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# Contract Net Protocol based Insertion Approach for the Dynamic multi-vehicle Pick-up and Delivery Problem

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***Abstract*—**In this paper, we investigate in the application of the Contract Net negotiation Protocol (CNP) to deal with a dynamic hard transportation problems. Our interest in the Multi-agent negotiation approaches accounts for its proved suitability with dynamic and uncertain domains [8][9].

We address the resolution of the uncapacitated-multi-vehicle-Dynamic Pickup and Delivery Problem with Time Windows m-DPDPTW, which is applied in the real world to the courier distribution services. This problem consists in finding the least cost routing allowing to satisfy requests of carrying items from pick-up locations to delivery ones, while dynamic requests continuously come to the planning center [4].

Our problem is implemented into a multi-agent system where cooperative agents representing the transporters and planning center negotiate possible m-DPDPTW solutions under the Contract Net Protocol [17],[20].

***Keywords***- *Multi-agent, negotiation, Contract Net Protocol, Dynamic Pickup and Delivery Problem, combinatorial optimization.*

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## I. INTRODUCTION

In the scope of the present paper, we deal with the Contract-Net-Protocol multi-agent negotiation approach to solve the m-DPDPTW, variant of the Vehicle Routing Problem (VRP), known to be NP-hard combinatorial optimization problem [9]. The *m-DPDPTW* is made harder than VRP because of the hard operational constraints, the dynamic occurrence of service requests and the real time implementation of the produced solution [6], [9].

Multi-agent implementations are compliant with such dynamic contexts [20]. They allow the distribution of computation efforts and consequently reduce the solution complexity and explore the best the solution space.

Contract Net Protocol figures out among the most successful cooperative negotiation methodologies supported by Multi-agent systems. Originally designed to deal with Distributed Task Allocation Problems [13]. It involves manager agents that initiate conversations with participant agents. The process consists in building a compromise between different perspectives with the purpose of achieving the best collective decision [20].

General Contract Net Protocol allows several managers to act in the frame of the same negotiation round. Tasks are independent and allowed to be announced simultaneously. The available participants evaluate announced tasks and submit bids on those they think convenient. Managers, then, evaluate the bids and contracts are awarded to the most estimated opportune bids [10].

Our proposed multi-agent model is based on CNP negotiations that are triggered by requests occurrence. The planner agent intends establishing contracts between transporters about requests assignments. The transporter agents are provided with calculation mechanisms enabling them to efficiently estimate requests insertion costs in their routes. They are also responsible for their own routing and scheduling. Thus, proper pricing and evaluation strategies are needed to help the system carrying out the minimum transportation costs.

The remainder of the paper is structured as follows: In Section II, we show a literature review illustrating uses of the CNP Multi-agent systems to solve VRPs. Section III gives a description of the m-DPDPTW. The CNP framework is then globally presented in section IV. Section V and VI, respectively deal with the manager and participant roles. In section VII, we discuss implementation driven results. Final concluding remarks and future scope follow in Section VIII.

## II. RELATED LITERATURE

Centralized approaches based on insertion and construction heuristics are provided to deal with the m-DPDPTW among other constrained and computationally hard planning and scheduling problems. Their usage is frequently powered by the employment of accurate large neighborhood search and metaheuristic approaches [21].

However, because of the large amount of required calculations particularly, while dealing with large sized problems, these methods are criticized for their relatively heaviness and slowness. Planning decisions are centralized and idle transporters are forced to follow the planner-generated plans. This motivates researchers to investigate in distributed decision-making approaches and particularly the multi-agents systems [20].

Planning and scheduling in a shipping company where no complete specification of the problem is available a priori were simulated via the first multi-agent system MARS in [20]. TeleTruck then extended MARS [19]. It uses heterogeneous agents (drivers, trucks, trailers, containers) represented as holonic agents. Each holonic agent (or holon) consists of a set of subagents that coordinates and controls the activities and information flow of its subagents.

