KNOWLEDGE GENESIS

Multi-Agent Technology for Resource Management

Managing Complexity: Multi-agent Technology for Resource Allocation, Scheduling, Optimization and Control in Real Time

Prof. Petr Skobelev, Founder & Chairman of Directors Board

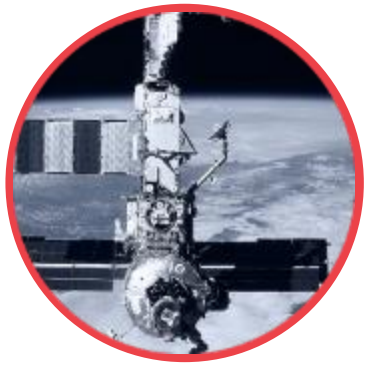
Introducing the Founder

- Founder and product/technology leader of Knowledge Genesis group
- Prof. of Aerospace University & and Technical University
- Software engineering company Smart Solutions Ltd (Samara, Russia) is one of most innovative and fast growing companies in Russia by AIRR, RVK and PriceWaterhouseCoopers
- Focused on developing multi-agent technology and solutions for resource management
- Research interests include multi-agent platforms, solutions and applications as well as Semantic web, ontologies and knowledge bases, emergent intelligence, Internet of Things and systems of systems
- Member of IEEE IES Technical Committee on Industrial Agents
- Author of more than 150 publications
- US patents on multi-agent systems for logistics, dynamic data mining and semantic processing
- Co-author of “Managing Complexity” book, published by WIT Press in 2014 (UK, London), available on Amazon: http://www.amazon.com/Managing-Complexity-G-Rzevski/dp/1845649362

Introducing the company

- Software Engineering Company “KNOWLEDGE GENESIS” - 2016 (Moscow, Russia);
- Multi-agent platform for resource management
- 150 employees, average age - 28;
- Scopus/WoS publications (2019): 228
- Invited talks at scientific conferences in England, Germany, Spain, Japan, China, Poland, Portugal, Italy, etc.

Specializing at Smart systems for real time resource management based on multi-agent technology


Smart Aerospace


Smart Factories for Machine-building


Smart Transport (LTL & FTL)


Smart Mobile services


Smart Railways


Smart Supply chains

Our **customers** and **partners**

Challenges of modern economy

Growing complexity of decision-making in business management

Uncertainty
Hard to predict change in demand and supply

Dynamics
Disruptive events, which totally change the plan

Contextuality
Decisions made depending on the current situation

Multicriteriality
Multiple criteria, preferences and constraints

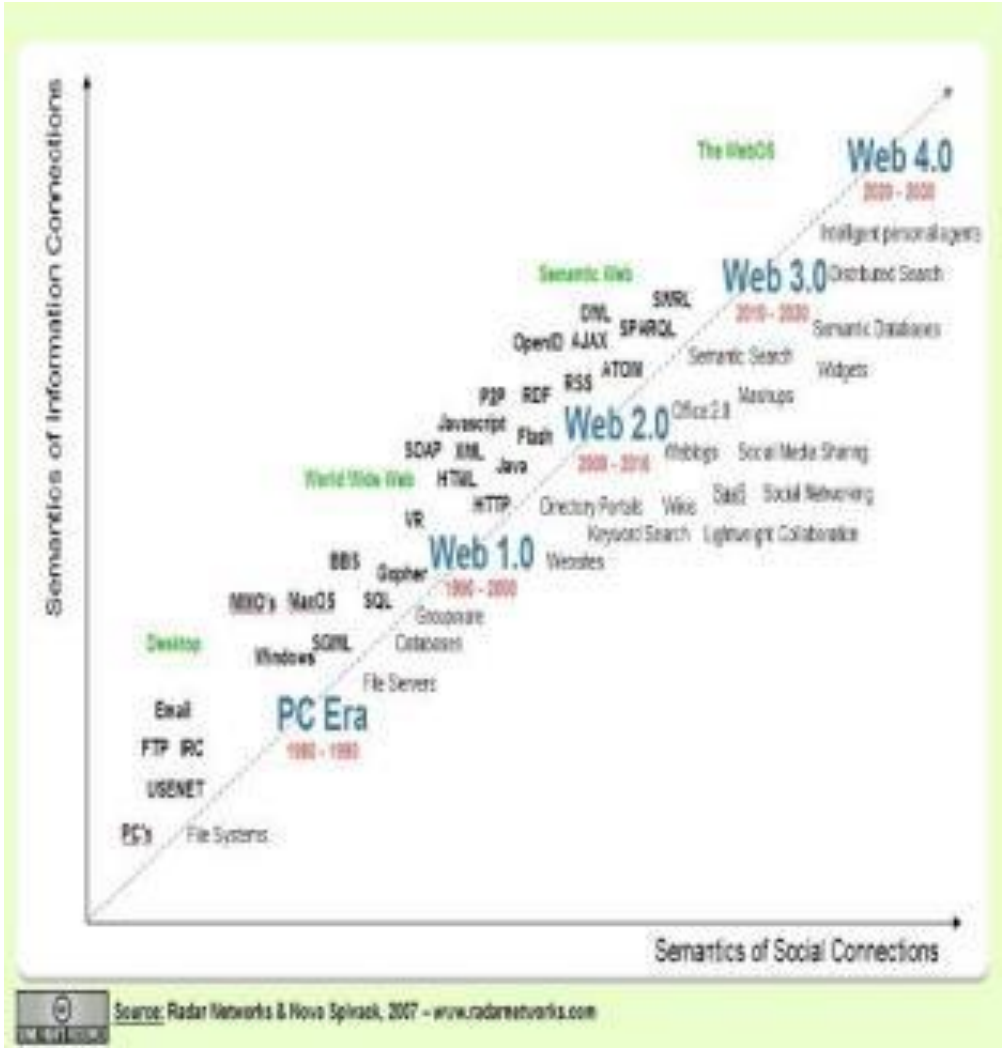
Interdependence
Making one decision can change the others

