Automating Supply Chain Negotiations using Autonomous Agents: a Case Study in Transportation Logistics

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ABSTRACT

This paper presents a case study for the application of agent-mediated negotiation techniques in transportation logistics. More specifically, we consider the interaction between several logistics service providers negotiating over the allocation of transportation orders. In this context, we show that automated negotiation techniques (especially multi-issue or multi-item negotiation) can bring significant advantages, by allowing parties to discover jointly profitable bundles (allocations) of orders. The model, evaluations and results reported in this paper concern the business processes of Vos Logistics, one of the largest European transportation logistic providers.

Categories and Subject Descriptors

I.2.11 [**Distributed Artificial Intelligence**]: Intelligent agents
H.4.2 [**Information Systems Applications**]: Logistics

General Terms

Management, Performance, Design, Measurement.

Keywords

Automated negotiation, multi-agent systems, transportation logistics, supply chain management.

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1. INTRODUCTION

Negotiation represents a key form of interaction in agent-mediated electronic markets that transcend the sale of uniform goods. Through negotiation, suppliers and consumers can reach complex agreements in an iterative way, which better match the needs and capabilities of different parties. Recent research work has led to a variety of new, increasingly complex algorithms to deal with application of automated negotiation (especially multi-issue or multi-item negotiation) in a variety of settings [4, 9, 11].

Transportation logistics and supply chain management represents a challenging, but potentially very fruitful area for application of automated negotiation. In this setting, it is often possible for all parties in a supply chain to obtain joint savings through more efficient, fine-grained matching of their requirements and capabilities (i.e. orders and transport capacity). The increasing complexity of modern supply chains, as well as increasing competitive pressures in this market has led to an increasing demand and interest for such distributed optimization techniques.

The practical impact of improved allocation which can be achieved through such techniques can be significant. For example, in the Netherlands, the average transport performance is between 40% and 60%[1]. [2]. Improving this utilization rate is also the goal of the DEAL (Distributed Engine for Advanced Logistics) project, which groups together several universities and large logistics service providers in the Netherlands. The work reported here is also carried out in the framework of this project, involving the CWI and Vos Logistics.

The paper describes a case study application of automated negotiation to the logistics domain. It is important to stress that, in this paper, we do not aim to propose a new algorithm or analyze

[1] Defined a defined as the extent to which transportation units are utilized as percentage of total capacity, usually given in ton-kilometer. Thus, a truck that is driving with only half its capacity has a transport performance of 50%.

fundamental aspects of agent-mediated negotiation techniques as such (this has already been done elsewhere, in papers by the same authors at the research track of AAMAS and AMEC [4, 9, 6]. Our goal is to focus more on the specifics of the application domain and to describe our experience with agent-mediated negotiation techniques in the real-life case of the organizing branch of Vos Logistics. The paper is largely based on the Master Thesis work of the first author, performed jointly at Vos Logistics and CWI [13].

The remainder of the paper is organized as follows. In Section 2 we describe the logistics of the transportation domain and briefly outline the profile of Vos Logistics as well as the transportation market in which it operates. Section 3 goes more in depth, by providing a more detailed analysis on how the order allocation and negotiation processes are actually conducted at the Vos Logistics Organizing branch in Nijmegen. Section 4 briefly outlines the potential of existing techniques from agent-mediated negotiation and discusses to what degree and how they are relevant or applicable to this domain. Section 5 describes our proposed multi-issue negotiation solution and how it can be used to discover more efficient allocations (or bundles) of orders during trading. Section 6 presents an analysis of the gains which can be actually achieved by bundling of transportation orders, based on the real order set of Vos Logistics Organizing. Section 7 provides a discussion of how our approach compares to other approaches to this problem (both from the theoretical literature and industrial-grade solutions). We conclude the paper by pointing out some of the challenges which can be encountered in the application of a pilot project on automated negotiation at a company such as Vos Logistics.

