Comparing Adaptive and Non-adaptive Models of Cargo Transportation in Multi-agent System for Real Time Truck Scheduling

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Abstract: The application of multi-agent platform for real-time adaptive scheduling of trucks is considered. In case of unpredictable events the system works adaptively and doesn't stop to restart the plan from the beginning. Different models of cargo transportation for truck companies having own fleet are analysed. The results show that using adaptive scheduling in real time it is possible to create significantly more profitable schedules (up to 40-60% compared with rigid models) and save a number of trucks (up to 20%) for the same amount of orders.

1 INTRODUCTION

The problem of resource optimize allocation are usually solved, when all the orders and resources are given in advance and don't change in the process of scheduling. In these cases classical batch planning methods can be used characterized by the time-consuming full combinatorial search or different types of heuristics requiring a lot of computational power (Leung, 2004); (Bonabeau, 2000).

Any change is considered as a need for full change of schedule, which have to be processed from scratch. But for solving real-life problems of resource allocation, existing approaches do not work at all or produce unfeasible schedules which require exhausting manual re-work for dispatchers.

For solving such problems we apply multi-agent technology (Wooldridge, 2002). The approach we are working on is based on Demand-and-Resource Networks (DRN) of agents representing orders and resources (Skobelev, 2011). That allows us to find a 'well-balanced' solution acceptable for all the agents as well as for company as a whole.

As a result of such interactions of agents a near-to-optimal (acceptable) solution of the problem is achieved in the form of 'not-stable equilibrium', which can be adaptively corrected in real time after each new incoming event representing new order or order cancellation, truck breakdown, delay of work execution, etc. The developed multi-agent technology allows us to solve complex resource allocation, when the number of orders and resources is not given in advance and there is a high dynamics of occurring events (Ivashenko, 2011).

The results of the research are important for the future developments of intelligent freight management systems and dispatching of any other mobile resources that are able to operate in real time.

2 THE MODELS OF TRANSPORTATION PROCESS ORGANIZATION

Let's assume that we have a fleet of M trucks based in certain cities in a transportation network. The operation cost of each truck is given. Orders come into the system with the specified points of loading and unloading, loading start time, unloading finish time, price and penalties for delays when a loading or unloading is done later than they should. Distances between points are also given and described by a matrix of distances.

The objective is to schedule the trucks in real time and determine transportation company profit

depending on the scheduling strategy (model) and the number of trucks.

The optimization criterion of the task is the maximal total profit of all the trucks in company fleet. The research is done for four different models of organization of transportation process including not-adaptive and adaptive models described below.

The total profit of the fleet of trucks is calculated as a sum of profits of each truck:

$$P = \sum_i p_i. \tag{1}$$

The profit of one truck is:

$$p_i(t) = \sum_j \{(c_j - q_i)t_{ij} - q_i t'_{ij}\} \tag{2}$$

where sum includes all orders j executed by the truck i, c_j – price of order j per time unit, q_i – cost of the truck per time unit, t_{ij} – time of execution order j by truck i, t'_{ij} – empty run time for order j.

Let's consider 4 models of transportation process organization.

Model #1 – the 'Returning to base after an order execution' model. After each order execution the truck should return to the base point. Order is assigned to a truck that has a 'window' in its schedule during the order time period. If the loading point of the order is a different city, then the truck should arrive there at the loading time. No reassignments of the trucks already assigned to the orders are allowed.

Model #2 – the 'No return to base after an order execution' model. After each order execution truck stays at the order destination point, without returning to base, and waits for a next order.

Model #3 – the 'Delays with penalties' model. Orders can be scheduled with delays of time of arrival at the loading point. In this case profit with penalty calculation is:

$$\begin{aligned} p_i(t) = &\sum_j \{(c_j - q_i)t_{ij} - q_i t'_{ij}\} + \\ &\sum_k \{(c_k - q_k)t_{ik} - q_i t'_{ik} - p_k t''_{ik}\} \end{aligned} \tag{3}$$

where the sum by index j includes all orders that were executed just in time by the truck i, the sum by index k includes all orders that were executed with delays t''_{ik}, p_j – penalty of each delay per time unit.

Model #4 – the 'Adaptive scheduling with penalties' model. It is equal to the previous model, but it allows the truck reassignment when a profit from a new order is higher than a profit from the previous one.

3 THE MULTI-AGENT SIMULATOR

A special multi-agent simulator (MAS) has been created for modelling of adaptive real time scheduling. It works as follows. Every truck is associated with a truck agent, every order – with an order agent. The agents are able to send and receive messages and take decisions according to their logic and current situation. The unified spatio-temporal scale is defined to achieve visibility of results and unified logic: time is counted from the moment of the first order entry. The upper border of planning is determined by the planning horizon, calculated in days. The distances are brought to time scale by division of the distances by the average speed.

