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Multi-agent Approach to Dynamic Pick-up and Delivery Problem with Uncertain Knowledge about Future Transport Demands

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Abstract. This work focuses on the dynamic Pickup and Delivery Problem with Time Windows (PDPTW). The transport requests should be performed using the available fleet of vehicles. The vehicles move between the nodes of a road network. The aim of this work is to propose a model which allows, during a transport plan creation, to take into account predictable events. Particularly, we consider the frequency of requests at any node in the road network and the construction of vehicle routes that will allow new requests to be inserted without any significant route modification. Therefore, we construct routes that pass near the nodes where transport requests are most frequently generated.

Keywords: transport planning and scheduling, dynamic PDPTW, multi-agent systems

1. Introduction

Effective construction of a transport planning allows companies to highly limit sustained costs and be more competitive on the market. Therefore, an important challenge is to create tools, which support development of such planning on the basis of acquired knowledge on available transport resources, incoming transport requests and road network structure. One of the applied approaches is simulation research, which facilitates selection and configuration of transport planning algorithms.

There are several uncertain elements which have an influence on the realization of any transport planning such as, the arrival time of new transport request, the location of request, the travel time between the nodes in a road network or other different unexpected events like car failures, crashes or the transport requests being withdrawn. There has been research carried out on elaborating more effective transport planning and scheduling algorithms, based on simplified models of reality e.g. VRPTW (Vehicle Routing Problem with Time Windows), PDPTW (Pickup and Delivery Problem with Time Windows) and their different versions.

In our previous work [9], the structure of our system and some preliminary results were presented. This work focuses on the dynamic PDPTW which is defined as follows: when new transport requests arrive, they should be performed using the available fleet of vehicles. The vehicles move between the nodes in the road network. In this case, the uncertainty is a consequence of request arrival time and its parameters. Each request is defined by the node of pickup, the node of delivery, the necessary capacity, and the allowed periods of time when pickup and delivery may be performed.

The aim of this work is to propose a model which allows, during a transport plan creation, to take into account predictable events. Particularly, we consider the probability of requests arrival at any node in the road network and construct vehicle routes that will allow new requests to be inserted into the route without any significant route modification. Therefore, we try to construct routes that pass near the nodes where transport requests are most frequently generated.

The Section 2 contains a research overview. In Section 3 our model and its modification, which allows to take into consideration the information about request distribution, are described. Section 4 presents the realisation of the system and performed experiments. Section 5 concludes and presents plans of future works.

2. Related works

This section contains the presentation of dynamic transport problems, description of problems concerning stochastic planning, advantages of a multi-agent approach for dynamic transport problems and an overview of several multi-agent systems for transport planning and scheduling.

2.1. Static and dynamic transport problems

For each transport problems such as PDPTW or VRPTW [5, 3, 10] one can distinguish two main versions: static and dynamic. The solution consists of a set of routes associated with particular vehicles. Each route contains a list of visited request points with information concerning times of arrival to the request points and departure from request points. Solving the static problem consists of calculating the optimal routes which means serving the all requests from a set of fixed requests. The solution has to respect additional constraints like time constraints (time windows) or capacity constraints. Because of the high computational complexity of exact method problem solving, the approaches based on heuristics, like tabu search, evolutionary algorithms or simulated annealing are used. Initial solutions are built on the basis of different versions of construction heuristics, which insert subsequent request points into the routes. Operations of solution modification (local search, mutations) are based on emptying some routes, by moving request points to other routes, on different versions of request exchange among routes or on changing the order of request within a route. In dynamic problems it is assumed that requests may also arrive while the system is running which makes dynamic modification of vehicle routes necessary. The modelling of vehicle displacement has to be considered. In [8], the parallel system using tabu search with adaptive memory is presented. One processor (master) assures the management of the set of memorized solutions, while other processors (slaves) provide tabu search on the space of solutions created by the master in order to optimize main objective.

2.2. Uncertainty in planning and scheduling problems

Because of the uncertainty of real life transport problems, research on the stochastic version of transport problems is also performed. Particularly, the stochastic VRP (Vehicle Routing Problem) is examined, which is simpler than the problems with time windows or PDP, because the solutions have to respect fewer constraints. In the case of VRP one point of transport request (either pickup or delivery) is the same for all the requests. The stochastic transport problems are characterized by uncertain (stochastic) clients which may be present or not, uncertain requests (uncertain points of pickup and delivery, time windows and capacities), uncertain travel times among the nodes and uncertain service times.