2. THE TRANSPORTATION LOGISTICS DOMAIN

Several trends have recently produced a significant impact on the area of transportation logistics. One of these is an increase in competition, with the continual entry of new carriers in the market pushing down expected profit margins. Another one is the increasing complexity and sophistication of modern supply chains. In fact, due to increasing and shifting trade patterns, not only the complexity of transportation chains has increased, but also their variability and dynamics. These challenges require increasingly sophisticated optimization solutions, that exploit all the niches in the supply chains involving different companies.

We note that his optimization has to occur both intra-company (where a company optimizes its own activity), but increasingly also inter-company, between different actors that do not necessarily share the same goals. Inter-company optimization poses considerable extra challenges, since the parties forming the supply chain can be self-interested, so they may be unwilling to share private planning information and strategic concerns make the problem considerably harder than cooperative case. The solutions proposed in this paper specifically address this case of inter-company optimization of the logistic chain.

The transportation management literature [12] identifies two main types of orchestrator companies for transportation logistic chains:

- Third Party Logistics service providers (3PL), which orchestrate the logistic processes and assures they are well executed according to a current logistic concept
- Fourth Party Logistic service providers (4PL), which orchestrate the supply chain and are responsible for the design of the logistic concepts.

There is, however, considerable disagreement about the exact meaning of these terms, both in existing literature and in practice. In our approach (and the remainder of this paper) we use the term 3PL provider companies to denote those that have their own transport capacity (i.e. truck fleet) and plan (or orchestrate) their movement, based on a set of orders from shippers and other companies. Fourth Party Logistic companies (4PL) have recently emerged as a result of the increasing complexity of supply chains and mostly have a role of coordinating these chains. In this paper we denote as 4PL companies those that do not have their own transport capacity: they receive large transport orders from shippers and then distribute them among a set of 3PL companies or independent carriers. This process involves direct negotiation with 3PL companies and often entails breaking up large orders or bundling orders for partial loads, in order to increase efficiency. The remainder of this section describes in more detail the company which forms the object of our solution, as well as the market in which it operates.

2.1 Company profile

Founded in 1944 as a one-truck company, transporting loads between Oss and Nijmegen in The Netherlands, Vos Logistics has grown into one of the larger logistics service providers in Europe. It has over 3000 trucks, 10000 trailers and containers, 350000 square meters of warehousing sites, 325 storage silos and 2 rail service centers. Vos employs 5000 people working at more than 45 locations throughout Europe. Annual turnover is around 800 million euro.

The increasing complexity of transportation chains has determined Vos to offer new solutions to its large corporate customers (shippers), which can now outsource all of their transportation activities to Vos. This lets them avoid the problem of finding and negotiating with individual suppliers, billing, following up orders etc. Another advantage of using this outsourcing service for large shippers is that Vos Logistics has a much better knowledge of the transportation market, so it is better positioned to find suitable sub-contractors.

Vos Logistics Organizing from Nijmegen (henceforth abbreviated VLO in this paper) is a subsidiary of Vos Logistics B.V. that was set up in order to handle such complex supply chain orchestration activities. Based on the taxonomy above, VLO (the subsidiary) can be seen as a 4PL company, though its parent company, Vos Logistics performs mainly 3PL activities. Hence, VLO acts as an intermediary company that acquires large (sets of) orders from suppliers and negotiates the allocation of the orders, the terms of transportation (i.e. delivery deadlines, destination) as well as the price with which 3PL companies that subcontract these orders.

2.2 Market organization. Closed vs. open group negotiations

This section describes the operation of a 4PL logistic company, which simultaneously interacts with customers (shippers), a set of 3PL companies (with actual carrying capacity) and the open market. For the purpose of this paper we identify this 4PL company with Vos Organizing (VLO), but the model should be a general enough to be applied to other companies in the same field.