When a new order comes, a request for its allocation is sent to all the truck agents. 'Candidates' for re-scheduling (in case of increasing profit) are ordered of the prospective profit. Then the order agent chooses the truck that gives the maximal profit. The profit is calculated as a difference between the order revenue (price) and the order full cost. When order implies an empty run to loading point, its cost is also deducted from the revenue. In case of strategy (model), where penalties are applied, their influence on profit is analyzed. For penalty is proportional to time of delay, the orders with big delays will not be scheduled.

Let's consider world of simulations for one truck. There are 4 cities (points) given, among which the distances are determined by the matrix (see Table 1) in days of trip. Time of trip doesn't necessarily correspond to the distance, because of roads quality.

At the beginning of the trip the truck is located in the point 1. At different times cargo transportation orders #1-5 to different points come into the system. Duration of execution of an order is 1-2 days. Scheduling horizon equals $t = 10$ days. The costs of orders are calculated equally using company tariff as $c = 3$ standard units (SU) / day, i.e. 2-days trip would have cost of 6 SU. Idle time of a truck leads to daily loss of $q=0.3$ SU.

Table 1: Matrix of distances among cities.

	Point 1	Point 2	Point 3	Point 4
Point 1	0	1	1	2
Point 2	1	0	2	1
Point 3	1	2	0	1
Point 4	2	1	1	0

Daily running cost in case of empty run of truck or order execution is $q=1$. Drivers are allowed to

execute orders with delays, but every day of delay costs $pp = 0.6$ *SU*. Some orders are shifted to the right on the time axis because of this. The aim is to be able to schedule trips, as orders come in (the orders are not known in advance) and calculate profit. Orders are marked with a number according to the place in the sequence of entry into the system and characterized by time of their entry (moment of entry t), moments of start and finish of order execution, duration (in days), point of loading and point of unloading (Table 2).

Table2: Parameters of orders.

Characteristics	Order number				
	1	**2**	**3**	**4**	**5**
Time of entry	1	3	5	6	7
Start time of execution	3	4	7	8	9
Finish time of execution	5	5	9	9	10
Where from	4	3	1	4	3
Where to	1	1	4	3	1

Figure 1 shows orders as rectangles, with the order number and the time of entry. Above each rectangle 'where from – where to' locations are described. The start and the finish of each rectangle correspond to the start and the finish of the order execution.
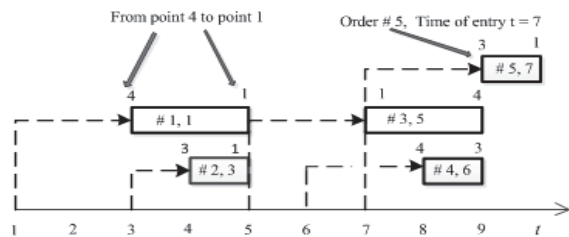

Figure 1: Diagram of orders entry and scheduling.

Let's calculate the profit of truck #1 in the Model #3, where penalties are applied. We will calculate the profit P at the moments of transition of the truck from one state to another step by step.

Step 1. Execution of order #1 will require to start at the moment t=1 from point #1 to point # 4 and will take 2 days till the moment t=3. At the moment t=3 the profit is $P=-q*2=-2$.

Step 2. The transportation of cargo from point 4 to the point 1 will take 2 days, and at $t=5$ the truck will arrive at the point 1 with the profit $P=-2+(c-q)*2=-2+2*2=2$. Assume that the truck agent assesses options of further schedule and execution upon arrival to point 1 at time $t=5$. Its profit at point 4 is $P=2$. By this time order # 3 has been entered at the moment of time #3. There are two options to execute it:

▪ Order #2 is to be executed with delay;

▪ Order #2 is rejected, idle time cost is accepted, order #3 from the same point 1 is to be taken; for order # 2 can be executed with delay before execution of order #3, no further options will be taken into consideration. Let's take a more precise look at 2 options.

Step 3. Truck needs to reach point 3, moving from point 1 (1 day trip), pick up the order and execute it, going from point 3 to point 1 (1 day). The increase of profit is $dp=-1*q+(c-q)*1=-1+2=1$.

Penalty applied because of delay is $-pp*2=-2*0.6=-1.2$. As a result the truck will be at the moment $t=7$ at the point 1 with the profit $P=2+1-1.2=1.8$. Execution of the order would seem to be unprofitable, but one should take into consideration that in case of cancellation of the order the truck would stay idle for 2 days, and the profit at the moment $t=7$ would be $P=2-2*0.3=1.4$.

Step 4. That's why the truck agent is interested in the execution of order #2 with delay, order #3, $t=7...9$ (from point 1 to point 4) - 2 days, profit is $P=1.8+2*(c-q)=1.8+2*2=5.8$, and the truck moves to point 4.

Step 5. At the moment $t=9$ new order# 5 comes in at the point 3 with start time of execution $t=9$; empty run to its loading point is 1 day, what puts the order beyond the 10-days scheduling horizon limit. That's why the truck agent rejects the order. There is an outdated order #4 from point 4 to point 3, its execution start time should be $t=8$. The truck agent assesses profit from possible shift of order by a day.