JABAT-DVRP is developed to support the process of solving the dynamic vehicle routing problems. The platform is based on JABAT (JADE-Based A-Team) middleware, originally developed for solving difficult combinatorial optimization problems [18], where various dedicated optimization software agents are used for solving the problem. Using JABAT for dynamic VRP required creation and implementation of additional software agents representing such objects typical to the DVRP as for example, vehicles or shipping companies.

An agent-based approach for a Dynamic version of the full truckload pickup and delivery problem with time-windows was proposed in [5]. The studied problem was resolved by means of Multi-agent auctioning system based on the Vickrey mechanism. It involves individual agents with specific tasks and goals : transporter agents, fleet agents, job agents and shipper agents. To assign jobs, the job agent starts a new auction asking all transporter agents to bid only once by submitting its expected departure and arrival time. Simulation experiments on instances with 20 vehicles and 20 locations showed that the agent-based approach behaved generally better than simple scheduling heuristics.

The Contract Net Protocol, is a powerful coordination mechanism in distributed systems that was first designed by smith [13] in order to deal with the distributed task allocation problems. It was applied in industrial and transportation fields.

Sandholm proposed the Transportation *CNP* system (TRACONET), a bidding protocol, where dispatch centers of different companies cooperate automatically to provide a least cost routing. TRACONET extended CNP with bidding and awarding strategies based on marginal cost calculations [10]. The author concluded that parallel bids could not lead to good solutions when jointly used with true and precise valuations. It was also implemented in [10]

More details of existing research on agent-based approaches to transportation management can be found in [19].

## III. PROBLEM DESCRIPTION

Totally dynamic requests for transportation services are received in the planning center throughout the working day.

A request $r_i = \{i^+, i^-\}$ is about small sized items to be carried from a pickup location $i^+$ to a delivery location $i^-$. The loading and unloading services, respectively, at pick-up and delivery locations require $s(i)$ units of time.

$t_{i,j}$ is the travel time associated with the direct travel distance $d_{i,j}$ from location $i$ to $j$.

We denote by N (t) = $\{r_1,...,r_n(t)\}$ the set of the available requests at time $t$ ; $0 \leq t \leq T$ and $n(T)= |N(T)|$ the number of requests received over the working day.

By the beginning of the working day, *m* Transporters are available at the depot *O*. Considering *T* , the daily service period, and a depot working time window $[e_0, l_0]$=[0,*T*], the transporter journey starts at the depot *O*, at $\underline{t}^k \geq e_0$, and ends when he returns in, at $\overline{t}^k$.

The transporter reaches its $i^{th}$ planned location at the arrival time *A*(*i*), starts service at *b*(*i*) and leaves towards the next planned destination at planned departure time *D*(*i*) and then he may no longer be diverted from it. The location is henceforth blocked. A request whose pickup and delivery services are performed is a blocked request. The number of served requests at the time *t* is denoted as $\dot{n}(t) = |\dot{N}(t)|$.

The problem may be divided into three interdependent sub problems. First one concerns the assignment of requests to transporters. The routing sub problem is the second sub problem and is about achieving the best traversal order for the transporter assigned locations and the sub problem is scheduling which is a question of determining the best time and location to wait in. It consequently fix arrival, starting service and departure times.

These sub problems should be solved in such a way to respect operational constraints:

(1) The pickup and delivery operations of a request are necessarily processed by the same transporter.
(2) The pick-up and delivery operations are subjected to a precedence constraint such that the pick-up operation is necessarily performed before the delivery one.
(3) For each location *i*, the service should be carried out within a given *soft service time window* defined by the earliest time $e_i$ and the latest time $l_i$ the service can take place. The service deadline violation incurs a penalty to be added to the objective function value. Because of the third constraint, each service location scheduling dates have lower and upper bounds that are given by (1), (2) and (3):

$$\underline{A}^k(i) \leq A^k(i) \leq \overline{A^k}(i) \quad (1)$$

$$\underline{b}^k(i) \leq b^k(i) \leq \overline{b^k}(i) \quad (2)$$

$$\underline{D}^k(i) \leq D^k(i) \leq \overline{D^k}(i) \quad (3)$$

Finally the waiting time at the $i^{th}$ location is given by (4):

$$w^k = D^k(i) - \underline{D}^k(i) \quad (4)$$

These scheduling information are maintained up-to-date for computation efforts $O(n - \dot{n})$ .