Figure 1 presents a graphical model of this interaction.As depicted in Figure 1, there are two main mechanisms for allocating orders received from shippers:

- **Closed group negotiation.** Most of the orders (i.e. around 80%) received by the 4PL company are currently not auctioned off to an outside market, but are allocated among a small group of trusted 3PL carriers. The size of this group is around 5-10 companies. The composition of this "closed group" of trusted companies is based on trust and a history of good business relationships – in fact for each shipper there may be a customer specific list of companies with which the negotiation takes place. In current practice, the protocol for conducting negotiations is usually bilateral and sequential.
- **Open market.** A small subsets of orders (around 20%) is offered on the "open market". Usually this means offering the loads through transportation matching sites such as Teleroute [15]. The important point here is that there are no barriers of entry or "admission rules" on these sites (i.e. any company or individual carrier in the Netherlands or in the whole of Europe can make offers by phone for these orders)

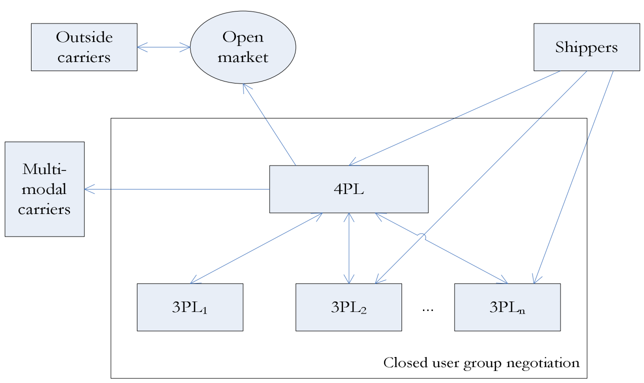

Figure 1: Interactions between parties in a multi-party logistics setting

We argue that both types of mechanisms can benefit from agent-based automation, though they may require different mechanisms. For the open group negotiation, auction protocols would probably be the most suitable, since here all agents are strictly competitive and there are no barriers of entry.

However, in our approach we concentrate more on the first set-up, the closed negotiation, chiefly because it is more applicable for our particular setting, i.e. it has a higher business impact and 80% of the orders are allocated in this way. For this set-up we considered two types of choices. The first one is automated negotiation, especially multi-issue and multi-item negotiation models that enable parties to reach mutually profitable (Pareto-efficient deals [8]) that go beyond strictly price competition. A second choice would be to have a combinatorial auction protocol, where the 4PL company would act as a "center".

In this paper we mainly explore the first option, since we feel it allows us more flexibility in dealing with side constraints and incomplete information. However, the auction option is also being considered, especially if the protocol could be adapted to quantify issues such as trust or other constraints. Further discussion of this issue is given in Section 5.

3. ORDER ALLOCATION AND NEGOTIATION PROCESSES AT VLO

This section aims to give a more in-depth look at how the order allocation and negotiation processes are currently performed at Vos Logistics. This is an important part of any industry analysis, in order to assure that the models considered can lead to usable pilot applications within the company and are not of merely theoretical interest. We focus here on the daily outsourcing (i.e. "spot orders"), which is the main area that could be automated through agent technologies, since it is unlikely that automated agents can be entrusted to take higher-level or strategic decisions.

3.1 Order set characteristics

There are several characteristics (parameters) that describe every transportation order. The following is a non-exhaustive list:

- The volume (or mass) to be transported
- The price (computed either per unit volume or unit mass)
- The time windows (in the form of time for picking up the goods and the deadline for delivery)
- Locations where the order is picked-up/delivered
- Extra transport conditions (e.g. refrigeration, liquids, fragile merchandise etc.)
- Arbitrary constraints that the shipper may impose (e.g. do not transport my goods at the same time as company X's)
- Flexibility of contractual terms (e.g. time ahead of the actual transport when a contract may be re-negotiated or cancelled)

Due to the time limitation of human planners, currently most of the parameters are not explicitly negotiated about every order. From the above set we identify two characteristics that are particularly important from the perspective of how orders are currently priced by carriers:

- The percentage a load takes from the total volume of a truck, commonly referred to in the field through the acronyms FTL (full truck load) and LTL (less than truck load)
- The "fruitfulness" of the region the order originates from or is to be delivered. Here by "fruitfulness" we mean the likelihood that there will be return freight from that region.

