MAGENTA MULTI-AGENT SYSTEMS
FOR DYNAMIC SCHEDULING

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Abstract: The document presents an overview of Magenta multi-agent solutions for real time scheduling and optimization of mobile resources. Brief survey on traditional scheduling methods, main principles of multi-agent approach, system architecture, functionality, industrial applications and perspectives are described. The multi-agent approach for dynamic scheduling gives opportunity to solve complex problems, react on events in real time, improve resource utilization and provide a number of other benefits.

1 INTRODUCTION

The increasing number of the modern enterprises meets problems of optimal scheduling resources in real time. This problem becomes especially actual and important for enterprises of transportation logistics operating large fleets of mobile resources (ships, trucks, taxi and others), in connection with increase of complexity and dynamics of business, and also a rise in fuel prices.

Thus it is a question of the enterprises having hundreds and thousands of mobile resources, simultaneously being in movement, receiving tens of thousands orders a day, in unpredictable moments of time, operating in regional or national scale, and trying to satisfy various client requirements. For such enterprises the solution of the specified problem becomes crucially important for business, as without using of the automated systems of resource scheduling these enterprises simply can not run business successfully in the future, to be effective and competitive.

However, new methods, algorithms and software tools which would allow adapting flexibly plans of realization of orders in real time are necessary for solving this problem. Flexibility supposes an operative automatic reaction on unpredictable events to be here, such as a new order arriving, the cancellation of already accepted and allocated order, failure or a delay of a resource, arriving of a new resource, change of criterion or strategy of planning, etc.

Thus, unlike known "batch" methods when all orders and resources are known in advance (and can be more or less optimized with well-known methods), in case of real time software solution should work in adaptive manner dynamically adjusting existing plans instead of full re-scheduling of already allocated orders each time: any new event should activate processing of corresponding orders and resources, causing a chain of re-scheduling operations which depth can be limited by available time of the reply or other factors. At the same time, if there is enough time, the schedule can be exposed to continuous optimization or, in general, to balancing of interests of all participants as each order or a resource can have their own specific system of criteria, preferences and constraints.

Introduction of such new methods and tools in many respects is stimulated by the appearance of the Internet-services supporting work in real time (giving operative data about possible routes, weather, traffic jams, etc.), opportunities of GPS navigation, e-maps, and new mobile phones, handheld computers and communication devices with an opportunity of getting user geographic coordinates. A driver, armed by such device, can constantly be on "radar" of system that allows to react instantly to arising events, to look for the best resource for each order, to count the schedule of performance of the order, constantly to compare

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with the plan and a reality, to monitor possible risks of delay. Besides these devices allow to cooperate online with control centre of the enterprise (or other drivers), receiving and choosing possible options, chacking order starting and finishing, reporting about unforeseen events, requesting the information on the nearest fuel station, etc.

Thus modern e-maps (Map24, MapPoint, Google Maps, MapInfo and others) allow to receive a detailed route "door - to door", considering not only seasonal throughput of roads and typical places of traffic jams occurrence during various time of day, but also traffic signs. At last, modern Internet-services in big cities allow receiving the information on weather conditions change or really arisen jams on the roads, the nearest restaurants and cafe, auto repair shops, etc.

In this document the multi-agent approach for developing adaptive schedulers for mobile resources is considered, the generic architecture of adaptive schedulers is shown, examples of industrial applications in transport logistics are given, and also next steps of the developments are discussed.

2 BRIEF SURVEY OF SCHEDULING METHODS AND TOOLS

In spite of significant progress regarding development of large-scale Enterprise Resource Planning (ERP) systems, opportunities of the enterprises on development of adaptive scheduling systems remain very limited.

Traditionally the ERP systems include subsystems of orders collection, large databases for orders and resources, accounting and reporting subsystems and a lot of other components. However in these systems batch or manual scheduling of orders is supported, that was already discussed above. The schedulers offered by such large companies, as SAP, Oracle, Manugistics (it was recently bought by JDA), i2, ILOG and others usually realize various versions of Constraint programming methods, based on combinatory search of options in depth, for example, a method of branches and borders (Handbook of Scheduling, 2004).