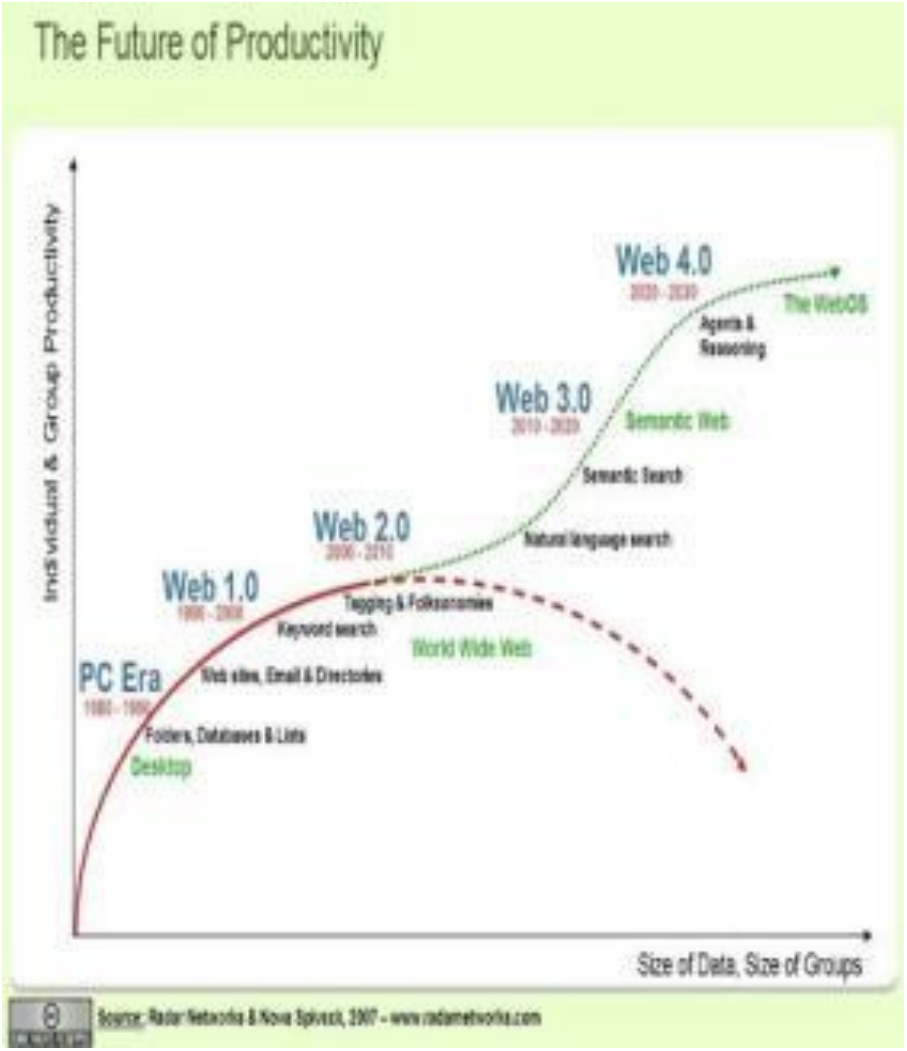
Individuality
Customers want a customized approach

Conflicts
More and more players with contradicting interests

Labour intensity
Too many options to be able to predict consequences

Development of IT for **productivity** growth





These trends require

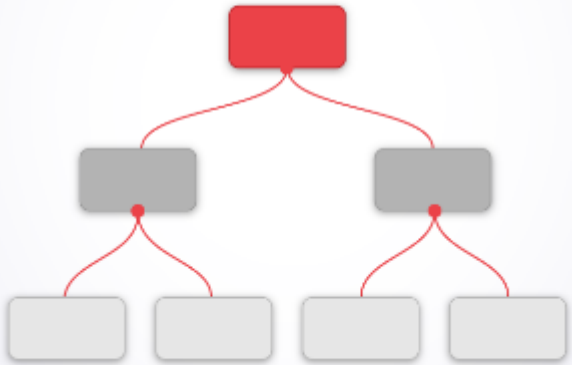
NEW METHODS AND MEANS

for decision-making

in real time

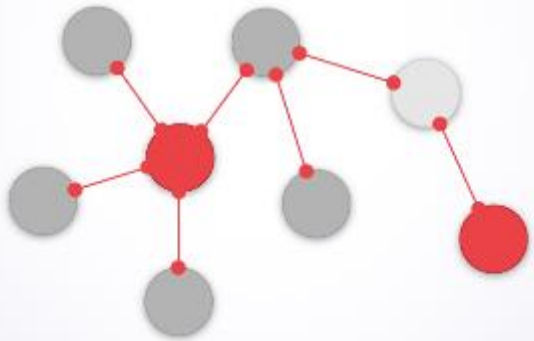
Multi-agent technology

Traditional Systems



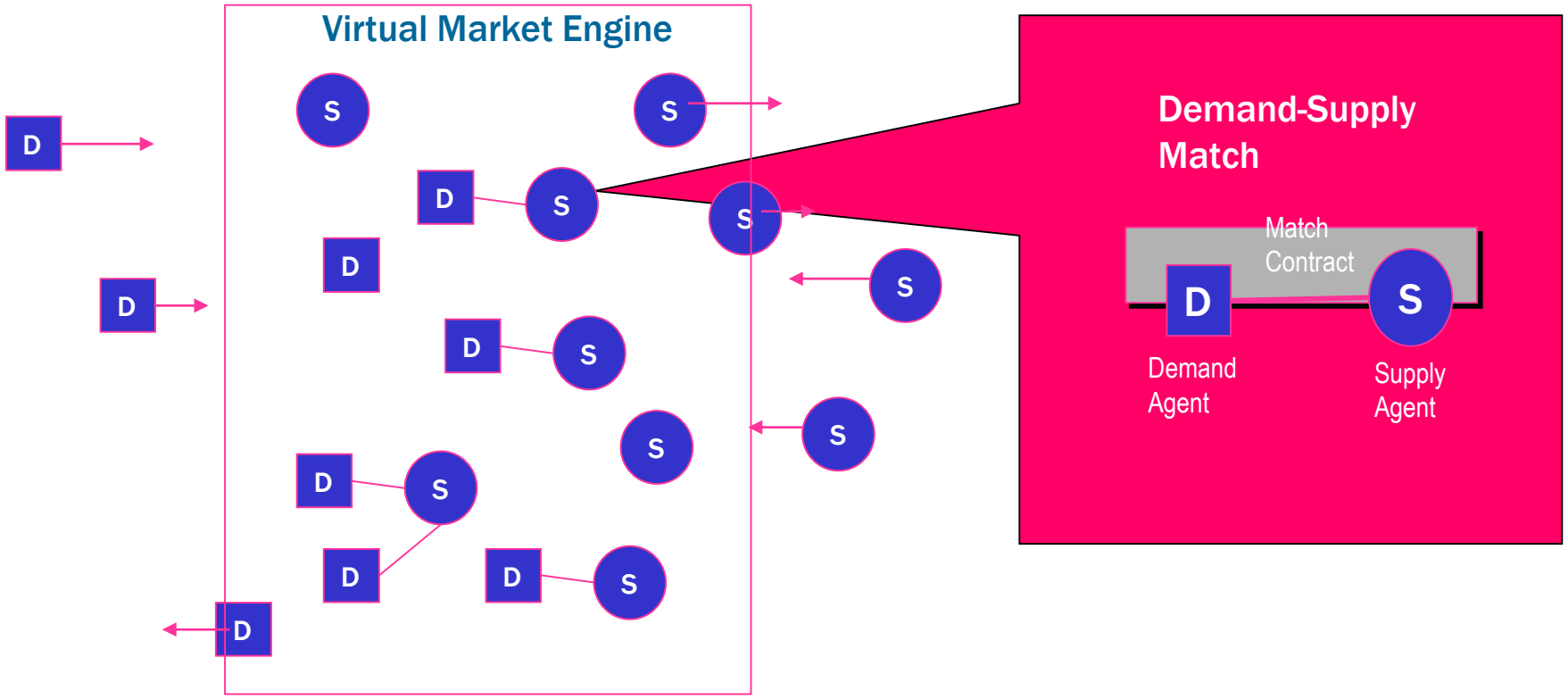
- Hierarchies of large software products;
- Sequential Processing;
- Top-down instructions;
- Centralized decisions;
- Data-driven;
- Predictability;
- Stability;
- Aim to reduce complexity;
- Full control.