The problem of uncertainty in planning and scheduling problems have been widely examined [4]. Research is especially advanced in production scheduling problems (job shops, flow shops, open shops etc.) [11].

2.3. Multi-agent approaches

The multi-agent approach is based on the cooperation of intelligent, autonomous elements, called agents. Each agent constructs a plan so as to accomplish its goal interacting with other agents. This results, ideally, in system goals being accomplished.

Multi-agent systems for transport planning and scheduling offers additional features in comparison to metaheuristic approaches. A model of the problem is developed for the purpose of being as close to real life situations as possible. For example, the components of the vehicles, the available drivers, and the loading and unloading process specifications for different kinds of cargos are considered. Multi-agent systems are often based on an environment which is distributed and decentralized. Looking for local solutions (routes of particular vehicles, managed at least partly by them) may be useful in considering the complexity of obtaining a global solution. Additionally, some elements (like drivers) need a degree of autonomy which favours the multi-agent approach (e.g. they should rest if they feel very tired, or take decisions concerning detours if it is necessary). We review some MAS based systems for transport planning and scheduling.

Simulated trading. Simulated trading approach [1] is a basis for optimisation algorithms used in MARS and Teletruck systems. Several processes are executed concurrently and each of them represents one route. There is one distinguished process which manages the stock of unattached requests. The idea is based on buying and selling requests by processes representing routes; process sells requests which have bad influence on its cost function, and to buy these which do not increase it. A graph, representing the flow of requests between routes, is built and serves for the creation of feasible and efficient plans (trading matching).

MARS. MARS system [7] is realized to simulate planning and scheduling for a society of shipping companies. The agents represent transportation companies and trucks. Protocol Contract Net [12] is applied to assign requests to particular vehicles. Simulated trading is used for dynamic re-planning or for optimization of the current solution

TeleTruck. TeleTruck [2] is a distributed multi-agent system for shipping company planning and scheduling. The architecture is based on the concept of holonic agents. There exist several types of agents (driver, truck, trailer, container) which possess and manage specific types of resources. Such approach makes possible to consider different aspects of transport problem like storing, transportation, management of cargos, drivers, trucks etc.

3. Model description

This section contains a description of the basic model and its modification, the goal of which is to take into consideration potential locations of future requests while constructing a solution.

3.1. Basic Model

The model of the multi-agent system for transport planning consists of the following elements:

- environment: it represents a transport network and it is implemented through a graph describing road connections,
- several kinds of agents: customer agent - responsible for the generation of transport requests, company agent - representing a transport company and agent-vehicle - representing a vehicle of the transport company for example a mini-bus, bus, or taxi etc.

Agent-vehicle. The Agent-vehicle represents a vehicle that travels between the nodes in the transport network and possesses plans of its routes and schedules of the requests to be realized. An Agent-vehicle is defined by the following parameters: its current location (node, direction, percentage of traversed arc), current gain, current costs, maximal capacity, number of passengers, list of nodes requested to visit, planned path, list of embarked orders (after pickup and before delivery).

Agent-company is responsible for receiving requests from the Agent-customer and its subsequent scheduling to the Agent-vehicles. The Agent-company is characterised by the following parameters: incomes, gains, costs, a function of choice of Agent-vehicle which will perform the request, a list of received requests with information concerning the state of how they are to be realized (received, rejected, scheduled to agent, pickup performed, delivery performed). On receiving a transport request, a company receives offers from those agents which are able to realize them. The quality of an offer is estimated on the basis of the following equation:

$$QOS = \Delta g - \Delta d \tag{1}$$

where:

QOS - quality of solution submitted by a vehicle,

Δg - increase of gain after request realization calculated as distance between pickup and delivery points calculated using Dijkstra method multiplied by number of transported persons and by coefficient (equal 5 in experiments), which represents a payment for transport of 1 person across one distance unit.

Δd - increase of total vehicle travel distance after request acceptation.

The Agent company chooses the offer with the highest quality value. The conversation is based on the Contract Net Protocol.