To reduce the number of options considered in combinatorial search new methods consider various heuristics and meta-heuristics (the term "heuristics" is usually understood as a set rules, defining what option is the best, and "meta-heuristics" means a rules to choose heuristics), allowing to provide good decisions for reasonable time and reducing search iterations (Stefan Vos., 2000 – 2001).

Well-known heuristics in optimization are "greedy" methods. In such methods the decisions are taken by a choice of the best of options on each step, and once made decision is never reconsidered. Various other methods of local optimization are more complex, where initial solution which then is improving by local changes can be changed randomly or in some pre-defined way, if the good final solution is not reached, and the process repeats many times.

As one of the most known meta-heuristics we can consider Simple Local Search Based Meta-heuristics (SLSBM) – local optimization meta-heuristics. Here one of heuristics can implement casual choice of one candidate from the list of the best, another one - looking forward or randomizing of criteria, etc. One more meta-heuristics developing recently is Simulated Annealing which is based on modeling of process of cooling. This method represents an expansion of methods of local optimization in which many options could be formed on each step and it is possible to consider not only the best options, but also some worsening decisions with the probability calculated as function from some attribute, analogue of temperature.

The main idea of becoming more and more popular Tabu Search is the usage of history of decisions of local optimization when some investigated options are becoming prohibited (tabu) and consequently they are not considered on a following step.

One more new meta-heuristic is Ant Search, in which the behavior of the ants, getting food is modeled. The success of one ant in getting of "food", i.e. taking of some decision, during some time prompts other ants a correct direction, but in due course signs on this successful direction "fade". In last period of time also many other meta-heuristics become more and more popular inheritting physical or biological concepts. Another example here is Adaptive Memory Programming method which inherits the use of common memory of decisions. In last developments researchers apply mixed miscellaneous meta-heuristics, in which several parallel algorithms are acting, and each of them suggest their own decision.

At the same time, even in view of considered methods and tools of local search of variants require greater expenses of memory and time for producing schedules. For example, producing of the optimum plan for the large transport company in one of available software packages takes about 8-10 hours. During this time the volume of orders can be essentially changed that will require to start planning all over again. At the same time the technology for planning in real time remain rather primitive, and an opportunity of flexible adaptation on the base of happening events refer mainly to an opportunity of manual plans updating. As a result, according to the estimations of transportation logistics experts, the created schedules are feasible only on 40 %, that compels many large transport companies still to contain staff of very skilled and expensive operators on planning and to carry out time-consuming manual or semi-automatic planning.

This, certainly, is promoted by both high complexity and labour intensity of planning, unpredictability of dynamics of a stream of events, by requirements of an individual approach to each order and resource, constant change of conditions of functioning of the enterprise forced by clients and competitors, and also necessity of the account of many other very specific features in each business. For example, the operator of trucks fleet should constantly keep in a head preferable time windows of loading-unloading of warehouses and shops, conditions of contracts with clients, rules of compatibility of cargoes, experience of the concrete driver and even such specific facts, that the certain road became impassable for greater wagons because of rank branches of trees.

As a result many of existing classic methods of planning and resource optimization have a number of very important limitations in practice:

- Do not consider complexities of the modern business operating in thousand of orders and resources, supporting interdependency between all operations, reflecting and balancing interests of many parties involved, having a lot of their own features;
- Do not provide opportunities for adaptive planning in real time which requires dynamic event-driven conflict solving in already available schedule;
- It is supposed that all orders and resources are "identical" but in practice they all have their own individual criteria, preferences and restrictions, each can change during the sistem work (service level, time of delivery, costs and profits, risks of delivery, inconvenience of the driver, etc);
- Do not give the tools for the aquiring knowledge which are specific to every enterprise, influencing quality of provided schedules;
- Do not allow an operator to explain and adjust decisions easily and in convenient way.

All this not only reduces productivity and efficiency of existing methods and tools, but also in practice in many respects stops their use.