Step 6. Execution of the order #4, empty run is not required, $dp=(3-1)*1=2-penalty$ $0.6=1.4$. If this order were rejected, the truck would stay idle for 1 day till the end of the scheduling horizon and then $dp=-1*0.3=-0.3$. That's why the truck agent accepts the order #4.

Outcome: orders #1 and 3 are executed without delay, order #2 – with allowed delay of 2 days and order #4 – with allowed delay of 1 day. Order #5 is rejected. Total profit in 10 days is $P=5.8+1.4=7.2$.

Final track of the truck is shown on the Figure 2. The truck starts from the point 1 to the point 4. Then it executes the order #1 from the point 4 to the point 1 without delay. Then it goes to the point #3 to execute the order #2. Then it executes the order #2 with delay. After this the truck executes the order #3 from the point 1 to the point 4 without delay. Then it executes the order #4 with delay. The order #5 remains unfulfilled, because it goes beyond the scheduling horizon ($t=10$). The delayed orders on

Figure 2 are shown with dark grey, when penalties are applied; light grey marks orders without delay; shifts in schedule are shown with wide arrows; shifted orders are shown with dotted borders; rejected order is white (not visible).
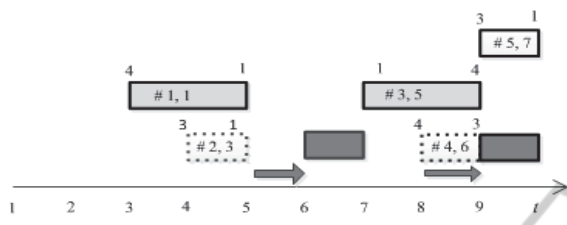

Figure 2: Diagram of execution of adaptive schedule by one truck.

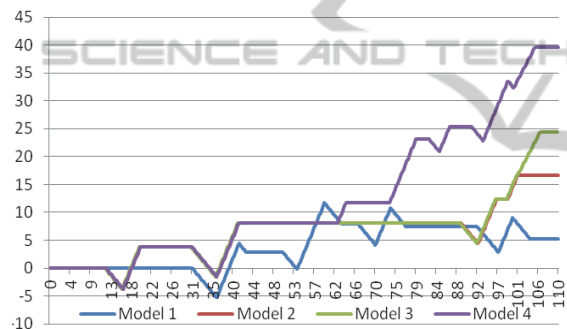## 4 THE RESULTS OF THE EXPERIMENTS

Figure 3: Dynamics of a profit for the truck depending on model of transportation.

Trucks schedules were created for orders based on the 4 used models of transportation. Graphs of dynamic profit per each truck and dynamics of sum of trucks profit depending on time was found (Figure 3 – Figure 4). The designed MAS allows also to study the profit depending on trucks number for each flow of orders. For simplicity we don't consider standing costs of trucks. The trucks amount was varied from 0 to 50 (Figure 5). Satiation modes differ for the different models. The lowest profit value is in the Model #1 because less amount of orders are scheduled and additional expenses occur after returning to the base. The Model #3 far exceeds the Model #2 because it uses the same amount of trucks as in Model #2 but more orders are scheduled. But in a satiation mode it gives almost no benefits vs. the Model #2, because when the trucks number is high enough there are very few orders that are executed with delays so Model #2 and Model #3 will be almost equal. The Model #4 is the best one. It

gives approximate 20% more profit then Model #2 and Model #3. It allows using less trucks during the plan execution. The reason is the adaptive re-scheduling of orders in real time.
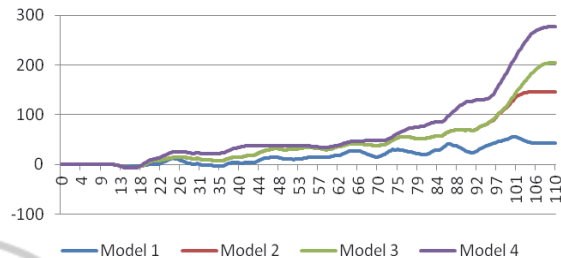

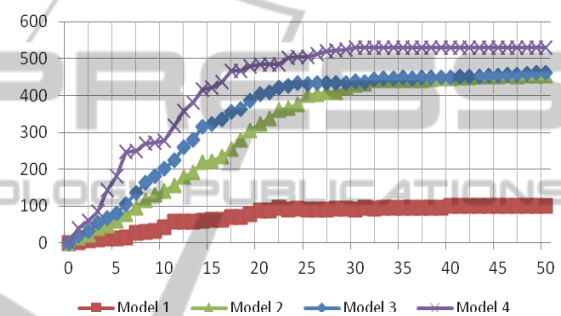Figure 4: Dynamics of sum of trucks profit depending on transportation models.

Figure 5: The dependence of the profit to the used trucks number in the different transportation models.

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