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The 1st IFAC Conference on Modelling, Identification and Control of Nonlinear Systems

Final Program and Book of Abstracts

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Saint Petersburg State University

Ouadi, Hamid — Ismra
Giri, Fouad — Univ. of Caen Basse-Normandie

This paper deals with the problem of wind energy conversion systems control. The considered aero-generator involves a hybrid excitation synchronous generator (HESG). To extract the maximum power from wind energy system, it is recommended to operate at variable speed. However, this control requires the measure of wind speed, rotor speed and aerodynamics torque, which are both difficult in practice and not very reliable. This paper presents a design of sensorless maximum power point tracking (MPPT) speed controller for achievement of the above energetic goal without resorting to mechanicals sensors (wind velocity, HESG rotor speed and aerodynamic torque). To this end, the control observation strategy is developed, based on the nonlinear model of the whole controlled system and only using electrical variables measurements. The control strategy involves: (i) online reference-speed optimizer designed using the turbine power characteristic to meet the maximum power point tracking requirement. (ii) an interconnected state observer providing online estimates of stator resistance, rotor permanent flux, rotor speed, aerodynamic torque and wind speed. (iii) a nonlinear MPPT speed regulator designed (using the backstepping technique) for the case where the wind speed remains lower than a maximum level (denoted wb). (iv) an optimization of the electromagnetic torque provided (by controlling the machine timing angle (ψ)) to improvement the HESG efficiency. The performances of the proposed regulator are analyzed using tools from the Lyapunov stability. These theoretical results are validated by a series of simulations to show the contribution of hybrid excitation with a wide variation of the wind speed.

16:00-16:20 — ThPM_1T3.4

Decentralized Control for Self-Deploying Robotic Networks: Sweep Boundary Coverage

Semakova, Anna — Saint Petersburg State Univ
Ovchinnikov, Kirill — Saint Petersburg State Univ
Matveev, Alexey S. — St.Petersburg Univ

Several nonholonomic Dubins-car like robots travel over paths with bounded curvatures in a plane that contains an a priori unknown region. The robots are anonymous to one another and do not use communication facilities. Any of them has access to the current distance to the region and can determine the relative positions and orientations of the companion robots within a finite and given visibility range. We present a distributed navigation and guidance strategy under which every robot autonomously converges to the desired distance to the region with always respecting a given safety margin, the robots do not collide with one another, and the entire team ultimately sweeps over the respective equidistant curve at a speed exceeding a given threshold, thus forming a kind of a sweeping barrier at the perimeter of the region. Mathematically rigorous justification of the proposed strategy is offered; its effectiveness is confirmed by extensive computer simulations.

16:20-16:40 — ThPM_1T3.5

Solving the Initial Transport Resources Allocation Subproblem in a Special FTL Real-Time Transportation Optimization Problem by the Hungarian Method

Skobelev, Petr — Smart Solutions, Ltd
Mayorov, Igor — Samara State Tech. Univ
Lada, Alexander — Smart Solutions, Ltd
Malkovskii, Nikolai — St. Petersburg State Univ

The special real-time problem of transport resources allocation for freight transportation companies that deliver cargo via FTL business model was considered. Each freight transportation company should react on incoming events adaptively reallocate available resources. For this purposes multi agent systems are well proved and used in many modern freight companies. But it was admitted that there is a possibility to improve a quality optimization level by using classic optimization approach in the special initial allocation subproblem. By using expert human real logistic scheduling knowledge for a long time period the essential set of limitations to this initial allocation plan problem was defined. The problem was formalized similar to the classical assignment problem of linear programming. Acyclic and cyclic cases of the problem were considered. It was shown that the acyclic case of the problem could be reduced to the assignment problem easily but for the cyclic case it requires to exclude important resource to order matching condition. Finding the exact solution of the initial plan problem was proposed by using the Hungarian method, which is well proved exact method. It was also shown that this method couldn't be applied in case of real time optimization, because even in static cyclic case of the problem it is impossible to support resource to order matching condition for next future orders, but it can be applied as an addition to the multi agent approach.