3 MULTI-AGENT APPROACH TO DYNAMIC SCHEDULING

To provide opportunity to build adaptive schedulers on the top of existing ERP systems and eliminate the specified lacks in scheduling mobile objects multi-agent approach was offered which is based on the concept of networks of demand and supply (Skobelev P.O., 2002; Vittih V.A., Skobelev P.O., 2003).

Below there is a short description of the offered approach in application to transportation logistics. The model of any transport network can be based on the description of dynamic interaction of agents which take roles of demands and resources. For example, for truck operator the model of a transportation network can include agents of a client and an order, a truck and a cargo, a crossdock and a store, a driver, etc. Complexity of model and accuracy of modeling of a real network increase as with growth of a number of program agents representing interests of different physical and abstract essences, necessary for the description of network, and growth of intensity of interactions between agents of different types.

Thus a basis of interaction of all specified agents is a virtual market on which agents can buy or sell the services: the order searches for the truck, the truck for the driver, etc. During these interactions agents can take decisions on building links between demand and supply and change their decision when new events take place.

The role of demand bears in itself the knowledge of "ideal" requirements of order implementation (future), and a role of an supply (resource) - knowledge of "reality" (past and present). As a result, each truck knows for certain what is its route, where it is now, what cargo it is loaded, etc. Receiving offers from different trucks, the order can decide, which of them suits better. But, on the other hand, the truck can generate new demand, specifying which orders are necessary for it at present to be full and significantly increase utilization.

The constant activity of all agents, either from demands' side, or from supplys' one, calls multi-thread negotiations in the virtual market, going quasiparallely. Thus the feature of the approach is that each agent is considered as a machine of states that returns control to the dispatcher after each step of negotiations. Each agent constantly tries to achieve its goal and for this purpose enters into relations with other agents (the order is reserved on the truck, the truck on the driver, etc.) which can be reconsidered by agents as a result of decision making, and also under action of events coming from the outside or generated inside.

So, after getting the new order in the system its agent is created, that on behalf of this order enters interaction with agents of resources for search of the best location. If the most suitable resources are already occupied, they can start to suggest to the orders placed on them earlier to look for new locations. This process, as chain reaction, can grasp all new orders and resources, forming a wave of negotiations and changes, and, theoretically, can end with full reconstruction of the whole schedule.

If suddenly by some reason a chosen truck becomes not available (damage, breakdown, etc.), then its agent must be activated and then it will find all the orders, which are planned to this truck and report them about resource un-availability. These orders activate and start to look for other trucks. This allows to re-plan the routes of trips operatively, flexibly and safely. The result is considered done and the system ends its work when all agents don't have opportunities to improve their status anymore.

Thus the decision of a problem at the given approach is formed evolutionary during the exercising of each new event and consequently is irreversible (for convertibility it's necessary reproduction of conditions at which the decision was accepted). But the formed schedule is considered not as "static" structure of data received as a result of unitary application of one central monolithic algorithm, but as unstable balance of interests of many parties involved, being got and supported during interactions of two opposite entities of demands and resources.

As a result the given approach in many respects integrates the considered above modern ideas of the dynamic planning and optimization and provide a number of meta-heuristics and solid framework for developing various number of competing and cooperating agents implementing modern algorithms of optimization. It helps significantly to increase quality and efficency of scheduling and make results more clear, adjustable for end-users, and also to reduce delivery time.

4 ARCHITECTURE OF SYSTEMS FOR ADAPTIVE SCHEDULING

To implement the developed approach in scales of the large enterprise the architecture of system for adaptive scheduling is offered, it's presented on Fig. 1.

Let's consider in detail the basic components of the given architecture expanding applicability of the adaptive scheduler up to scales of the enterprise (Andreev V.V., Vittih V.A., Batischev S.V., Ivkushkin K.V., Minakov I.A., Rzevski G.A., Safronov A.V., Skobelev P.O., 2003; Batishev S.V., Ivkushkin C.V., Minakov I.A., Rzevski G.A., Skobelev P.O., 2001).

In general, the system implements a standard three-tier architecture including servers for web-interface, business-logic and databases, and also can get the operative information from external web-services and cooperate with communication devices of users (for example, drivers).