Agent-customer. The Agent-customer is responsible for the generation and sending of transport requests to the agent-company. A method of request generation is inspired by work [8]. The time of request arrival is calculated on the basis of Poisson distribution with the given coefficient, which may be changed during the simulation. The request parameters, whose values have to be defined, are time windows of pickups and deliveries, the number of transported persons and the nodes of pickup and delivery. The number of transported people is calculated on the basis of the uniform distribution on the interval from 1 to a given maximal variable (in performed simulations it was 10). Nodes of pickup and delivery are selected by lots, assuming that they have to be different. The beginning of the time window is calculated as follows. The time which is left until the end of a simulation is divided into two parts based on the values entered. The first part starts just after the request arrives and the second starts later after the first has finished. A request is associated either to the first interval or second, depending on its probability. After the selection of the part, a time point in this interval is selected on the basis of the uniform distribution. In the experiments presented in the work, the time windows have a constant size, so their starting point determines their ending point. The start of the delivery time window is calculated on the basis of the uniform distribution on the interval, where the starting point is the earliest possible time a vehicle can arrive from a pick-up to delivery point, and the end time is the latest time which guarantees a vehicle will arrive to its terminal point on time. As in the case of the pickup time window, the size of the delivery time windows in performed experiments is constant so the start of the time windows determines the end.

3.2. Modifications taking into consideration future requests

Those nodes where the frequencies of pick-ups or deliveries are higher than the average, are called central points (CP). It is assumed that a higher concentration of vehicles in a neighbourhood of central points may increase the number of realised requests. It may be particularly important, when dealing with wide road networks (representing a region or a country), where the number of vehicles is relatively low.

In the fig. 1 a part of the graph which represents the road network is shown. A vehicle travels from the node on the left (marked "Start") to node on the right (marked "End"). The numbers on the nodes represent the frequency of requests (e.g, a node marked "5" has a five times higher probability of a request appearance than nodes marked "1"). The routes on the upper arcs and the lower arcs have the same length, but the lower route passes closer to the node marked "5" (distance 2000) than the upper (distance 4000), so the vehicle should chose the lower route. This idea is realized as follows: the Δc factor expressing how the number of central points in any neighbourhood of points on the route increases, if a vehicle realises a new request, is added to the value of estimation of the results after inserting a new request into the route served by a vehicle (presented in chapter 3.1).

$$QOS = \Delta g - \Delta d + \Delta c \tag{2}$$

$$\Delta c = 1000(\frac{c_2}{l_2} - \frac{c_1}{l_1}) \tag{3}$$

where:

the meaning of QOS, Δg and Δd are the same as presented in 3.1,

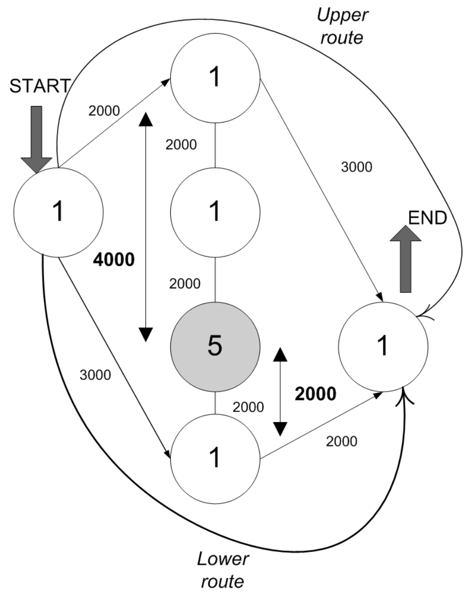

Figure 1. Preferences for the route passing in the neighbourhood of a central point

Δc - a measasure of the increase of number of central points in the neighbourhood of route,

c_2, c_1 - numbers of central points in the neighbourhood of the route after and before the insertion of a new request,

l_2, l_1- the sizes (the numbers of visited nodes of the graph) of the routes after and before the insertion of a new request

4. Realization description

4.1. Platform description

Currently there are two versions of the system in existence, one written in Java and the second one based on the MadKit platform [6]. The MadKit platform was designed and realised by prof. J. Ferber and his group using the JAVA language. It consists of modular JAVA API which facilitates the development of multi-agent systems. For example, communication and distribution are handled by the MadKit kernel. What interests us most is the organizational foundation of MadKit namely the AGR architecture which stands for Agent, Group and Role. It makes possible to develop multi-agent systems which are based on this organizational model which assumes that agents belong to corresponding groups and play roles defined in the system.
The organizational concepts provided by MadKit platform is similar to the ones existing in our model of the system, with the interaction schema based on Contract Net Protocol [9]. A view of the graphical interface of the version realised using MadKit is shown in fig. 2.