Let *S* be a feasible solution for the *m-DPDPTW* problem, the global objective function $F_{global}(S)$ is the sum of the transporters local objective functions (5). Local problems deal with minimizing the sum of the total travel time $T^k$, the produced time windows penalties $\sum_{i \in N^+ \cup N^- \cap R^k} \max(0, b_i - l_i)$ and the drivers overtime $\max(0, t^k - l_0)$ as shown in (6).

$$F_{global}(S) = \sum_{1 \leq k \leq m} F_{loc}(R^k) \quad (5)$$

$$F_{loc}(R^k) = T^k + \sum_{i \in N^+ \cup N^- \cap R^k} \max(0, b_i - l_i)$$

$$+\max(0, t^k - l_0) \quad (6)$$

## IV. GLOBAL DESCRIPTION OF THE CNP FRAMEWORK FOR THE DPDPDTW OPTIMIZATION

In this work, we propose to build a Contract Net negotiation Protocol model able to solve the *m-DPDPTW*.

The proposed system insists on the distribution of calculations and decisions. Through the multiple negotiations, the planning process is iterated several times from different perspectives.

The planning center is represented by the *Planner agent* who interacts with *Transporter agents* representing the potential transporters. The negotiation process effectively handles real time events. All agents are informed about the under progress solution and all the information about available unassigned requests.

The general CNP permits assigning a task to the bidding participant transporter agents, depending on the participant's capacity to honor the service task and then on its offered price. Related to the routing context, the participant's proposal expresses its estimation of the cost of inserting the announced request into its route, which describes the proximity between the announced request's locations and the transporter assigned locations. Figure 1 describes the global negotiation process.

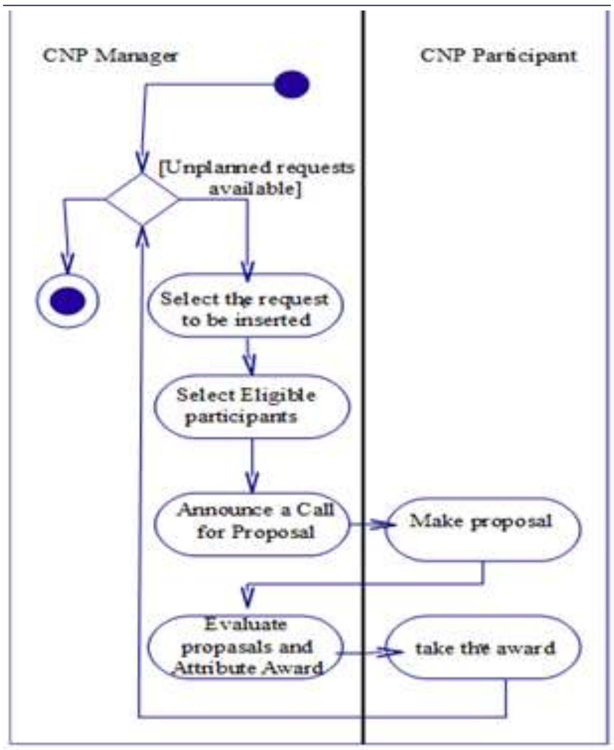


Figure 1. Activity Diagram of CNP negotiation process

Among exact and approximate cost estimations, we opt for true valuations, aiming to produce only feasible solutions. Submitted bids are binding so that each transporter is obliged to honor its awarded tasks.