Web-interface layer of the system gives an opportunity to make settings and process orders and resources of the enterprise, etc. Through a web-interface the system operator can see the current schedule of system formed by the adaptive scheduler, in the form of Gantt chart (the schedule on each resource) or in a tabulated mode, from the side of both orders, and resources. At last, one more important component is for a display and processing of events of different type which can be transferred to scheduling manually or automatically. It is important to note, that internal and external events processing report is available for a user, that allows to explain the decision making logic of the system to an operator.

If necessary a user can be provided both with a desk-top interface for more convenient work at the local machine using web-start technology.

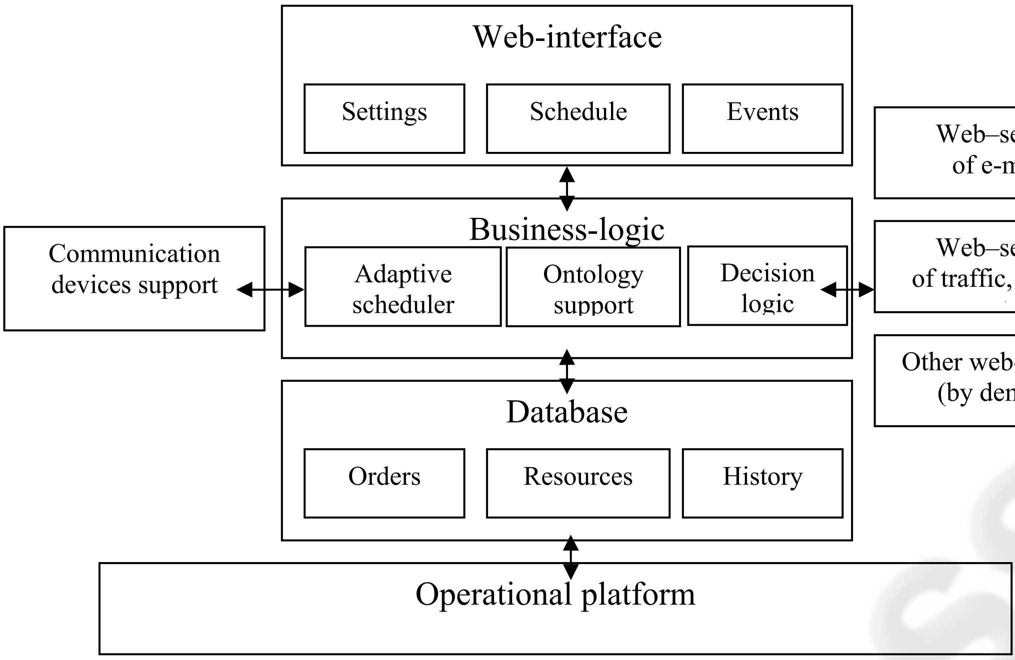

Figure 1: Architecture Of Systems For Adaptive Scheduling.

The layer of business-logic actually provides a reaction to events, adaptive scheduling and delivery of results. A basis of this part of the system is the adaptive scheduler constructed using the described above multi-agent approach. For each problem there can be developed a new scheduling engine, but at the same time there are certain opportunities of adaptation of existing "engine" according to new requirements by ontology configuration. The tools of ontology support allow to describe objects and attitudes of a problem domain, and also the scene describe current position of resources and orders in a transportation network at the moment of time. On this basis the rules of decision-making are formed, which can be switched on and off, be modified or adjusted by the user. The logic of decision-making is supported by the set of components, allowing to carry out calculations of distances or costs, which are specific for transport logistics, and other functions.

The database layer allows to save the information of concrete orders and resources, and also history of changes of the schedule.

The adaptive scheduling system can integrate itself with client platform or to use components of the offered platform including tools of a security control and management rights of users, provide visual reports, etc.

On the basis of given representation of architecture there can be developed the solutions on adaptive scheduling of resources for enterprises of various domains, considering the specific requirements and restrictions.

The examples of industrial application of the described approach and solution architecture are given below.