ThPM_1T4 — **Markov Room**

Modeling of Physical and Engineering Systems **(Regular Session)**

Chair: Caines, Peter E. — McGill Univ
Co-chair: Panteley, Elena V. — CNRS

15:00-15:20 — ThPM_1T4.1

An Isothermal Energy Function State Space Model of a Stirling Engine

Caines, Peter E. — McGill Univ
Mueller-Roemer, Carl — McGill Univ

A thermodynamic modeling framework for interconnected systems has been proposed by D. Gromov and P. E. Caines (2011-2014). Starting from an expression for a system's internal energy, a systematic procedure leads to models of the dynamics of thermodynamic systems on their non-linear (Legendre) manifolds of equilibrium states. Specializing to the case of one working gas, the method yields an isothermal model of a Free-Piston Stirling Engine which generates trajectories modeling the periodic motion of the mechanism.

15:20-15:40 — ThPM_1T4.2

On the Effect of Correcting the Electro-Hydraulic Servo Drive on the Dynamic Characteristics of the «servo Rive-Mass» System of an Airplane

Igumnov, Leonid — Lobachevsky State Univ. of Nizhni Novgorod
Metrikin, Vladimir — Lobachevsky State Univ. of Nizhni Novgorod

Response of the simplest servo system to an input perturbation is considered for two variants of correction of a servo drive to provide its stability and controllability. Numerical computations made it possible to find out the effect of the main parameters of the system on the dynamic characteristics of the controlling system.

15:40-16:00 — ThPM_1T4.3

On the Stability and Robustness of Stuart-Landau Oscillators

Panteley, Elena V. — CNRS
Loria, Antonio — CNRS
Ali, El Ati — Univ. Paris Sud

The study of oscillations, from a dynamical-systems- theory viewpoint is a subject of interest in a variety of research domains ranging from physical sciences to engineering. One of the main motivations to study the behaviour of solutions of these complex systems lies in their role in modelling of collective behaviour, such as synchrony, which appears naturally in some biological systems but also in technological creations such as power grids. In particular, Stuart-Landau oscillators are used to model the so-called Andronov bifurcation, from oue equilibrium to a limit cycle. In this paper, we employ modern tools of stability theory to analyse the behaviour of solutions of Stuart-Landau forced and unforced oscillators. We establish sufficient conditions for global asymptotic and input-to-state stability with respect to sets.

16:00-16:20 — ThPM_1T4.4

Frequency Analysis of Parametrically Controlled Oscillating Systems

Mandrik, Anton — Saint-Petersburg State Pol. Univ
Chechurin, Leonid — Lappeenranta Univ. of Tech
Chechurin, Sergey — Saint-Peterburg State Pol. Univ

The study attacks the problem of the stabilization of linear time-invariant (LTI) system oscillations. The paper suggests a new type of parametrical feedback and reveals the characteristics of such feedback. The feedback contains simple units of time-delay, squarer, differentiator, sign function, and linear gain. Frequency analysis based on stationarization of the time-varying parameter proves the stabilizing properties. A numerical example shows dependence between the time-delay value set in the parametrical feedback and time constant of the envelope curve of oscillations. A classical spring pendulum case is analyzed.

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Solving the initial transport resources allocation subproblem in a special FTL real-time transportation optimization problem by the Hungarian method

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Abstract
The special real-time problem of transport resources allocation for freight transportation companies that deliver cargo via FTL business model was considered. Each freight transportation company should react on incoming events adaptively reallocate available resources. For this purposes multi agent systems are well proved and used in many modern freight companies. But it was admitted that there is a possibility to improve a quality optimization level by using classic optimization approach in the special initial allocation subproblem. By using expert human real logistic scheduling knowledge for a long time period the essential set of limitations to this initial allocation plan problem was defined. The problem was formalized similar to the classical assignment problem of linear programming. Acyclic and cyclic cases of the problem were considered. It was shown that the acyclic case of the problem could be reduced to the assignment problem easily but for the cyclic case it requires to exclude important resource to order matching condition. Finding the exact solution of the initial plan problem was proposed by using the Hungarian method, which is well proved exact method. It was also shown that this method couldn't be applied in case of real time optimization, because even in static cyclic case of the problem it is impossible to support resource to order matching condition for next future orders, but it can be applied as an addition to the multi agent approach.