In the following sections we discuss these two dimensions in more detail and show their importance with respect to the different types of bundling.

3.2 Bundling of LTL shipments

Making bundles out of individual orders is a well known way to increase offer value [9, 4]. Two potential improvements have been found in the area of bundling; consolidating multiple part loads with overlap in route and the offering of return shipments or subsequent loads at the unloading destination.

VLO can gain considerable savings when multiple LTL or part loads, with overlap in (part of their) route, are offered as a bundle. To illustrate, a typical price table, using actual carrier data, is displayed in Figure 2 which depicts the price per pallet for the various loading percentages of a truck[2]. From Figure 2: Relationship between load and price per pallet, we can see that the pricing of LTL (less than truck load) orders follows a logarithmic–like pricing function. An order for a quarter of a truckload is roughly 50% of the FTL price for example whereas half of a truckload equals approximately 70% of the FTL price.

Currently, the process of bundling is executed by hand by VLO for the shippers that request it. A number of solutions exist, both agent-based and non agent-based, to automate and optimize the process of making efficient bundles out of a given set of orders.

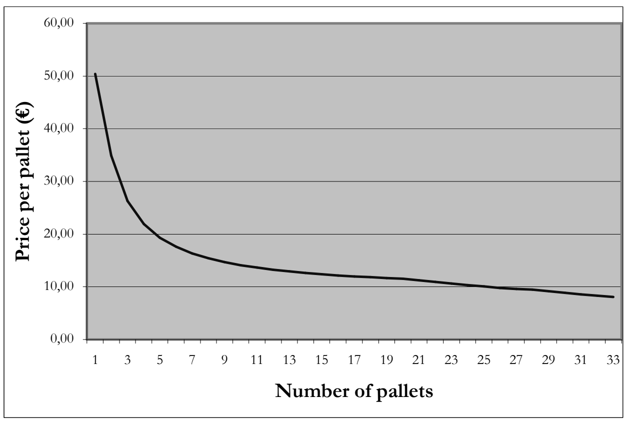

Figure 2: Relationship between load and price per pallet

3.3 Bundling of return or subsequent freight

For the bundling of a shipment with a corresponding subsequent or return shipment, the notion of fruitfulness plays a central role. In a fruitful region much freight is offered and a truck runs only a limited amount of empty kilometers, whereas in a fruitless region not much freights are offered and on average trucks run a significant amount of empty kilometers before pickup of the next freight. Depending on the fruitfulness of the unloading area and the quality of the carrier's own network and his own capabilities in matching demand and supply, a truck has to run a certain number of empty kilometers from the unloading point to the next pickup location. If VLO was to offer a new freight at or close to the unloading location, a significant discount might be obtained from the carrier as the truck is decreasing its empty kilometers. Savings depend on the area the new freight is offered in and the quality of the carrier's own network. If a lot of freight is offered in the region, the discount will be smaller. Similarly, if a carrier's own network is mature and the carriers are very capable of finding subsequent shipments, the discount will be smaller.

This concept can be seen in current business practice at VLO, in which a certain price/km value is used for a 'country of origin' to 'country of destination' combination. Different values are used for each combination, e.g. for a shipment from France to the Netherlands a lower value is used than for shipments from the Netherlands to France. This has to do with the amount of return freights generally available in the country of destination. If a truck coming from France has to deliver freight in the Netherlands, chances are high that there is a freight weighting to get from the Netherlands to France. It is different the other way round. If a truck is empty in France there is a much smaller chance that there are freights weighting to get from France to the Netherlands and as a result there is a higher chance that the truck has to return empty. To illustrate, rates from France to the Netherlands are about € 0,60 to € 0,80 per kilometer, whereas prices from the Netherlands to France range from € 1,25 to € 1,50 per kilometer.

[2] A regular trailer (truck) has a volume of 33 euro pallets, while large-volume trailer can take 38 pallets. Note that a euro pallet is 1.20 meters wide and 0.80 meters long.