5 APPLICATIONS IN TRANSPORTATION LOGISTICS

5.1 Tankers Scheduling System

This system is used for management of large-capacity tankers, carrying out transcontinental transportations of oil (Himoff, J., Skobelev, P.O., Wooldridge M., 2005).

Everyday a company, carrying out up to 70 % of world transportation in a considered class of vessels, gets 10-15 inquiries about oil transportation. Operators of the company should make the analysis of a situation in real time, sometimes even on the phone, to analyze situation, provide all economic calculations and make a decision, on what tanker it is necessary to execute the order.

At the same time it is necessary to keep constantly in a head arrangement and traffic schedules of about 50 own vessels, and also positions of competitors, count routes of traffic, consider features of passage of Suez canal if it is necessary (time for partial unloading of oil is required), consider, what ships can enter into what ports, where and when it is better to refuel the tanker, what are weather conditions, etc.

To solve this problem the system of adaptive scheduling has been developed, which was integrated with a data management system. Due to small horizon of scheduling (the number of orders planned forwarding advance), in this system the arrival of a new event entails long chains of possible changes including up to 7 exchanges of orders between tankers. Thus, the new order can affect changes of a lot of tankers and even alteration of contracts with a number of clients.

Now the system is in regular operation by the customer for already more than two years, daily allowing to simulate orders allocations and schedule choosen orders more effectively. The cost of one day of idle time of such tanker is about $150,000 that allows to estimate economic benefit of introduction of the system.

At the same time, the opportunity to take and formalize valuable domain-specific knowledge of operators which are necessary for decision-making turned out also very important for the customer. Actually, as it was very difficult to replace operators, and in case of retirement, illness or vacation of those key employees before, all business of this company was under threat of efficiency loss.

5.2 Corporate Taxi Scheduling System

This system allows the company, who is the leader in its country, to schedule adaptively about 13 thousand orders a day at presence of several thousand machines, up to 800 from which are always on the road. The company basically serves orders of corporate clients, but also each interested person can call a taxi by phone through call center in which 130 operators simultaneously accept calls, or using the system of collecting orders in the Internet. The company tries to provide an individual approach to each client, allocating only machines of the necessary class or a class above, with well-reputed driver, give on demand the car for disables, with the trailer, for smoking passengers, for transportation of animals, etc.

The drivers work in the company as freelancers, deciding themselves what number of days and hours per week (with some restrictions) to work, renting cars at the company. At the same time they can come to work at any time. The drivers have handheld computers which allow the driver to appear on "radar" of the system when starting to work. At occurrence of the new order the system automatically finds the best car and preliminary reserves the order.

On the average the submission of the car takes about 9 minutes. From the moment reception of the urgent order, the system continues to redistribute orders for concrete time continuously in view of appearing of new resources, and does not make of the final decision till dynamically defined moment when it is necessary to send the car to client. During this time the system can change the decision on distribution of the order to cars some tens times. When already it is time to send the car to the client, the system makes the final decision and sends a message with criteria of order to driver, after that gets a message about receiving the order. At the same time the driver also gets a city map in view with the route how to reach the client with the view on police signs.

It's important to note, that the system balances distribution of orders to the driver, providing fair distribution of orders. Thus, it is possible to avoid claims of drivers to dispatchers who they think often distributed good orders to “own” drivers. Besides when the driver informs, that finishes the work, the system selects orders on road home for him, that not only raises profit of the company, but also earnings, and satisfaction of drivers.

The system is in commercial operation for half a year and has allowed the client to increase total amount of sold orders by 7 %, at the same volume of fleet.

5.3 Truck Scheduling System

This system provides the truck scheduling for world famous networks of supermarkets on the country scale. Among the transported goods there are food stuffs and drinks, including the frozen products, household electronics, clothes, etc. (Himoff J., Rzevski G.A., Skobelev P.O., 2006; Skobelev P.O., Glashchenko A.V., Grachev I.A., Inozemtsev S.V., 2007).