Multi-agent Systems



- Large networks of small agents;
- Parallel Processing;
- Negotiations and Trade-Offs;
- Distributed decisions;
- Knowledge-driven;
- Self-organization;
- Evolution;
- Thrive with Complexity;
- Managing growth.

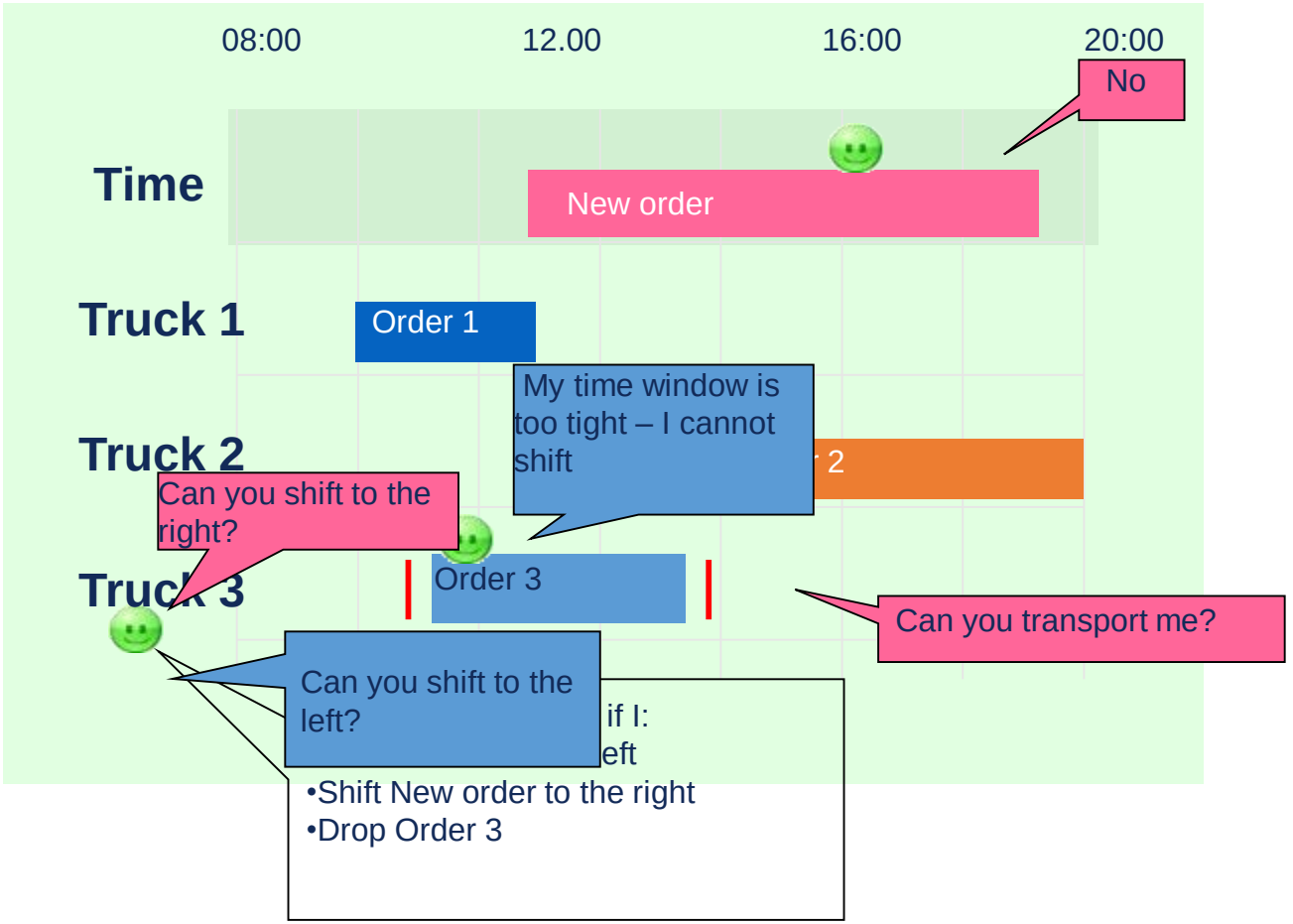
Multi-agent technology



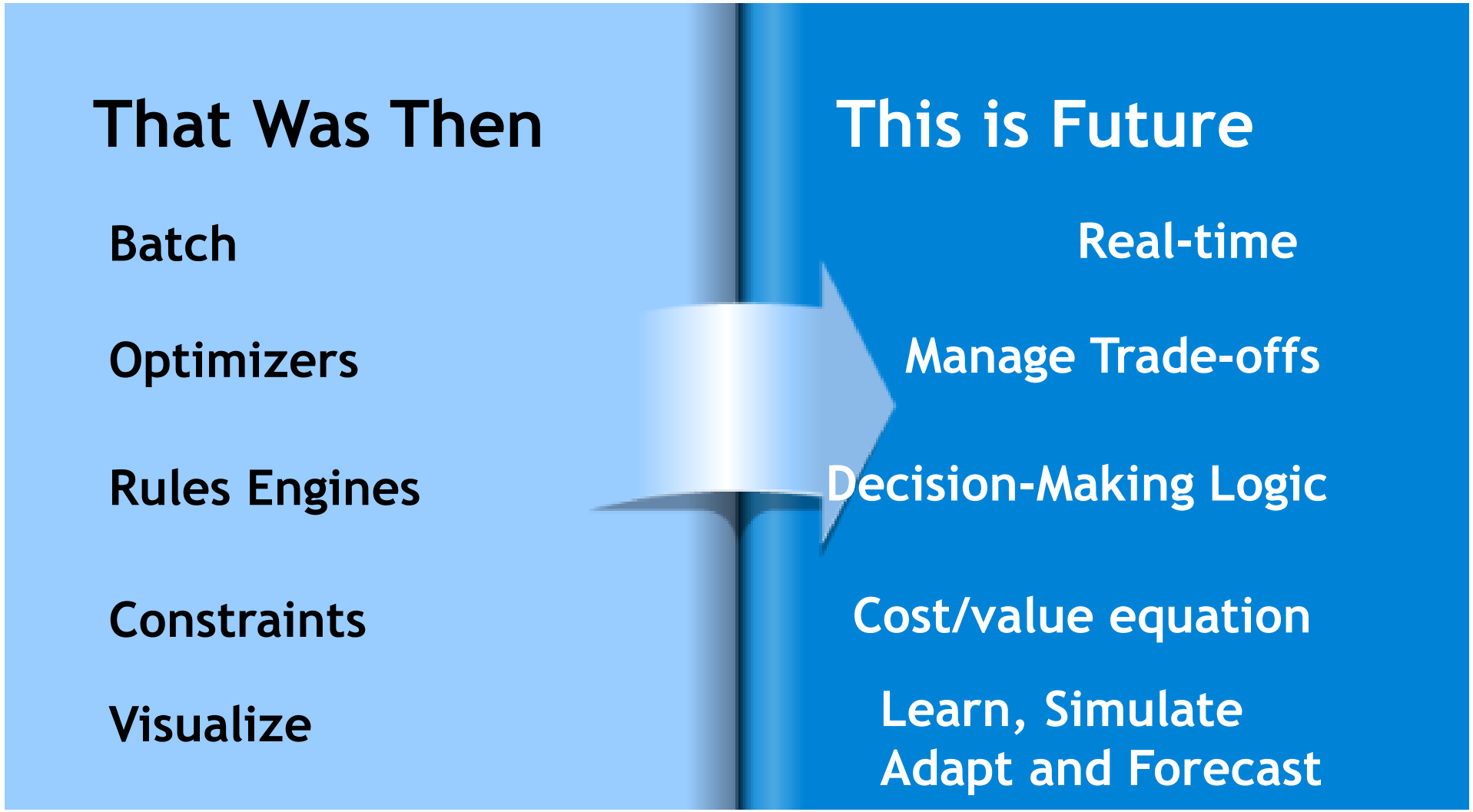
Demand and Supply Matching on Virtual Market Engine - is the Core Part of Real-Time Multi-Agent Solutions for Complex Problems

Logic of Multi-Agent Scheduling

- Existing schedule
- Pre-matching
- New order 'wakes up' Truck 3 agent and starts talking to him
- Truck 3 evaluates the options to take New order
- Truck 3 'wakes up' Order 3 agent and asks it to shift
- Order 3 analyzes the proposal and finds option with Truck 1 with shift and loosing part of profit
- Truck 3 asks New order if it can shift to the right
- Truck 3 decides to ask Order 3 to leave and take New order
- Agents of New Order and Truck 3 finalize agreement
- Order 3 starts allocates on Truck 1 by shifting Order 1



Summary of Coming Changes in Real-Time Economy



Benefits of multi-agent technology for business

- ✓ Allows enterprises to move to real-time economy
- ✓ Improves efficiency of resources, quality of the service, reduces expenses (time and money), risks and penalties
- ✓ Solves complex scheduling problems in production and transport networks replacing combinatorial search by solving conflicts and finding trade-offs
- ✓ Supports continuous adaptive re-scheduling in real time with quick reaction to events
- ✓ Provides an individual approach to every order and resource
- ✓ Supports interactions with users in 2-way directions
- ✓ Helps to reduce the role human-factor in the process of decision making
- ✓ Reduces development costs by reusing the code in new applications
- ✓ Enables modeling of "if-then" scenario to optimize decisions
- ✓ Creates a platform to support the growth of the complexity

Key result of implementations – efficiency of enterprise resource management

increased by 20-40%

SMART SATELLITES

Multi-agent system for managing interactions
within the swarm of satellites

Objectives, functionality and **results**

The system is designed for managing group of satellites as a self-organized swarm for solving various problems, such as remote sensing, detection of emergencies, the observation of objects, etc.

Functionality:

- ✓ Interaction of satellites directly or through special transponders that are in geostationary orbit.
- ✓ Individual or collective problem solving with a dynamic team building.
- ✓ Adaptive scheduling together with the distribution of tasks and solving them by parts, depending on satellites positions and opportunities, their on-board equipment and other parameters.