Besides, submitting for simultaneous contracts may give rise to problems related to the bidder's capacity to honor the awarded service task. This may be, for example, with some transporter bidding for several requests, when he submits the best bids for more than one request. Unaware of the parallel contracts, managers may award the requests to the same winner who is unable to honor them together. To avoid such occurring failures, our model restricts the participation of a transporter agent to a single negotiation round at a time [10].

At the end of a negotiation, the task is awarded to the transporter agent that has submitted the least insertion cost. Then, this agent is responsible for improving the routing and scheduling of its assigned locations.

## V. THE MANAGER ROLE

Negotiation aims either inserting a new request or improving established assignments into the planned routes. The Planner agent is the manager of new requests assignments, while Transporter agents may act either as managers of the improvement negotiations or as participants in both types of negotiations.

### A. *Insertion negotiations*

Insertion contracts aim to re-instore the stability of the system by producing feasible solution according with the present problem features. The planner is responsible for this class of contracts. A new negotiation round is launched each time the request queue is no longer empty.

#### 1) *Selection of requests and participants*

The planner agent is informed of the state of the request queue. Once at least one request is available, a new negotiation round is immediately triggered by announcing the request.

Only transporter agents that are effectively able to carry on the request are involved. The manager agent selects transporters that are likely to offer feasible routes.

Eligible bidders are transporters whose workload $wrkld\,(R^{bdd})$ are low enough. The cost of adding the negotiated request to its route is denoted as $wrkld_{\,add}\,(r_j)$. It is equal to the sum of the added travel time to and from the location *j* beside the eventually produced blocked waiting time at the same location *j*. This added should does not draw the solution into severe penalties (7) and the transporter inactivity periods should match acceptably with the request time window (8).

$$wrkld_{\,add}\,(r_j) + wrkld\,(R^{bdd}) \leq T + cte \quad (7)$$

$$\sum_{i \in R^k} W^k{}_i \geq wrkld_{add}(r_j) \quad (8)$$

In the same scope, authorizing a little violation of the time window, permits to have more possibilities to minimize distances. *cte* is a bounded constant parameter, which is randomly determined in the frame of this paper.

*2) Announcement price*

The planner manager agent's announced price is associated with inserting the request into an empty route.

*3) Awarding strategy*

Awarding a contract to bidder agent is assigning the service request to the agent that submitted the best offer, i.e. the lowest insertion cost. An awarding message is sent to the winning bidder to inform him of the assignment.

When insertion negotiations do not lead to an agreement, then the planner creates a new transporter agent. The negotiated request is inserted under the new route.

Under improvement negotiations, if at least one among the bidders proposals is better than the announced cost. These costs are checked and the estimated local objective functions over manager and bidder are checked.

Let $F_{loc}(R^{bdd})$ and $F_{loc}(R^{mng})$, be respectively the local objective functions of the bidder and manager as, given in (6). The manager having the knowledge of current local objective function uses the submitted marginal cost to compare obtained local objective functions hoping checking true the next assertion:

$$F_{loc}(R^{bdd} \cup \{r_j\}) + F_{loc}(R^{mng} | \{r_j\}) < F_{loc}(R^{bdd}) + F_{loc}(R^{mng}) \quad (9)$$

Then the bidder offering the lowest value of $F_{loc}(R^{bdd} \cup \{r_j\}) + F_{loc}(R^{mng} | \{r_j\})$ is selected.

Otherwise, when all submissions are worse than the announced insertion cost, then no agreement may be established.

The transporter may not delegate the request service, because he may ensure it with the lowest marginal cost.

*B. Improvement negotiations*

Once insertion negotiation are finished, and all new requests are inserted, transporters are free to announce improvement contracts, in order to improve the current global m-DPDPDTW solution.

In order to allow exploring the space of solutions, transporters exchange requests under improvement negotiations. Once insertion negotiations finished, Transporter agents randomly selects one among its planned requests with unserved pickups and announces it.

To avoid reproducing visited solutions, negotiation rules are considered: following rules are respected by manger and bidder transporters.