Keywords: transportation logistics, real-time, FTL, linear programming, the assignment problem, the Hungarian method, multi-agent technology

1. Introduction

The freight optimization problem (Vehicle Routing Problem, VRP), first described in [1], is one of the most urgent and important tasks of the modern theory of optimization. Classification of optimization transportation logistics problems is described in [2, 3]. In this paper, the special trucks to orders allocation problem via FTL (Full Truck Load) business model is formalized and proposed for solving. FTL model is characterized by the direct customer's whole truck reservation contracts, which eliminates the need to take into account the volume of each cargo and build consolidated routes. This simplification allows to introduce a more accurate method for solving the task without using heuristic approaches. Various models of the organization of cargo transportation by FTL model are given in [4]. We also consider the time windows of truck arrival to loading and unloading points, so the problem belongs to VRPTW (Vehicle Routing Problem with Time Windows). Additionally we consider that some orders require only special truck and trailer with additional equipment installed: refrigerator, sheathing for transportation of tires, lifters, etc. Restrictions on the maximum length of the trip is not included, because big trucking companies can afford to adaptively change drivers during the trip, bringing them to trucks via other transport, such as aircraft. Also there is a need to choose most advantageous orders from the set in terms of prosecution of the trip, as in general, the number of demands exceeds the number of trucks and truck after the execution of the order don't return to the base but continue to move to a new order from the previous unloading place until it receives the order with unloading near its base. That's because unlike most standard VRP applications, where the return to the base is obligatory after each trip, in the task we are dealing with this condition is not rigidly defined. It generated dynamically during the problem solving process. And finally we have to keep in mind the real time factor. Considering the task as a real time problem, according to [8] orders and resources are presented as a network of requirements (orders) and opportunities (resources). But in practice it is always possible to distinguish some period of time, when the network remains stable (no new order appears, none of the parameters of an existing one changed, no new truck appears and no existing one became unavailable). In practice, this happens because at the end of the working day transport managers finalize and fix the part of the schedule that has to be executed on the next day. By this action, they assign some trucks to orders but the rest part remains unassigned because there is a time for making decision. During the night before the next working day, there is a time to allocate this rest part according to some basic optimization criteria. It means that the real-time transportation optimization problem has the initial resources allocation subproblem that we are solving in this paper. During the multi-agent system introduction [6] in [13,14,15], we analyzed and summarized the empirical knowledge of the transportation companies staff that was accumulated by them for a long period of time and define a set of practical constraints, which can be used for the mathematical formulation of the linear programming problem:

1. Time of arrival at an order loading point, which is calculated as the time of a truck release plus the empty driving time for the truck, must be less than the right edge of the order loading time window, so earlier arrival is permissible, but to be late is not acceptable.
2. An empty driving time to an order loading point should be less than 500 kilometers, taking into account the fact that the average speed of trucks accepted as 50 km/h, the empty driving time should not exceed 10 hours.
3. Truck idle time, which is calculated as the left edge of the order loading time window minus empty driving time to the order for the truck, must be less than 24 hours. So if the truck has enough time to drive to the loading point, but it additionally has to be idle more than a day, such an assignment is not acceptable.

2. The problem definition

Let's assume that we have a set of orders O_i $i = 1, N$, each order is characterized by a geographical point of loading and unloading with time window [TOs_i; TOf_i] when point is available. There is a set of resources which are trucks with trailers R_j $j = 1, M$, each resource is characterized by its initial location geographical point and the time of its release from that location TRf_j, which corresponds to the previous executed order unloading location and time or truck's base. For any truck R_j the empty driving time D_{ij} is known for each order O_i. Each order O_i occupies a whole truck R_j with trailer that satisfies the order constraints, so the truck R_j can match or mismatch to the order O_i. All orders are considered as equal that means we can assign order O_i to truck R_j or just skip the order O_i without any penalties from the order O_i customer (in practice these orders will be resold to another external carrier company 3PL). The goal of the problem is to assign all M resource to orders where the total empty driving time will be minimum, with a maximum quantity of assigned orders Q and constraints for acceptable assignment are fulfilled:

$\sum_{i,j} D_{ij} \to \min, Q \to N$	(1)
$\begin{cases} \mathrm{TRf_j} + \mathrm{D_{ij}} < \mathrm{TO_{fi}} \\ \mathrm{D_{ij}} < 10 \\ \mathrm{TOs_i} - \mathrm{TR_{fj}} - \mathrm{D_{ij}} < 24 \end{cases}$	(2)

3. The proposed method for solving the problem

For solving the problem, we propose two stages. At first stage, we construct the matrix of acceptable assignments for defining all possible assignments satisfying the given constraints of the problem. At the second stage, the matrix is reduced to the classic assignment problem, which can be solved by one of the linear programming methods.