- ✓ Assigning roles dynamically in real time with their possible changing according to situation.
- ✓ Interaction with the data center to meet the objectives.

Results:

✓ Reducing the time for object detection up to 2.5 times in comparison with classical methods with data transmission via the data center

Demo of Smart Satellites

Link to Demo on YouTube:

https://www.youtube.com/watch?v=r7vKK9XnTCE

Tea Industry: The Example of Potential Application

The main requirements of the pest's control

1. The examination of the bushes very carefully!

2. Only after the expert 's conclusion and decision making

The main feature of pest's control

80% of manual labor due to relief and refinement s of tea leaves

Ceylon: Tea Production
> 4% of state area
> 2,5% GDP
> 700 million USD /year

A lot of tea bush ENEMIES:

- *Red spider Tetranychusbioculatus(5 kinds)*
- *Yellow spider Acarustranslucens(7 kinds)*
- *Mosquitoblight (Helopeltistheivora).*
- Caterpillars *Gracillariasp.* (4 kinds)
- Fungus *PestallozziaGuepini*
- Tea moth and aphids
- Mites
- Wireworms
- Medvedka

Pests control and struggle methods:

- ✓*Chemical spraying by emulsions*
- ✓*Manual cutting and burning of sick shoots*
- ✓*Using of the bug - the enemies of pests*
- ✓*Toxic baits*
- ✓*and many others*

The LOSSES from PESTS:

10-15 % of crop := > 0.25- 0.38 GDP

> 70-100 million USD /year

SMART FARMING

Multi-agent system for resource management in precision agriculture

Objectives, functionality and **results**

The work of the system is aimed at increasing productivity and reducing the cost of crop production through the use of modern decision-making technologies based on self-organization in complex systems, intelligent recommendations and knowledge bases, satellite remote sensing (ERS) data, jointly operating groups of Autonomous unmanned aerial systems and local changes using stationary field sensors (weather stations).

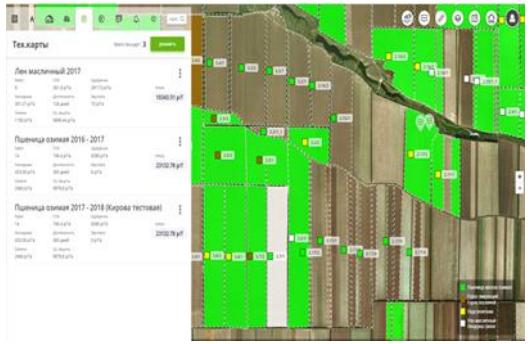
Functionality:

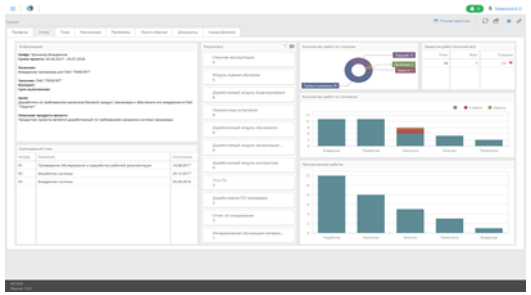
- ✓ Autonomous intelligent system (AIS) is used for unmanned cyber-physical management of climate-optimized, environmentally friendly and cost-effective agriculture;
- ✓ AIS is an open digital AI platform with ecosystems of intelligent services;
- ✓ Knowledge base in the field of crop production, based on the experience of the best Russian farms in the field of precision agriculture (based on no-Till technology)

Results:

- ✓ Increase of productivity and efficiency of farms incrop production by 5-15%

Description of product





Zone of the slug in the fields

The product is designed to automate decision-making processes for plant management, including problem recognition, response to important events, resource planning and control of the implementation of planned plans.