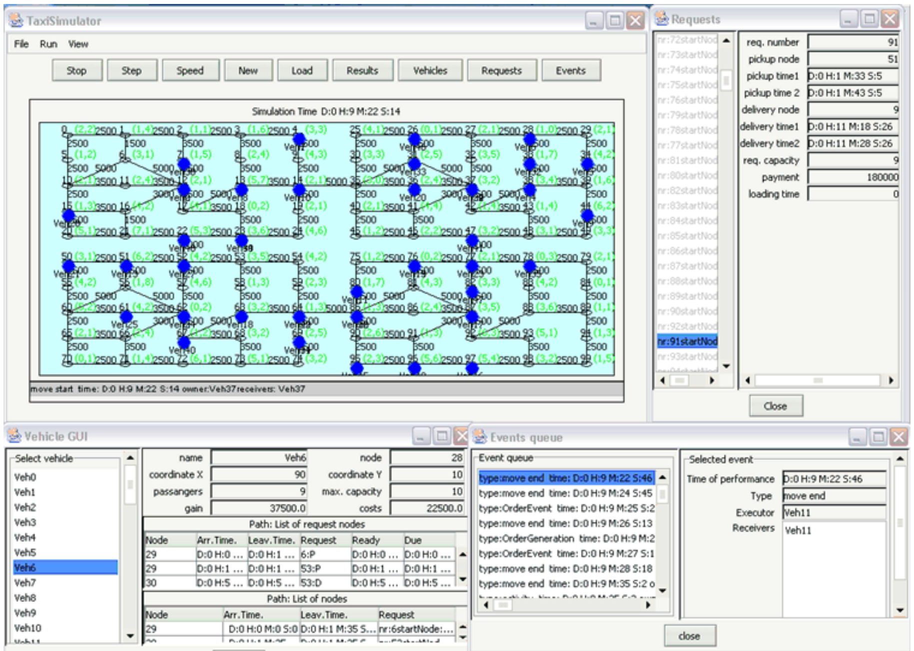

Figure 2. System interface

4.2. Results

In the experiments performed, the transport network consisting of 100 nodes and 272 arcs was used. The average length of an arc was 52 minutes and 42 seconds. The total simulation time was divided into 5 intervals with different frequencies of request arrival (5 x 4 hours). 12 central nodes, i.e. the ones having a request frequency of 5 times higher than normal nodes, have the numbers 6, 13, 16, 31, 38, 41, 56, 63, 66, 81, 88, 91 - these nodes are marked on the graph as black points. The transport network used in experiments is presented in fig. 3. The numbers above the arcs represent the length of travelled distances in seconds. The numbers above the nodes are node identifiers. We assume low quantities of requests and vehicles. The results (fig. 4 and fig. 5) are obtained based on two algorithm configurations: without special preferences being given for routes having nodes near to the central points (AVG NO CP) and with preferences being given for those routes (AVG CP).

To verify the approach based on the central points system, a set of tests was prepared where it took a long time to traverse the arc and where requests arrived rarely. In the case of a high number of requests and short arcs it seems that, the approach based on CP will not be useful because we will have a sufficient number of vehicles to perform the majority of requests and a factor supporting a non optimal route (not the shortest distance) may only make the solution worse.

Another unfavourable consequences of the approach based on CP is a possible decrease in gains for the cases where the number of vehicles is high because of a possibly given support to non-optimal - longer routes.

As a result of experiments, an improvement of the degree of requests realized, thanks to considering