Rule 1: Once a transporter agent wins a request $r_j$, it should wait at least $\beta_1$ requests moves to be performed on the solution before re-announcing it. Once transporter agent is attributed a request it keeps information of the previous owner and the number of the contracts that led to the request attribution.

Rule 2: When the request $r_j$ is announced, its previous owner is discarded from bidding it until $\beta_2$ request moves may be observed in the solution.

Rule 3: In order to lead the MAS towards the convergence of the CNP, negotiations of post-optimization could not be infinitely launched. A number of $\beta_3$ of failing contracts is enough to decide the solution is stable and is a good solution. the negotiation rounds are stopped.

## VI. THE PARTICIPANT ROLE

The transports behave the same as within insertion or improvements negotiations

*1) The pricing mechanism*

Making a reasonable request pricing is a key issue in the bidding operation. Bidders are interested in offering the lowest possible cost. for this purpose, a Cheapest Insertion Heuristic *(CIH)* is locally launched. The marginal cost is calculated for each possible insertion position and the solution with the lowest cost is retained and submitted. The process is iterated until all routing solutions are met or the bidding limit time is reached.

*CIH* iterates calculations of $C_{marg}(r_j) = C_{marg}(j^+) + C_{marg}(j^-)$, the additional cost caused by inserting the request $r_j$ into the transporter's route. It needs a computation effort equal to $O((n^k - \dot{n}^k)^2)$ in the worse case. To avoid unfeasible insertions and accelerate the bidder response, the feasible insertion positions are first determined.

The Cheapest insertion first, selects the matching routing block of the request beginning in the earliest insertion position of the pickup location and ending at the latest possible insertion position of the delivery location. It iterates calculating $C_{marg}(r_j)$ for a limited number of iterations.

Let us consider that a tentative insertion of $j$ between the pair of planned locations $(i,i+1)$ costs $C_{add}(j)$, which is the sum of the additional workload, $wrkld_{add}(j)$ and lateness eventually caused to $j$ and to customers expected to be served next to the $i^{th}$ planned location, $delays_{add}(j)$.

$$C_{marg}(j) = wrkld_{add}(j) + delays_{add}(j) \quad (11)$$

The additional workload is the sum of additional travel time, service time and binding waiting time (the time, the transporter should stay inactive waiting for the location service window to open).

$$wrkld_{add}(j) = t_{\tau_i,j} + S(j) + t_{j,\tau_{i+1}} + \max(0, e_j - (\underline{D}(\tau_i) + t_{\tau_i,j})) \quad (12)$$

Penalties caused by time windows violations are given by:

$$delays_{add}(j) = delay_{add}(j) + delays_{add}(R^{bdd}) \qquad (13)$$

$$delay_{add}(j) = \underline{D}(\tau_i) + t_{\tau_i,j} - l_i \qquad (14)$$

$$delays_{add}(j) = \max(0, \underline{D}(\tau_i) + wrkld_{add}(j) - D(\tau_{i+1}) \qquad (15)$$

Beside the Cheapest Insertion Heuristic, we rely on the named *WE Scheduling strategy* proposed in [23] to minimize the added workload and achieving the best routing and scheduling. WE forces the transporter to arrive at the next planned location, as early as possible but no earlier than its release date. This reduces the blocked idle time fragmentation and expands the request insertion possibilities.

*2) Award Attribution*

The bidder keeps track of the insertion positions and timetable leading to lowest obtained marginal cost. whenever the agent is awarded, feasible routing and scheduling are directly loaded.

The agent then uses its local neighborhood search heuristic to bring down ever better routing opportunities. Information about available requests is used by the scheduling improvement heuristic to opportunistically shift the free waiting times, in order to give bigger chances of insertion to the next requests.

Bidding pricing, announcement pricing and evaluation operations are key issues in the negotiation process. Efficient pricing and evaluation heuristics push the negotiations in that direction that supports the optimizing of the global objectives.