4. AUTOMATED MULTI-ISSUE NEGOTIATION: MODELS & RELATION TO THE TRANSPORTATION DOMAIN

The concept of electronic negotiations or e-negotiations is a very broad one. As shown in [1], it covers a whole spectrum of negotiations ranging from the unstructured exchange of messages using email and chat systems, to partially structured e-negotiations supported by negotiation support systems, negotiating software agents or online auctioning platforms for selected tasks, to completely structured negotiations conducted autonomously by computer systems.

The scope of our approach is the automated case, where parties are represented by software agents. More specifically, we are interested in multi-issue or multi-item negotiation models, which allow agents to exploit so-called "win-win" opportunities. As shown by Rosenschein & Zlotkin [10], such negotiations represent non-zero sum games, where "as the values shift in multiple directions, it is possible for both parties to be better off". In our application domain, this means that negotiations between agents representing different transport providers (carrier companies) do not focus exclusively on price, but also allow the discovery of mutually beneficial bundles of orders, which are customized to accommodate for niches in their supply chains.

In the following we discuss some of the issues identified by our case study at VLO that could potentially form the object of automated negotiation techniques. Some of them (especially the question of time windows) is important because it influences the potential gains which can be achieved through the bundling of orders.

4.1 Negotiation over price

In current practice at VLO, price is the only issue negotiated. This negotiation currently is performed by humans and takes place over the phone. Even for this one issue there are some advantages to be gained from automation.

First, efficiency could be improved, since transaction costs would be reduced by automating the process. Furthermore, humans have a cognitive limitation on how many parties they can negotiate with at the same time and how many counter-offers they can make in each negotiation. In current VLO practice this leads to rather large bid-offer spreads between offers and between negotiations for similar orders. If these negotiations could be automated, this would increase the effectiveness of the deals made as well.

However, we should point out that automated negotiations are however no panacea and should be treated with care. In human-controlled, traditional negotiations, the communication, formulation of offers and making of concessions is a vehicle for both a consensus and understanding [7]. In vaguely defined negotiation situations, a human-controlled negotiation process will probably be more efficient and effective than what would be possible with even the most sophisticated intelligent agents currently available. Therefore, having a clear protocol is crucial in automated negotiation models.

4.2 Negotiation over time windows

Currently, time windows (i.e. time interval when an order is to be delivered) are considered to be fixed, due to the complexity and high cost of negotiating a potentially exponential number of combinations of order bundles/time windows. It has however been indicated that VLO's customers would be willing to be more flexible if doing so would result in savings to them. Basically there are two ways to handle this option. VLO could give a discount if shippers would be willing to extend their time windows, e.g. a 5% discount if the time windows are increased from 1 to 3 days. This would require that VLO knows what savings can be achieved in the various situations, to make sure that the discount percentage given is a realistic one. The other option is to let the customer specify discounts or penalties in case of earlier or later delivery.

	Three days earlier	**Two days earlier**	**One day earlier**	**Original date**	**One day later**	**Two days Later**
Initial amount/ shipper	€ 650,00					
Penalty for date change	Not accept	- €150,00	- €50,00	€ 0,00	- €150,00	Not accept
Actual revenue	n/a	€ 500,00	€ 600,00	€ 650,00	€ 500,00	n/a
Best carrier's offer	n/a	€ 530,00	€ 530,00	€ 630,00	€ 490,00	n/a
Gross margin of VLO	n/a	- € 30,00	€ 70,00	€ 20,00	€ 10,00	n/a

Table 1: Example of margin fluctuations with flexible time windows

Table 1 illustrates this later concept through a fictional example (but which, nevertheless matches characteristics of real orders – as discussed with VLO planners), how VLO can benefit from deviating from the original date, e.g. because capacity on the original date is hard to find and prices are high.