The system includes:

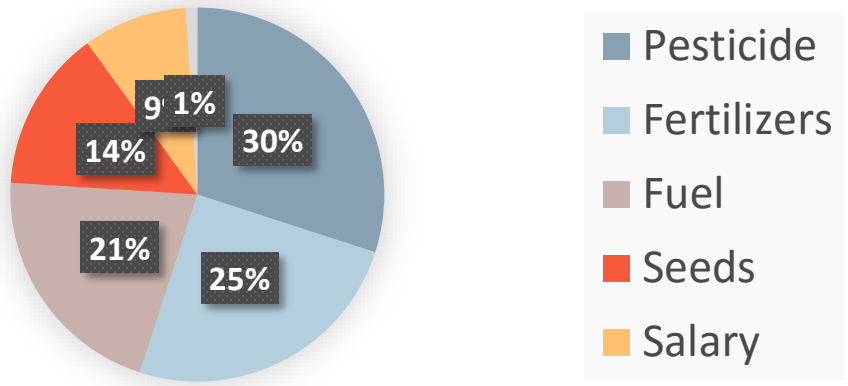
- ✓ Open platform for creating digital eco-system of smart services (cloud storage, shared bus, subscription and payment module, etc.)
- ✓ Knowledge base on crop production (varieties, technologies, diseases, pests, etc.).
- ✓ Eco-system of smart services for the daily management of accurate agriculture:
  - Maintenance of the fields, including the receipt of agrochemical analyses of soil;
  - Crop rotation planning;Selection of technologies and machines, fertilizers and plant protection products;
  - Monitoring of plant development and growth;
  - Operational management of teams of operators;Warehouse management;
  - Conducting the economy of the enterprise, etc.
- ✓ Virtual round table module for issuing recommendations and developing agreed plans by service agents on the context of the situation in the fields.
- ✓ Electronic market of products, supplies of goods and services for crop production, etc.

AI services: big data, neural network, learning from experience, etc.

The competitive advantages of the platform are based on the application of knowledge bases (Semantic Web), multi-agent technologies, models and methods of collective decision-making, smart Internet of "everything" (people, things and documents).

Expected result from the introduction of precision agriculture and cost reduction in the industry chain

The structure of costs for the production of main crops (for example, winter wheat):



The introduction of precision farming methods can significantly reduce the costs of the main items:

Fertilizers	**10 - 30%**
Pesticide	**15 - 60%**
Seeds	**10 - 15%**
Salary	**5 - 10%**

Reduce equipment downtime
15 - 20%

Increase productivity
10 - 20%

The platform and ecosystem of smart services will work in the cloud – there will be no need to introduce new staff to implement new tools

Subscription costs will be recouped for enterprises in the first year of operation by improving the quality and efficiency of products and reducing costs throughout the chain

SMART FACTORY

Multi-agent system for workshop management

Challenges in manufacturing

- Increasing risks for product immaturity and production disruptions due to high time to market pressure
- Complex and highly customized products for small production series
- Significant demand for automation and ICT controlled manufacturing systems and planning & control
- Weak integration of engineering to production (horizontal) and enterprise ICT to shop floor automation (vertical)

Goals of the project implementation

- Risk mitigation and management strategies for integrated control and optimization
- ICT systems implementing knowledge processing multi-agent-systems for pre-planning and production control and optimization within a scalable architecture
- Intelligent and knowledge-based tools supporting the control and dynamic optimization of factory assets
- End-to-end integration with legacy systems and across all production levels and along the planning and production phases

Project **results**

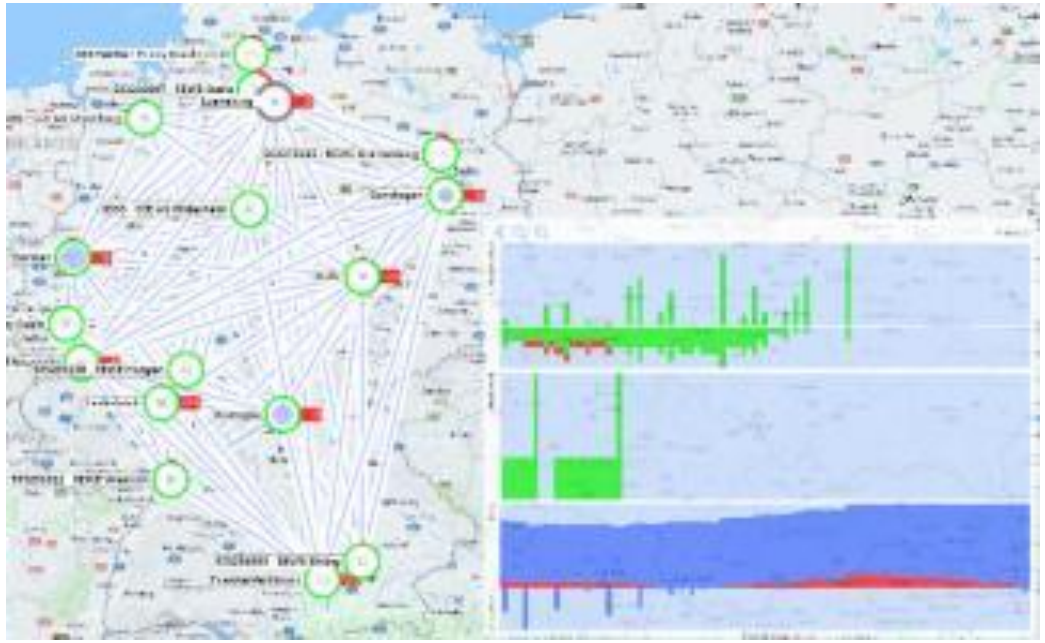
- Strategic plan of the enterprise is coordinated with plans of workshops;
- Capability to find resource bottle-necks in real time;
- Dynamic real time scheduling of new orders taking into account workshop capacity and labor intensity of the operations;
- Setting deadlines for start and finish of operations in workshops;
- Coordination (through interaction) of the deadlines with the workshop operative scheduler;
- Recalculation of plan and production indicators in real time;
- Capability to evaluate delivery dates for a new order and its influence on the others;
- Always relevant production schedule, updated in real time;
- High productivity of scheduling process;
- On-line integration with PLM- and ERP-systems.