## VII. Experimental Results

The first purpose of the experiments is to validate the application of the Insertion CNP based approach (Insertion-CNP) in m-DPDPTW solving.

Our CNP based solution is implemented using the JADEX BDI agent-oriented reasoning engine realised as an extension to the widely used JADE middleware platform [14].

We used the test beds of Mitrovic-Minic [12],[14]. We examined the instances with 100 requests.

All instances consider service area of 60 * 60 km$^2$ with a unique depot. All considered requests occur during the 10 hours service period according to a continuous uniform distribution. The vehicle fleet is free sized and the vehicle average speed is set to 60 km/h.

Test beds (Rnd8) have effective Degree of Dynamism eDoD = 0,6. Details of the degree of dynamism of dynamic transportation problems may be found [6][7]. Similar to the Test beds author experiments, we consider that one hour of real life operations is simulated in 1/20 hours of computer time.

Tests are realized with 12 to 19 vehicles and the average values of the objective functions is retained.

Our test results are compared to the average results brought by the cheapest Insertion heuristic with WE scheduling strategy and Tabu search post optimizing heuristic [11].

For each planning round, best results are provided for values of $\beta_1 = (n - \dot{n})/4$, as an average time inhibiting the re-announcing of an awarded request, $\beta_2 = (n^k - \dot{n}^k)/4$, 10 failing negotiations are enough to consider that the negotiations may not enhance the current assignments any more.

Figure2 shows the results from experiments comparing the relative performance of the Multi-agent Insertion based CNP -approach provided solutions with these obtained by running a sequential CIH Routing heuristic. Average Insertion-CNP solutions for Mitrovic 100-request instances range from -12% to 3% better than the sequential CIH-TS Routing approach solutions. Considering longer negotiations may bring better results.

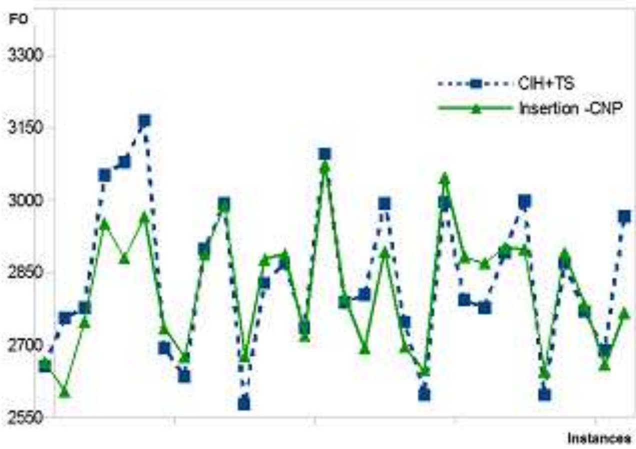


Figure 2. Comparison of the Insertion based CNP Approach and CIH-TS Routing Approach.

Thanks to employing simultaneous re-assignments and CPU time bounded pricing and evaluation heuristics $O((n^k - \dot{n}^k)^2) < O((n - \dot{n})^2)$, the proposed heuristic easily and quickly explores the solution space.

The provided results prove that the Multi-agent systems are really suitable for the dynamic transportation problems.

## VIII. Conclusion and Future Work

We proposed a Contract Net Protocol negotiation multi-agent approach for the m-DPDPTW resolution. Involved planner and transporter agents negotiate the insertion and assignment improvement of the unserved requests and optimization of the planned routes. The proposed approach was adjusted in that way to deal with the special features and constraints of the addressed problem.

We considered one request per contract and disjoint simultaneous negotiations in order to carry out precise insertions and avoid infeasible solutions. Agents are well informed about their past negotiations and are able of using their knowledge about the tasks subjected to next negotiations in that way to better present their estimations and promote their objectives. Congestion of the negotiation network was avoided thanks to the used thoughtful selection among requests to be announced and interested participants. Experimental results showed that the proposed Insertion based CNP approach afforded promising results. It dealt successfully with the studied problem.

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