Hierarchical structure, rigid relations between employees	Networking structure, flexible relations between employees
Closed to environment	Open to environment
The knowledge in decision making is rigidly fixed, the decisions are made according to formal rules of business processes	The knowledge is not fixed, priority is in generating new knowledge, the decisions are made not formally and are situation-driven
Planning approach, all resources are allocated in advance	Market approach, the resources are allocated when necessary
Top-down communication according with hierarchy	Peer-to-peer communication as required for problem solving
Batch planning, following the regulations and instructions	Flexible planning in real time, following events
Total control	Self-motivation
Fixed salary	Dynamic salary

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.

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 re-quires 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.).

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

Task description	**Expected results**	**Virtual shares**
Searching for a new customer and preparing an initial letter	The letter attracted customer interest and resulted in signing the contract	50 - 150
Selecting a tender for	The tender is won and it helps to	150 - 350

participation and submitting the proposal	improve P&L for BC activities	
Preparing patent review or review of product market tendencies	Competitors that show competitive advantages of the product or resulted in stating the scope of work for product improvement	100 - 300
Preparing and signing a contract with a customer	Demonstrations and negotiations were made, business and functional requirements are specified, project schedule and budget prepared.	350 – 500

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 out-side 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 III. Main agent classes of the system

Agent name	Agent description	Attributes
Order	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.	Contents, cost, time preferences, etc.
Project	Tries to organize and execute the project according to the given criteria, preferences and constraints, technological and business processes, availability of the employees	Ontological descriptor of the project contents, employees, belonging to BC, budget and deadlines, results
Organization (BC, KU, or project team)	Tries to achieve and improve the results of the group in general by the given criteria, monitors the situation, changes the	Organization type, list of employees, criteria and strategies, expected results and current KPIs

	strategy for the selected agents, stress or release the constraints and preferences to find out and resolve "bottlenecks", fixes result achievement	
Employee	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.	Organizations, to which he or she belongs, competencies profile, work schedule, current task, qualification level, VPS, wages, author of documents and software components, etc.
Software component or document	Wants to be maximally used in the projects, if necessary, be improved. Considers the relation between other components, documents, tests, etc.	Design, application, ontological descriptor, author, project utilization, relation to other components, cost.
Technological or business process	Wants to be executed in the best way as a chain of separate operations (tasks) required to fulfill orders for the projects.	Product components, operations list and graph of relations between them, execution criteria, cost and other terms.
Operation	Looks for the best employees, documents and components according to the preferences and constraints of the project and relations with other operations.	Competencies and qualifications of the employee, duration, relation to the project and other operations.
Result (product)	Tries to be created as a result of project execution from ready-to-use or new components	Product (results) characteristics

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.

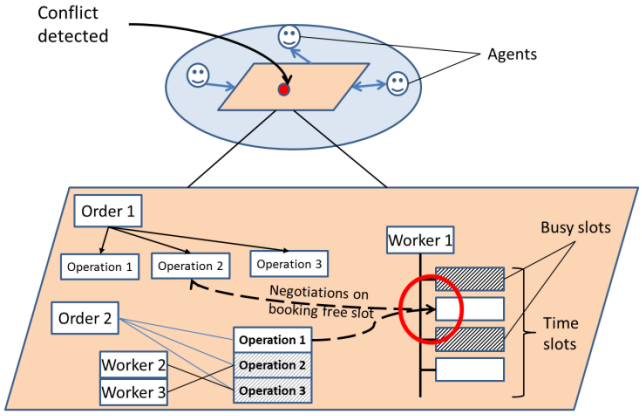

Fig. 1. Scene representation

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.

The main components of the multi-agent scheduling subsystem are: dispatcher agent, message interaction service, agents lifecycle support service, services for creation and deletion of the agents, support of the agent communication protocol and access to scene.

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.

Fig. 2. Home screen of the Smart Enterprise Intelligent System

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).

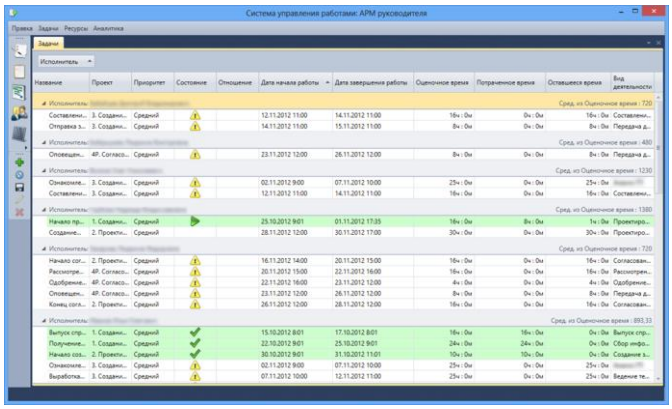

Fig. 3. Current tasks log

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.

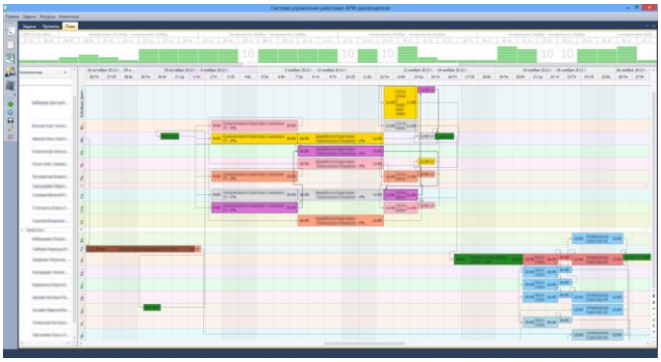

Fig. 4. The schedule represented by Gantt chart.

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).

Fig. 5. Project member user interface

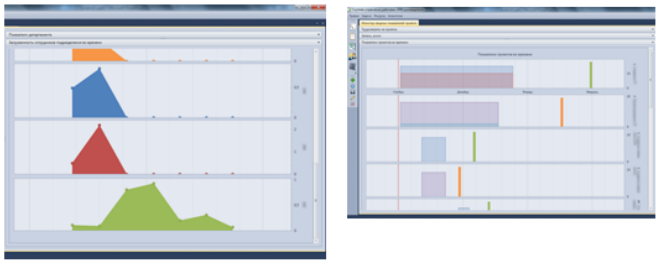

Fig. 6. Reports and dashboards screens

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

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