SMART SUPPLY

Multi-agent system for supply chain management

Example of delivery scheduling task for Coca-Cola

- More than 300 distribution centers.
- 8 factories.
- 3000 orders in the operational plan.
- Delivery from internal and external factories.
- Individual importance criteria for each order.
- Searching for the cheapest delivery options.
- Taking into account repackaging operations.
- Taking into account confirmed production and transportation plans.



Challenges of supply chain management

- Complex network structure, multiple options for order execution.
- Various order importance.
- Necessity to improve quality and reduce costs.
- Distributed production capacity.
- Dynamic, changing constraints in production and transportation.
- Various cost of transportation, depending on the direction, transport types and cargo volume.
- Current warehouse stock.
- Accuracy of sales forecasts.

Quantitive parameters of scheduled networks :

- 10 thousand items.
- 2 thousand nodes in the network (enterprises, dealer centers, warehouses).
- 1 thousand delivery channels.
- 2 thousand orders per day.
- Horizon – from 1 week up to several years.

Implementation **effect**

Smart Supply

- Improving service level (up to **10 %**)
- Increasing profitability (up to o **25 %**)
- Increasing schedule quality (finding better solutions)
- Decreasing complexity and labor intensity of dispatchers' jobs
- Decreasing dependence on human factor
- Mitigating risks of unfulfilled orders
- Global evaluation of the current state
- Transparency and availability of information

Competitive **advantages**

Smart Supply

- End-to-end scheduling in distributed heterogeneous networks
- Relevant plans - always, not only when requested
- Automatic rescheduling based on new events
- Engaging people into the scheduling process
- Capability to adjust only certain schedule sections
- Personal settings and criteria for different workflow participants

SMART RAILWAYS

Multi-agent system for adaptive real-time train scheduling with conflict solving

Challenges of real-time train scheduling

Railway infrastructure:

- About 700 km of railways
- 5 scheduling regions
- 49 stations
- 48 railways segments: 2 – four-track, 14– three-track, 31– double-track, 1 – single-track
- 3700 block sections

Operational Scheduling:

- 5 dispatchers and 1 chief dispatcher
- Scheduling time horizon – from 6 to 18 hours
- 810 trains: cargo, service, suburban, passenger, Sapsan Siemens fast trains. Support of up to 50 various train priorities
- Intensive traffic in suburban areas of Moscow and Saint-Petersburg
- Up to 100 conflicts during dispatcher shift (track maintenance, track damage, warnings, track occupancy, train damage, out of schedule)
- Update on train placement– about 50 signals per minute

Factors of good scheduling:

- No crowding of train graphic lines or traffic jams at spans
- No unjustified choice of the opposite track
- Stays only on suitable infrastructure block stations (not on the main tracks)

Functionality of the system

Loading input data for operational train scheduling:

- Uploading the planning section infrastructure
- Downloading train traffic master-plan / Generation of the initial train schedule for the given time horizon
- Downloading planned maintenance windows

Adaptive processing of disruptive events/conflicts:

- Unplanned maintenance windows
- Warnings on infrastructure sections
- Train breakdown
- Track breakdown
- Train delay / running ahead of schedule

Processing updates of the current situation:

- Routing by dispatcher schedule (in particular cargo trains without a schedule)
- Processing the current train placements
- Processing track occupancy

Managing a set of constraints:

- Train lengths
- Tonnage ratings
- Normative running/acceleration/breaking times

Implementation **effect**

- Decrease in manual work needed for train re-scheduling
- Increase in the dispatcher's efficiency - by more than **twice**
- Decreasing overall reaction time to an unexpected event
- Returning to the master-plan is at least **1,5 times faster**
- Increasing railways network efficiency
- Potential for increasing the number of trains in the schedule
- Real-time analysis and forecast of traffic indicators
- Decreasing the risk of serious disruptions of train traffic
- Reducing human factor of dispatchers
- Double-checking all decisions and reducing time of training

SMART TRUCKS

Multi-agent real-time cargo scheduling system

Objectives, functionality and **results**

The system is designed for implementation in logistics companies: to enter and track orders for the delivery of goods and resources (trucks), allocate orders for trucks and schedule delivery in real time.

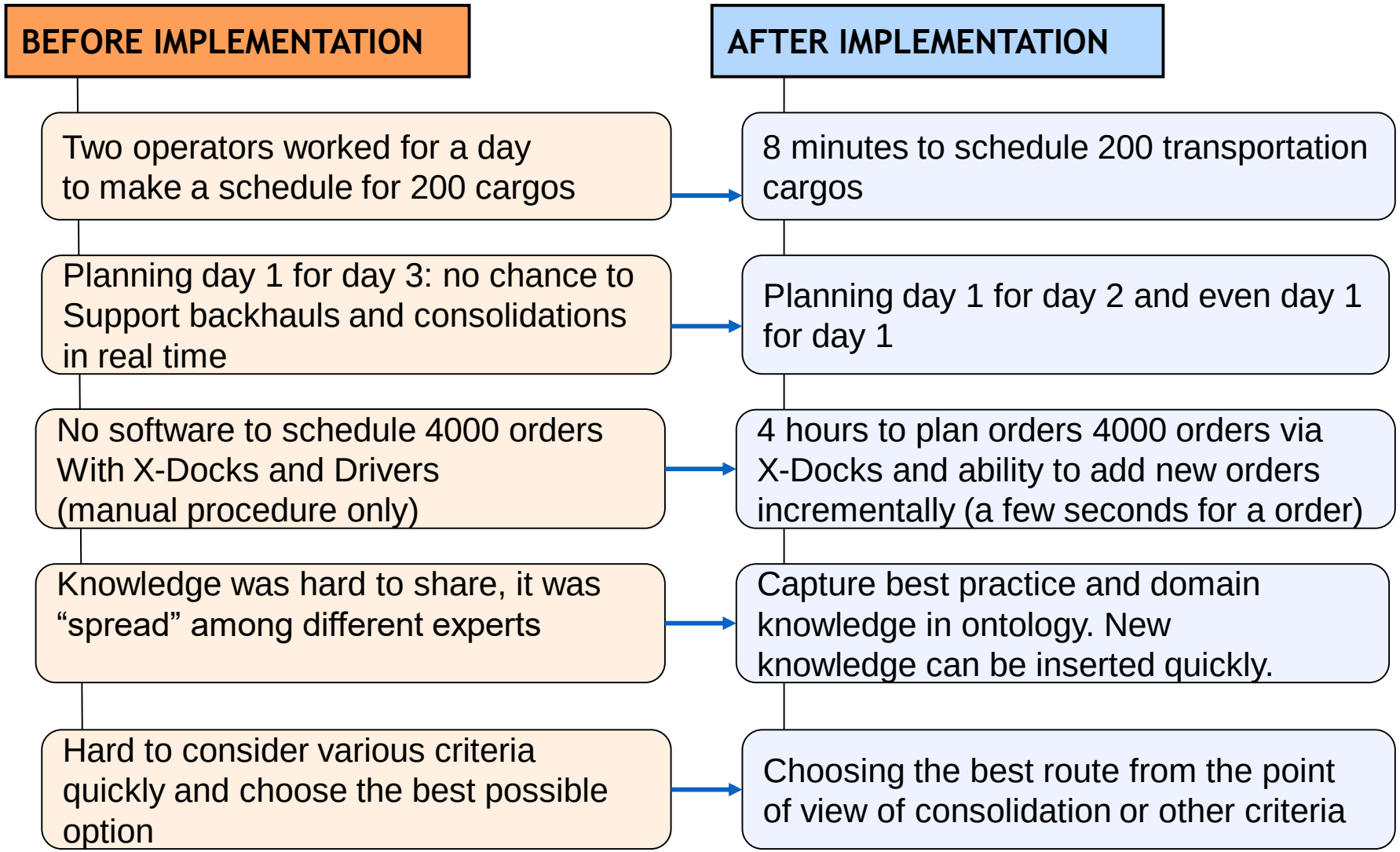
Functionality:

