>Order looks for the best possibilities to be fulfilled within the frames of existing or new BC and Ku, interests and competencies of the employees.</td>
<td>Contents, cost, time preferences, etc.</td>
</tr>
<tr>
<td>Project</td>
<td>Tries to organize and execute the project according to the given criteria, preferences and constraints, technological and business processes, availability of the employees.</td>
<td>Ontological descriptor of the project contents, employees, belonging to BC, budget and deadlines, results</td>
</tr>
<tr>
<td>Organization (BC, Ku, or project team)</td>
<td>Tries to achieve and improve the results of the group in general by the given criteria, monitors the situation, changes the</td>
<td>Organization type, list of employees, criteria and strategies, expected results and current KPIs</td>
</tr>
</tbody>
</table>
strategy for the selected agents, stress or release the constraints and preferences to find out and resolve “bottlenecks”, fixes result achievement

<table>
<thead>
<tr>
<th>Employee</th>
<th>Wants to be fully occupied according to his or her profile and receive bonuses for quality, productivity, etc. Also tries to master his or her competencies to achieve the higher level of qualification and salary.</th>
<th>Organizations, to which he or she belongs, competencies profile, work schedule, current task, qualification level, VPS, wages, author of documents and software components, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software component or document</td>
<td>Wants to be maximally used in the projects, if necessary, be improved. Considers the relation between other components, documents, tests, etc.</td>
<td>Design, application, ontological descriptor, author, project utilization, relation to other components, cost.</td>
</tr>
<tr>
<td>Technological or business process</td>
<td>Wants to be executed in the best way as a chain of separate operations (tasks) required to fulfill orders for the projects.</td>
<td>Product components, operations list and graph of relations between them, execution criteria, cost and other terms.</td>
</tr>
<tr>
<td>Operation</td>
<td>Looks for the best employees, documents and components according to the preferences and constraints of the project and relations with other operations.</td>
<td>Competencies and qualifications of the employee, duration, relation to the project and other operations.</td>
</tr>
<tr>
<td>Result (product)</td>
<td>Tries to be created as a result of project execution from ready-to-use or new components</td>
<td>Product (results) characteristics</td>
</tr>
</tbody>
</table>

The schedule is considered optimal under two conditions: Either when no agent can improve it or when the time for identifying alternative solutions has elapsed.

C. Ontology of the Holonic Enterprise

Ontology is an explicit specification of a conceptualization [11]. The ontology of the enterprise allows users to specify concepts and relations of project management domain, for example for the specific enterprises that are used by the agents as illustrated in TABLE III. (above)

Ontology allows creation of the formalized situation model for the real enterprise hereafter referred to as “scene” (Fig. 1).

The scene is formed by instances of semantic concepts of objects and relations, designed on the base of the enterprise ontology that connects the classes of orders, projects, business and technological processes, operations and employees with each other. These relations are analyzed by the agents and help to work out and make decisions, restricting combinatorial search in the system.

As a result, the key advantage of the developed system is the ability of customization of the system to enterprises including the specifics of their business-model, technological processes, competencies, employees’ qualification structure, etc.

D. Solution Architecture and Key Components

The solution is designed with three-tier architecture containing a user interface, the multi-agent scheduling business logic and a relational database. Each tier can be located at a separate server if needed.

![Fig. 1. Scene representation](image)

The key component of the solution is the application server that executes the adaptive scheduling based on events, interacts with subsystems, performs data processing and provides mechanisms for managing access rights in the system. At the moment there are two user interfaces:

- The management interface is designed for common project-management tasks, such as tasks allocation, jobs scheduling, results monitoring, schedules modification and other similar functions.

- The project member interface allows the employee to select tasks, create new ones if required, specify their preferences and browse list of the preferred tasks, and, report the progress on work done together provide their own estimations of completion time and other comments required for adaptive learning by the system.

An integration subsystem allows the system to interact with other information systems. At the moment Windchill and Microsoft Office Project are supported.

At runtime different events are imported which are processed by the scheduling subsystem in real-time. Examples of such event are:

- change of tasks parameters (planned execution time, etc.),
- change of the resource state (appearance of a new resource, change of the resource availability, change of employee skills),
- task completion messages and many more.
V. USER INTERFACE OF SMART ENTERPRISE SOLUTION

In the following, the users interaction with the system is illustrated. On the home-screen of the application (Fig. 2) the user can see the information about current projects, status of the created tasks, employees, and new events, as a dashboard. The information is displayed using the live tiles.