There are several reasons why rates could fluctuate at different time periods:

a) Using extended time windows there is the possibility to better match freights with the location of a carrier's vehicles. For example, in the case of shipments from Germany to the Netherlands, a Dutch carrier will be cheaper as they are likely to have freight from the Netherlands to Germany and can pick it up on the way home. However, these carriers do not arrive in Germany until Tuesday, as trucks and drivers return to their home base during the weekend. If the time windows for a freight which is scheduled at Monday are extended by 1 day, a Dutch carrier is able to take on this shipment, whereas VLO otherwise would have to go with a more expensive German carrier.

b) Extended time windows might also lower specific costs. Again, a simple example helps illustrating this principle. Consider freight from the Netherlands to the North of France with an original pickup date of Wednesday and one from the North of France back to the Netherlands with an original pickup date of Thursday. If the time windows are extended, the carrier could load the freight to France very early Wednesday morning for example and drive to the North of France. If the carrier can pickup the return freight that same Wednesday right after unloading, he can drive back the same day. As a result, instead of chartering an international driver, a much cheaper so-called national driver can take care of these shipments, as there is no need to sleep over in the truck and wait to pickup the freight the next day.

Besides these effects, specific to certain carriers, there may be market-wide or industry-wide effects as well, such as the "end of the month" effect, when shippers want to transport the goods to remove them from their inventory lists, and one-time effects caused by disruptive events such as strikes etc., which cause a backlog of orders in certain periods. In this case, extending the time windows to help carriers better cope with such events may be desirable.

5. PROPOSED SOLUTIONS FOR MULTI-ISSUE NEGOTIATION AND BUNDLING

From the discussion in Sect. 2-4 above, we can see that there is a wide variety of issues that could, potentially, be considered in automating the negotiation processes al VLO.

Here we focus on one of them: automating the "closed group" negotiation (see Sect. 2) between the 4PL and 3PL companies over the distribution of transportation orders. We chose this setting because of its relation both with existing research lines at CWI and with current practice at VLO. In our models, we consider that orders can exhibit utility dependencies of two types:

- Complementarity dependencies, if the orders can be transported by the same truck (i.e. their pick-up/destination regions, delivery time windows and/or capacity fit)
- Incompatibility (or substitutability) dependencies, if orders cannot be bundled together, due to a mismatch between their delivery time windows and/or capacity.

In our model, dependencies are represented in the form of a utility graph, which encodes complementarity/substitutability relations between orders. In previous work (in part by the same authors) presented at the research track of AAMAS [9] a general framework was proposed to handle this type of dependencies, and this was successfully applied to the logistics setting. A software tool was built for this paper (a screen shot of the negotiation phase is shown in Fig. 3). The tool should enable planners to compute (close to) optimal bundling of different sets orders and to explore different scenarios, by changing the constraints (e.g. time window constraints) and the information shared between parties.

This approach works by dividing the one-to-many negotiation between the 4PL and 3PL companies from the closed group in a series of one-to-one negotiation threads. This approach allows us to preserve the privacy of each party, since each company has to reveal their exact preferences and valuation only to its own automated agent. Furthermore, agents representing different companies do not have to reveal their preference information directly to other agents in the group, since approaches to automated negotiation such as those proposed in [9] allow agents to reach efficient agreements incrementally, with partial or incomplete information revelation.

There are, however, challenges when applying this model to a real-world setting. First, we assume all companies are represented by a proxy agent that does the bidding on their behalf. Second, we do not say much about how planning is performed, our approach concentrates only on optimizing the task allocation between a group of companies. Clearly for such approach to work well in practice, the planning of transportation within each company would need to be automated as well and connected to the negotiating agent. Alternatively, if planning is still done by humans, better mechanisms are needed to encode and elicit the preferences over the bundles - especially time and capacity preferences. An alternative to this automated one-many negotiation approach would be to use an auction-type of approach, instead of automated negotiation. For example, in other work, such as proposed by Sandholm and exemplified in the engine built by Combinenet [14], a similar problem is solved by means of a combinatorial auctions. This has other advantages (e.g. humans could also specify bids, so full automation from proxy agents is not needed), but also assumes that parties are willing to share truthfully their planning information and there is one trusted "center" to compute an optimal allocation.