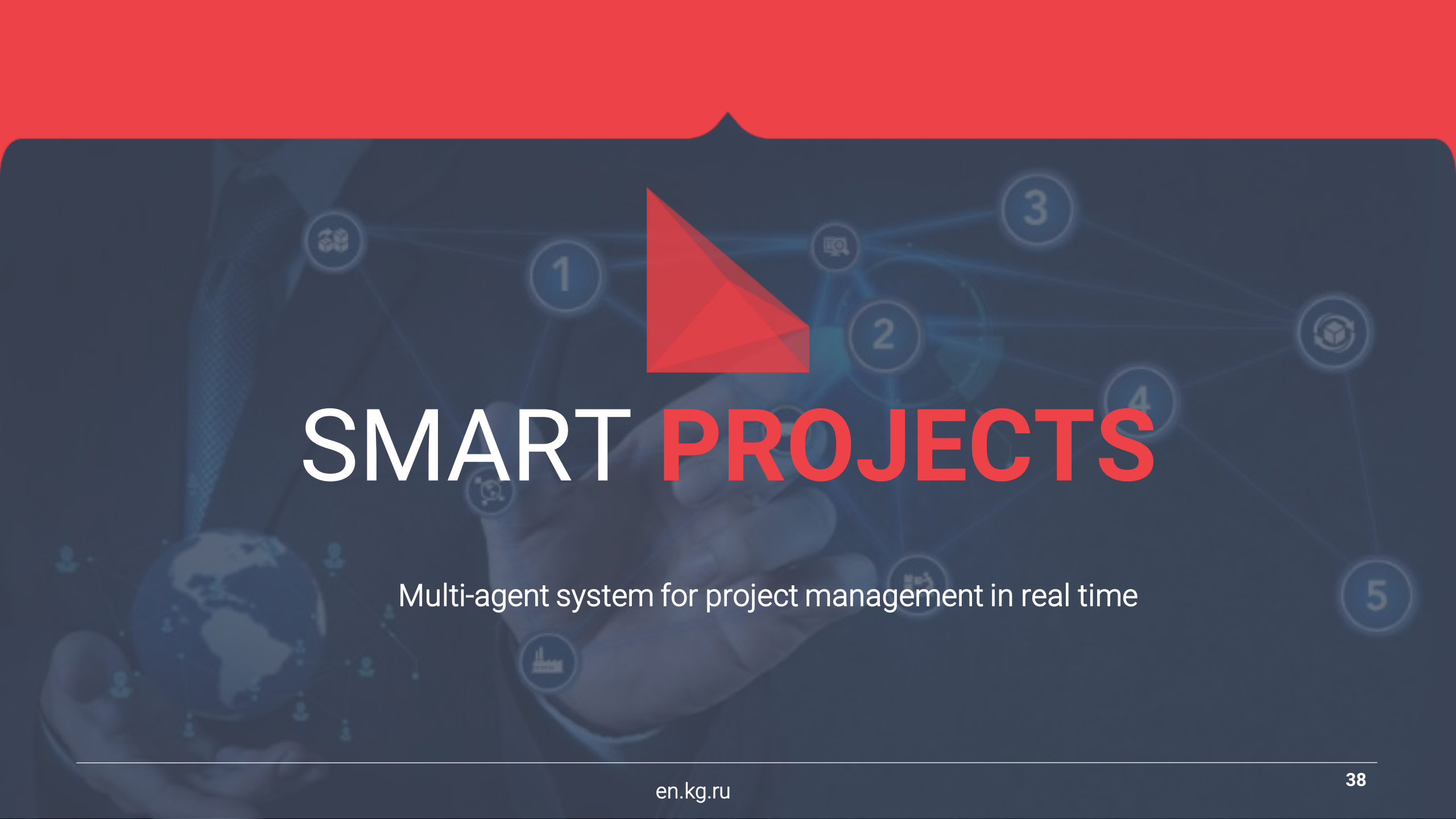
- ✓ Formation of orders, organizations, resources and other handbooks
- ✓ Order input or receiving orders from the customer portal, editing of orders
- ✓ Input adjustments of the current transport location
- ✓ Dynamic situational planning - automatic scheduling and rescheduling of orders in real time
- ✓ Monitoring own trucks position and the planned routes on the map (using GPS)
- ✓ Control of business processes and monitoring the performing of plans through the driver's cellphone
- ✓ Analysis of the performance of real-time (business-radar)

Results:

- ✓ Increasing the efficiency of business by **20-40%** for the same resource capabilities, without increasing headcount or truck fleet

Implementation **effect**





SMART PROJECTS

Multi-agent system for project management in real time

Objectives, functionality and **results**

The system is designed for implementation in enterprises engaged in project activities: to enter and conduct R&D projects and tasks, resources and processes, and automatically distribute the work load between the human resources in real time.