The level of orders in corporate network – about 4 000 a day, the fleet of the company includes about 300 trucks of various volume, and a number of them is equipped by the additional equipment (refrigerators, etc.), the delivery network includes about 600 geographical locations all over the country. The complexity of a problem in many respects is connected with presence of warehouses of intermediate storage, necessity of splitting of greater orders for some trips and, on the contrary, consolidations of small orders of different volume, requirements of compatibility of cargoes, different opportunities of acceptance of trucks in different warehouses, etc.

For solving this problem the adaptive scheduling system was developed. It automates all main steps of orders execution: from orders receiving and adaptive splitting and consolidation, routing and scheduling – to reports making. This system turned out to be the most difficult, where architecture of the virtual market includes a lot of agents acting together and proactively.

In particular, the orders are dynamically broken to sub-orders that are then consolidated in groups, and the trips also are formed dynamically from groups, and they, in turn, are planned for trucks. If the order has been splitted unsuccessfully, and it was not possible to plan good trips, it is made re-splitting and routing and scheduling begins anew. The big number of active agents (tens and hundred thousand) has led to necessity of application of more developed mechanisms of scheduling of agents, when only the most perspective agents get activity, competing with each other.

In present time the system is on implementation step, and decision making logic tuning is taking place. Before the deployment started the operators planned trips manually on the basis of numerous Excel tables. In this connection a lot of time was spent for adjustment of initial data in which there were many issues, including different versions of names of the same warehouse, etc.

It’s expected with the system introduction we’ll get not only significant economic benefit of more effective scheduling resources, but also the number of operators will be essentially reduced.

5.4 Car Rental Scheduling System

This system is for car rental scheduling. A company has about 100 stations. Each of them has on the average up to 150 cars of different classes. Clients can order the car by phone, directly come to station or book car via the Internet.

For convenience of clients it is possible to agree about delivery of the car during necessary time to the necessary place. But then it is required to send the car with the driver which can work at stations as in the certain days, and overtime. Also it’s necessary to send drivers, to take away cars from clients, therefore in some cases it is necessary to send several drivers in one car, someone will bring the car to the client, and someone will take away the used cars.

For solving the problem the adaptive scheduling system was developed, that allows to re-schedule operatively the delivery of cars for new-coming orders and also in case of different kind of events (delay, a driver’s sickness, traffic jams, etc.), and make schedule for drivers who bring or take cars. At the same time the system also addresses to an e-map and shows drivers recommended routes of traffic, and also sends them in real time all other necessary instructions. The system is integrated with an available system of gathering of orders by phone and Internet. Now development and testing of system on real data is finished and its expansion at first five stations is begun, up to the end of current year introduction in all other stations is expected.

The economic benefit of introduction of system consists in distributing cars in view of a situation being the whole country as a whole, and to estimate more precisely, from what station it is necessary to give the car. Before introduction of the system the decisions were made locally at stations that led to constant surplus of cars at one stations and to deficiency of the necessary cars at other stations, and also to infringement of obligations to clients. Besides after introduction of system reduction of the total number of cars in the network up to 10% and savings on fuel expenses and salaries of drivers are expected as the number of the superfluous trips, involved drivers and amount of overtime will be reduced.

Let's note that the developed systems have been constructed with application of methods and means (Rzevski G.A., Skobelev P.O., Andreev V.V., 2007; Andreev M.V., Rzevski G.A., Skobelev P.O., Shveykin P.K., A.Tsarev, 2007) which can be applied to a wide range of businesses.

6 CONCLUSIONS

In this document we described the multi-agent approach for development of the systems for adaptive scheduling of resources in real time. Positive results of the first industrial development on the basis of the offered approach prove its important advantages and define future benefits of its development and application in various spheres of transportation logistics.

At the same time, the first experience shows, that adaptive scheduling systems are demanded for a wide range of other enterprises (Rzevski G.A., 2008). In particular, for small enterprises, the workers who are supplied by specialized GPS-devices or usual cellular telephones, communicators or handheld computers with built in GPS services or services of definition of coordinates on cells, also can be considered as mobile resources.

At the same time the further development perspectives of all scale of adaptive scheduling solutions are connected with the use of emergent intelligence concept (Rzevski G.A., Skobelev P.O., 2007).

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