3.1. Construction of acceptable assignments matrix

We construct the matrix in which the rows correspond to order O_i and the columns correspond to resources R_j. In each cell that corresponds to O_iR_j assignment, we set empty driving time D_{ij} that takes for the truck R_j to move from its current location taking into account its release time TRf_j to the order O_i loading point, but only if the truck R_j matches the order O_i and the condition of inequalities system (2) is satisfied, otherwise the cell remains empty.

For clarity, let's consider examples for the matrix construction for the special (acyclic) and general (cyclic) problem cases.

3.1.1. Construction of acceptable assignment matrix example for the acyclic case

The set of orders with loading points and its time windows relative to initial time T_0=0 is given in table 1:

	Loading point	*TOs*	*TOf*
O_1	Moscow	2	4
O_2	Samara	18	22
O_3	Ekaterinburg	38	40

Table 1: set of orders

The set of resources with initial location point and release time relative to initial time T_0=0 is given in table 2:

	Location point	*TRf*
R_1	Moscow	1
R_2	Samara	6
R_3	Ekaterinburg	12

Table 2: set of resources

The driving time between each location is given in table 3:

	Moscow	Samara	Ekaterinburg
Moscow	1	13	24
Samara	13	1	9
Ekaterinburg	24	9	1

Table 3: driving time between each location

Each resource R_j is considered suitable for order O_i. It is also assumed that each order execution time (the time that it needs to drive from loading to unloading point) exceeds the latest order loading start time. That is why we call that case acyclic, because none of the resource has time to execute more than one order. For each potential assignment O_i to R_j we check satisfaction to the condition of inequalities system (2):

$O_1R_1 = \begin{cases} 1 + 1 < 4 \\ 1 < 10 \\ 2 - 1 - 1 < 24 \end{cases}$	$O_1R_2 = \begin{cases} 6 + 13 < 4 \\ 13 < 10 \\ 2 - 6 - 13 < 24 \end{cases}$	$O_1R_3 = \begin{cases} 12 + 24 < 4 \\ 24 < 10 \\ 2 - 12 - 24 < 24 \end{cases}$
$O_2R_1 = \begin{cases} 1 + 13 < 22 \\ 13 < 10 \\ 18 - 1 - 13 < 24 \end{cases}$	$O_2R_2 = \begin{cases} 6 + 1 < 22 \\ 1 < 10 \\ 18 - 6 - 1 < 24 \end{cases}$	$O_2R_3 = \begin{cases} 12 + 9 < 22 \\ 9 < 10 \\ 18 - 12 - 9 < 24 \end{cases}$
$O_3R_1 = \begin{cases} 1 + 24 < 40 \\ 24 < 10 \\ 38 - 1 - 24 < 24 \end{cases}$	$O_3R_2 = \begin{cases} 6 + 9 < 40 \\ 9 < 10 \\ 38 - 6 - 9 < 24 \end{cases}$	$O_3R_3 = \begin{cases} 12 + 1 < 40 \\ 1 < 10 \\ 38 - 12 - 1 < 24 \end{cases}$

The system of conditions satisfies to the following assignments: O_1R_1; O_2R_2; O_2R_3; O_3R_2. The acceptable assignment matrix for the case is given in table 4:

	R_1	R_2	R_3
O_1	1		
O_2		1	9
O_3		9	

Table 4: the acyclic case acceptable assignment matrix

3.1.2. Construction of acceptable assignment matrix example for the cyclic case

In the previous example, we assumed that none of the resource has time to execute more than one order, because all the orders loading time windows [*TOs*; *TOf*] were densely allocated, and any order execution time always exceeds them. Now we consider the general cyclic case where the time windows in the given set of orders are widely allocated because we include future orders with we know with a high possibility level (e.g., orders from regular customers, usually known with good accuracy for a week or even a month in advance). Therefore, each resource has chance to execute later orders after earlier orders execution. It should be clear that in this case, location and time of the release for each resource would change during the problem solving according to O_i unloading points. The acceptable assignment matrix will have a different structure. Let's consider how it will happen by another example:

The set of orders with loading and unloading points and its time windows relative to initial time T_0=0 is given in table 5:

	Loading point	Unloading point	*TOs*	*TOf*
O_1	Moscow	Samara	1	2
O_2	Samara	Ekaterinburg	23	28
O_3	Ekaterinburg	Moscow	50	52

Table 5: set of orders

The set of resources with initial location point and release time relative to initial time T_0=0 is given in table 6:

	Location	*TRf*
R_1	Moscow	0
R_2	Samara	0
R_3	Ekaterinburg	0

Table 6: set of resources

The driving time between each location is given in table 3. Each resource R_j is considered suitable for order O_i. For each potential assignment O_i to R_j we check satisfaction to the condition of inequalities system (2) and if the assignment is possible, we'll continue to consider the further assignment to the remaining orders taking into account the relocation of the resource R_j:

$O_1R_1 = \begin{cases} 0+1<2 \\ 1<10 \\ 1-0-1<24 \end{cases}$ =>	$O_1R_1O_2 = \begin{cases} 14+1<28 \\ 1<10 \\ 23-14-1<24 \end{cases}$ =>	$O_1R_1O_2R_1O_3 = \begin{cases} (23+9)+1<52 \\ 1<10 \\ 50-23-9-1<24 \end{cases}$
$O_1R_2 = \begin{cases} 0+13<2 \\ 13<10 \\ 1-0-13<24 \end{cases}$	$O_1R_3 = \begin{cases} 0+24<2 \\ 24<10 \\ 1-0-24<24 \end{cases}$	$O_2R_1 = \begin{cases} 0+13<28 \\ 13<10 \\ 23-0-13<24 \end{cases}$
$O_2R_2 = \begin{cases} 0+1<28 \\ 1<10 \\ 23-0-1<24 \end{cases}$ =>	$O_2R_2O_3 = \begin{cases} (23+9)+1<52 \\ 1<10 \\ 50-23-9-1<24 \end{cases}$	
$O_2R_3 = \begin{cases} 0+9<28 \\ 9<10 \\ 23-0-9<24 \end{cases}$ =>	$O_2R_3O_3 = \begin{cases} (23+9)+1<52 \\ 1<10 \\ 50-23-9-1<24 \end{cases}$	
$O_3R_1 = \begin{cases} 0+24<52 \\ 24<10 \\ 50-0-24<24 \end{cases}$	$O_3R_2 = \begin{cases} 0+9<52 \\ 9<10 \\ 50-0-9<24 \end{cases}$	$O_3R_3 = \begin{cases} 0+1<52 \\ 1<10 \\ 50-0-1<24 \end{cases}$

The acceptable assignment matrix for the case is given in table 7, where the columns O_1R_1; $O_1R_1O_2R_1$; O_2R_2; O_2R_3 are presented resources location R_1, R_2 and R_3 after a possible execution of orders O_1, O_1 then O_2 and O_2:

	R_1	R_2	R_3	O_1R_1	$O_1R_1O_2R_1$	O_2R_2	O_2R_3
O_1	1						
O_2		1	9	1			
O_3					1	1	1

Table 7: the case acceptable assignment matrix

3.2. The optimal assignment search method

After we found acceptable assignment matrix, we can solve the problem by searching such resources to orders assignment sequence in the matrix in which the total empty driving time for all trucks in the sequence will be minimum with the maximum quantity of assigned orders (1). It can be seen that the assignment matrixes we found in the above examples are similar to the matrix, which formalizes one of the standard problem of linear programming – the assignment problem. As shown in [10] for the assignment problem, in some special cases (the acyclic case), it is possible to find the exact solution, which is the purpose of this work. It is known that the assignment problem is solvable in polynomial time. There are traditional solving methods for the task solution (e.g. Hungarian algorithm [11]) that have an asymptotic complexity of $O(n3)$ that is more than enough even with a large dimension of the matrix in real transportation company cases.