Functionality:

- ✓ Real-time reaction to events and plan adaptation
- ✓ Formation of a project plan, based on knowledge
- ✓ Balancing the interests and objectives of actors
- ✓ Prediction of critical situations before they occur
- ✓ The semantic web of documents
- ✓ Situational adaptation of actor's plan
- ✓ Clear understanding of the development paths and results achievement
- ✓ Self-organization of labor groups
- ✓ Improving the consistency of enterprise objectives

Results:

- ✓ Better planning of actors workload and control over execution of the plan
- ✓ Rapid and flexible response to unforeseen events, timely schedule replanning
- ✓ Support for decision-making in the planning process
- ✓ Reducing costs and time of project implementation

Summary

Dynamic scheduling

- Reaction to events and plan adaptation
- Formation of a project plan based on the knowledge
- Balance of projects and engineers interests
- Prediction of critical situations before they occur

Accumulation of knowledge

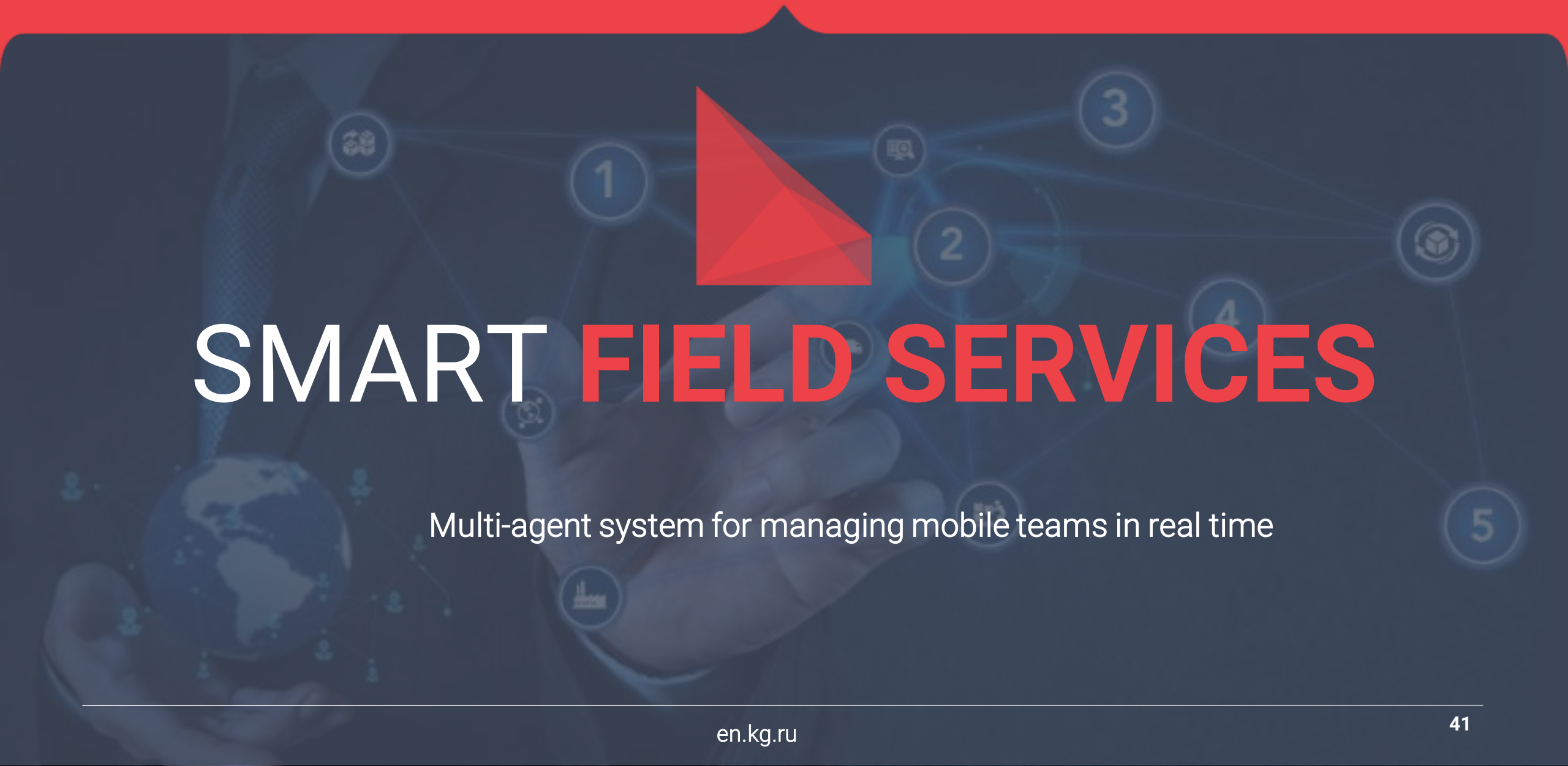
- Accounting of all the nuances of the organization for effective management and knowledge transfer
- Semantic net of documents

Execution support

- Special work place for actors
- Situational adaptation of actors plan
- The opportunity to participate in the management of

Motivation and development of staff

- A clear representation of the development path and achievements
- Self-organization of workforce
- Improved coordination of the company goals



SMART FIELD SERVICES

Multi-agent system for managing mobile teams in real time

Objectives, functionality and **results**

The system is designed for implementation in companies (gas, water, telecommunications, etc.) that operate on networks of different geographically separated sites using mobile teams: to conduct the work of municipal and emergency services, and resources (mobile units), and also automatically distribute workload among human resources in real time.

Functionality:

- ✓ Monitoring, control and management of mobile resources in real time
- ✓ Integration with order receiving system, accounting systems, GPS-navigation and mapping systems
- ✓ Construction of work plan as well as creating a list of tasks for each team and for each order
- ✓ Interaction between team manager and dispatcher with the help of applications for mobile devices
- ✓ Rapid adaptive scheduling of mobile teams on the events in real time
- ✓ Mapping routes and schedules on the electronic geographical map
- ✓ Intelligent decision-making support for selection of resources (analysis of the situation in real time, choosing the suitable team, building the route of the team, minimizing the time and adapting the schedule when different events occur, reducing mileage and so on)

Results:

- ✓ Increasing the efficiency of teams by **40%**
- ✓ Transparency of emergency teams business processes
- ✓ Reduction of complexity and simplification of work
- ✓ Reduction of human factor in decision-making, reducing the number of errors in planning by managers

Ideas for Cooperation

Cooperation within **Industry 4.0**

Areas of interest for collaborative projects:

- Smart transport, supply chains, mobile teams, projects, factories, etc.
- Multi-agent technology for resource scheduling in real time
- Ontologies and knowledge bases for real time scheduling
- Smart Internet of Things

Ways to catalyze projects:

- Pilot projects supported by local governments with universities involvement
- Forming international consortiums for Russian – Chinese Ministries of science and education
- Joint Ventures between Russian and Sri Lanka businesses: start locally and expand to the world

Conclusions

- ✓ We spent 15 years to develop first generation of Multi-Agent Solutions for scheduling
- ✓ It was proven that Multi-Agent Technology is innovative solution for full cycle resource management in applications with high uncertainty, complexity and dynamics
- ✓ Lessons learned in industry are showing 20-40% increase of enterprise efficiency
- ✓ Time is coming for the next generation of smart solutions based on advanced models of self-organization and evolution
- ✓ New developments will be focused on knowledge-driven fully distributed Smart IoT solutions

Why not to make it together?

Thank you!

Petr Skobelev

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