In any case, it is realistic to assume that at any time, human planners or negotiators should be allowed to overrule the suggested agreements reached by their negotiation/auction proxies. As such, we envisage that the system would work more as a decision support tool which helps to explore various allocation scenarios, rather than a replacement for human negotiators.

A practical disadvantage of traditional auction mechanisms is that competition occurs entirely on price and the seller (in our case, the 4PL company allocating the orders) cannot discriminate between subcontractors based on other aspects, such as trust. This is a departure from real-life settings, where it may be possible that a party with a higher bid is offered the deal, if it is deemed more trustworthy (although this is difficult to quantify, since it is based on previous interactions and experience of the human planners).

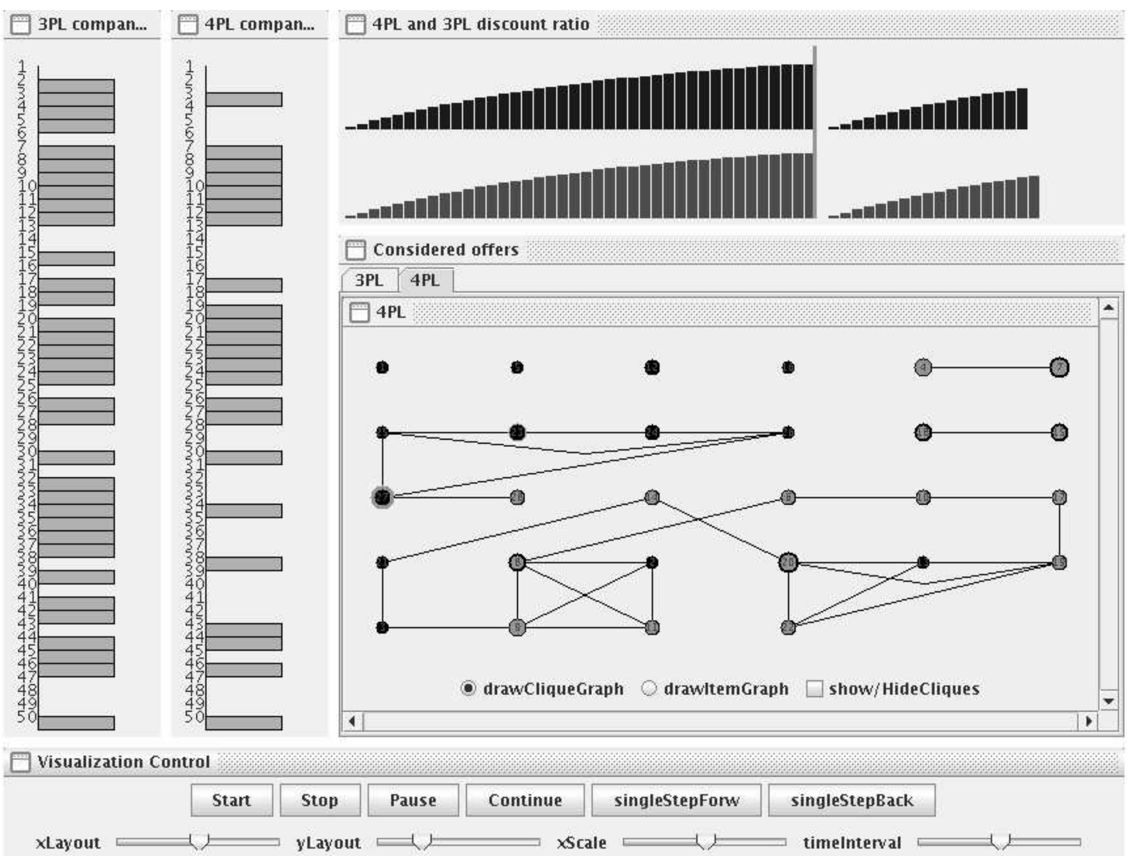

Figure 3: Screen shot of the negotiation tool built to visualize a closed group negotiation thread

By modeling the negotiation as a set of private one-one threads, asymmetric concessions to different parties (based on their trustworthiness) are possible. An alternative would be to modify the traditional open auction mechanism to take into account such considerations. Two alternatives have been proposed (c.f. [13]):

- Allocating closed-group orders through an auction with a pre-selection step, in which only certain companies are allowed (or invited) to submit bids. In this way, 3PL companies are already "screened" before accepting a potential offer.
- Modifying the winner determination mechanism of a traditional auction, such that not only price is minimized, but also a weighed element of trust is taken into account.