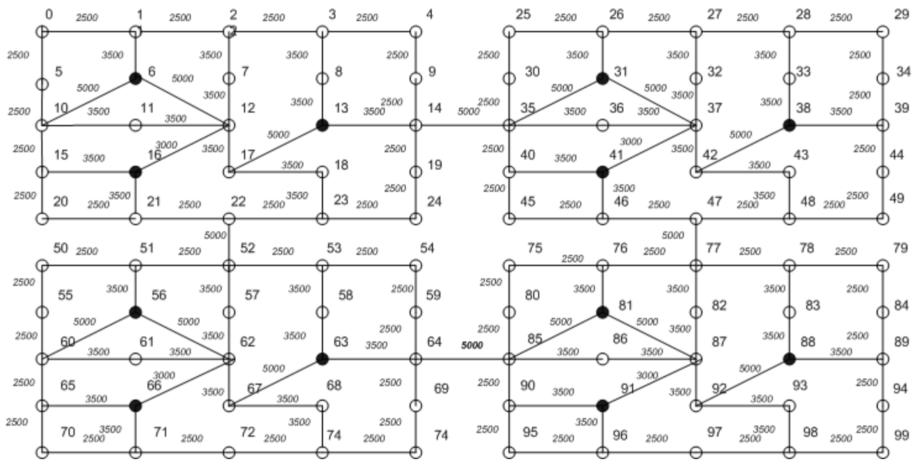

Figure 3. Transport network used in experiments

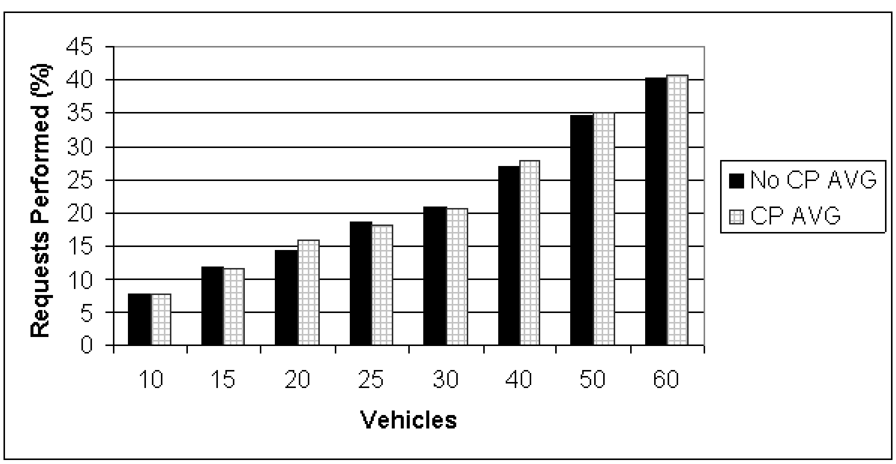

Figure 4. Performed requests (in %) depending on the number of vehicles and algorithms used

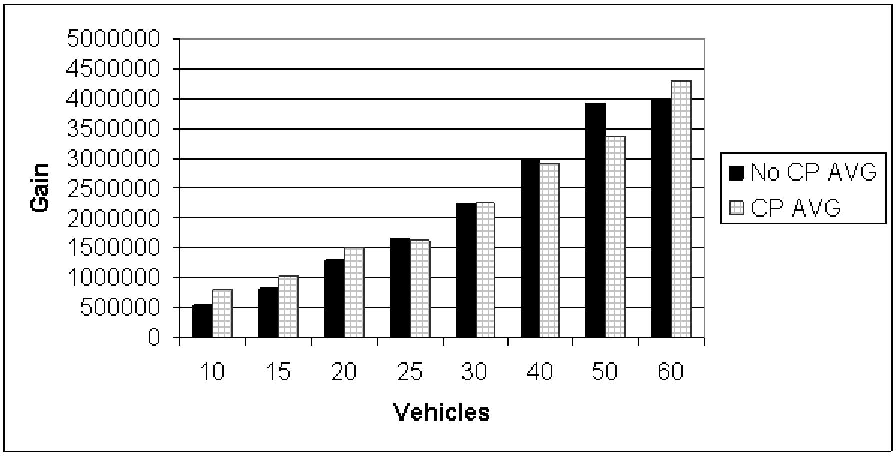

Figure 5. Gain (incomes - costs) obtained as a result of request realisation depending on the number of vehicles and strategy used

the influence of the central points, was observed for the low quantities (about 20) of vehicles (fig. 4).

Obtained gains are usually higher if an approach based on CP is used, especially for a low number of vehicles. It may be caused by a reduction of the costs of travel to pickups points, because the routes are more often in the neighbourhood of the nodes with a higher requests frequency (fig. 5), where new requests may appear.

5. Conclusion and future works

In this paper, a work concerning construction of pro-active plans, which take into consideration a simple model of the future containing information about transport requests frequencies, was presented. Elements of uncertainty which appear in this kind of problem are: the arrival time of a new request and the parameters which define a request (location and time). The results were obtained for a network with a relatively low number of distributed central points. They seem to confirm, that for specific conditions (i.e low number of vehicles, rarely arriving requests) the applied method increases the degree of performed requests and produces a higher income. The main advantages of the proposed approach to the construction of systems to transport planning is the possibility of adding emergencies, flexibility of configuration and the change of features of any particular vehicles, as well as taking the structure of transport organization and its policy into consideration during the optimization process. We intend to enrich the multi-agent environment by introducing the following elements to the system: variable time for arcs traversing e.g. caused by traffic jams and taking into consideration several cooperating transport companies.

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