The applications start screen (home) provides the access to all parts in the system:

- projects – project details and schedule;
- tasks – current tasks execution status and results;
- employees – employees profiles and workload, virtual project shares;
- dynamics – workload reports and dashboards;
- knowledge base – ontology and scene representing the situation of the enterprise;
- services – additional services (MS Project integration etc.).

The top-down project management is done using the management interface via the corresponding logs (Fig. 3).

The logs display the information using grid views with additional color indication that reflects task status (not allocated, scheduled, in-progress, delayed etc.). The visual data grid component provides functionality for grouping, filtering and sorting data by any number of fields simultaneously. For example, the user can filter data by project, time range and responsible person. The graphical representation of the project schedule over the whole resource set is done using the combined Gantt-Perth chart (Fig. 4), reflecting the dependencies between the tasks. Besides this, the top chart on the screen displays the total department workload resources lack or excess.

The most interesting component is the project-members’ user interface; a new component that supports interactive usage such as:

- browsing the suggested tasks and selecting the task to execute;
- task decomposition or creation of a new task, changing task parameters (for example, work estimation);
- accepting the task, starting the execution, specifying execution problems, task completion, requesting help for the task;
- ability to specify the attitude of the executor to the task, how much does he or she like it (the task, which executor doesn’t like, can be reallocated);
- setting the preferences and constraints of the executor;
- event input (work left estimation, etc.);
- displaying tasks by statuses (not started, in progress, completed, etc.);
- task filtering using the semantic descriptors etc.

A sample screenshot of the project-member user interface is shown below in Fig. 5.

This interface enables the system to interactively communicate with the users to obtain detailed information about their evaluation of the tasks and use that information to develop alternative schedules to achieve the best result as effectively as possible.

The tasks are not imposed on the user, but rather suggested, so the user can decide by accepting or declining. The application hereby uses statistics of the similar tasks executed before, but imports the knowledge by letting the user revise the assumptions and if needed suggest new tasks, re-specify parameters, etc.

To monitor the results of the team a set of reports were developed to display general summaries of results for respectively projects and departments. Dashboards are shown and updated in real-time to display the dynamics of changes in the projects of, for example, important tasks, new project stages, increase of the project workload etc. (see Fig. 6).
VI. Obtained Results and Prospects

The first two implementations for respectively the aerospace corporation Energia and the software engineering company Smart Solutions shows a high potential of the approach by increasing the efficiency of enterprise operations and support of solution by both management and employees.

From these experiences the following results are emerging:

- Increase of the employees work efficiency - by 10-15%;
- Reduction of the efforts on tasks allocation, scheduling, coordination and monitoring for running project - by 3-4 times;
- Increase of the reusability of the existing resources (documents, components, etc.) - from 50% and more;
- Reduction of the time of response to unexpected events - by 2-3 times;
- Increase of the percentage of the enterprise projects completed within the required budget and timeframe - by 15-30%;
- The platform for increasing the number of projects without increasing the number of developers and analysts.

The main prospects of the further system development are associated with the implementation of a network-centric p2p platform for coordination of the work of non-project oriented departments, the development of the adaptive scheduling method of multi-criteria decision making with self-regulation by criteria, with the use of the cloud computing to provide the developed system by SaaS model.

VII. Conclusions

We have presented a new concept of holonic enterprise management, which at the moment is being tested at the aerospace corporation Energia and the software company Smart Solutions for increasing the productivity of knowledge driven innovation in a socially motivating manner.

The practical application of the developed concept results in the change of the company structure and the shift of paradigm from the centralized decision making and hierarchical structures towards networked organizations made on the base of business centers that are in a constructive competition for the resources with knowledge centers that compete for projects. The important role in this structure is played by leaders (actors, as opposed to managers) that can take the responsibility, dynamically form the teams to solve the emerging problems and achieve the results, with the ability for online interaction and negotiations to make coordinated decisions in the project management, particularly, in allocation employees to the projects and team forming, making and adapting project schedules, coordination of work completion time-frames and solving other issues.

The designed solution is

REFERENCES