Consider how it is possible to reduce this paper problem to the assignment problem and solve it, for example, by the Hungarian algorithm. We begin by considering the special acyclic class of the problem, as described in above example 1, where any order execution time exceeds any order loading start time and none of the resource has time to perform more than one order. This class of the problem is simply reduced to the assignment problem, even if we assume that not all resources fit all orders. When considering a general cyclic class, as described in above example 2, where location and release time of each truck change during the task definition, it is also possible to reduce it to the assignment problem, but in that case we have to remove the resource to order matching condition, assuming that any truck fits any order. Taking this assumption, for reducing to the assignment problem we need to convert acceptable assignment matrix to a new one, where we'll generalize all possible assignments and won't consider the particular truck to a certain order assignment, so the matrix in table 7 will be converted to the matrix in table 8. In the matrix columns after specific resources R_1, R_2 and R_3, we have columns with undefined resources RO_1, RO_2 and RO_3, which correspond to unloading points O_1, O_2 and O_3. By using this approach we cannot determine which specific resource will arrive at the next order loading point, this will be evaluated during the solving process. That is why it is impossible to take into account the resource to order matching condition for these undefined resources, but for the first group columns with exact resources, that condition is possible to check. When for this matrix the assignment problem will be solved by the Hungarian algorithm, for all assignments kind a RO_iO_j, we will evaluate the resource, which was previously assigned to the order O_i. It is also important to note that before solving the matrix by the Hungarian algorithm, the empty rows and columns must be excluded from the matrix. Also cells with blank values with correspond to unacceptable assignments should be filled with large values, greater than the maximum value in the matrix.

	R_1	R_2	R_3	RO_1	RO_2	RO_3
O_1	1					
O_2		1	9	1		
O_3					1	

Table 8: the assignment problem matrix for cyclic case

4. Computational Results

We performed several experiments to test the described methods by using the real data from our client companies [13, 14, 15]. Each of them uses multi agent system [6]. The goal of the experiments was to compare multi-agent method, witch is real time oriented, with the Hungarian method in the task of initial allocation construction. We run the system [6] on each client data snapshots and stopped it just after the initial allocation was created. Based on the same data snapshots we created assignment problem matrixes and solved it by the Hungarian algorithm implementation [16]. For getting more clear picture the experimental data was snapped from the real client data in a different time during working month. It was clustered by the density (% of empty cells) in the assignment matrix because in general it varies from 5% to 95%. The results of the experiments are shown in Table 9. We can see that the Hungarian method gives more effective results and consumes less time almost in every experiment. These experiments were run on workstation with a 3.4 GHz Intel Core i7-4770 CPU with 8Gb of RAM under Windows 8.1.

Problem matrix			Multi-agent method		Hungarian method	
N orders	*M* resources	% of empty cells	KPI (1)	Execution time, sec	KPI (1)	Execution time, sec
25	140	5	35	0,014	34	0,001
25	140	30	43	0,012	41	0,001
25	140	50	49	0,009	47	0,001
25	140	70	73	0,005	68	0,001
25	140	95	341	0,003	339	0,001
76	300	5	82	0,6	77	0,001
76	300	30	93	0,4	92	0,003
76	300	50	111	0,3	106	0,001
76	300	70	127	0,2	123	0,001
76	300	95	483	0,052	472	0,001
240	680	5	242	39,91	240	0,011
240	680	30	245	29,91	241	0,01
240	680	50	255	21,8	246	0,01
240	680	70	285	13,29	273	0,008
240	680	95	980	2,66	934	0,006

Table 9: the results of computational experiments

5. Conclusion

In this paper, we solved the special initial trucks to orders allocation subproblem for large transportation companies with uses FTL business model. By taking into account the minimum necessary set of criteria, which were found based on human empirical knowledge, we reduced the problem, with agreed assumption, to the assignment problem that has an exact solution The Hungarian method. As a result of the problem solving, we obtained an exact solution, but with the assumption that any resource fits any order. To overcome this assumption and to obtain an exact solution taking into account this condition is not possible. However, based on industrial multi-agent planning system use experience [6], it is even not necessary, because further the initial allocation will be modificated according to real-time events, by using the multi-agent approach [5]. If the order agent has received the initial assignment to the resource, which is not suitable for it, the order agent will adaptively change the resource at the other suitable one, taking into account possible changes that has happened by this time. We can conclude, that when shifting to the real time trucks to orders allocation, when new orders emerges or existing orders change or cancel, using only classical methods is insufficient, but classical and multi-agent approach combination will give a good solution which can be applicable in practice. The study was supported by the Ministry of education and science of Russian Federation (the contract № 14.576.21.0014).

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