All the alternatives discussed above (concurrent, bilateral negotiation and modified auction mechanisms) will be considered as potential implementation options in the proposed pilot project.

6. ANALYSIS OF POTENTIAL GAINS ACHIEVED FROM BUNDLING ORDERS IN THE CASE STUDIED

From Section 5, we see that the way our negotiation model works is by finding more efficient "bundles" of transportation orders, which best exploit the niches in the supply chains of different market participants. The theoretical model presented above has been shown, through simulations, able to discover Pareto-efficient allocations, even in incomplete information settings [9]. However, for a practical setting, validating a model through simulation is clearly not sufficient and we need to explore what are the potential savings which can be achieved through such techniques in practice.

A thorough investigation of the potential savings which can be achieved through bundling of orders for Vos Logistics was performed using historic order data. The data consisted of the set of over 6000 transportation orders handled by the forwarding desk of Vos Logistics for the year 2004. We should mention, however, that in order to protect the competitive advantage of VLO as well as the privacy of their customers and associates, much of this analysis cannot be reported in this paper. For this reason we report here only the percentage improvements achieved through bundling, but without entering into details or monetary figures.

There are two main types of bundling considered with respect to transportation orders:

- Bundling of LTL shipments (i.e. bundling of orders that are less than one truck load)
- Bundling of subsequent/return orders for FTL shipments (full truck loads)

For the bundling of LTL shipments, we considered orders for which both the pick-up/delivery locations (computed based on the first 2 digit of the postal codes area) and the date matched. Additionally the sum of part loads in a combination should not exceed the maximum load capacity.

For the bundling of FTL shipments, the delivery location and delivery date of a first order had to match the delivery location and delivery date of a second order. In both cases, feasible allocations are considered, of course, only those in which an order belongs only to one bundle.

The results of the savings which can be achieved for a set of over 6216 orders handled in 2004 are shown in Table 2:

	Savings over the total over the total value of LTL orders	Savings over the value of all orders in the order set
Bundling of LTL shipments	19%	2-3%
Bundling of FTL shipments	-	12%

Table 2: Potential gains which can be achieved through bundling of orders using historic VLO order data for 2004

From the results in Table 2, two things stand out. First, we see that the potential gains which can be achieved from bundling partial loads seem rather modest, compared to that from bundling return or subsequent shipments. This can actually be explained by the fact that, overall, the percentage of partial (i.e LTL) loads in the order set was rather small. However, if one considers only the value of the subset of LTL orders, one can see that using more efficient bundling the average truck utilization (load) increases from 18% to 39%. Using actual carrier price data, this results in savings of 19% in terms of price per unit load. The result is significant, since it is estimated that in the future, the number of partial truck loads handled by VLO is likely to increase considerably. Finally, for the results above, we assume that only same-day orders can be matched, in order to be consistent with current practice. If more flexible time windows are allowed (through better negotiations), we estimate that the potential savings from bundling can increase considerably.

7. DISCUSSION

There are several other approaches which address similar problems to the ones discussed above, both in the literature on agent systems, but also implemented by commercial companies. Here we review them briefly and compare their functionality to our approach. The LS/ATN system developed by Whitestein Technologies and presented in Dorer and Calisti [3] is a multi-agent system for dynamic transport optimization. The system provides agent-based optimization and execution capabilities that automate order dispatching, a crucial phase of transportation planning. The chief difference from our work is that the system proposed by Dorer & Calisti is mostly concerned with distribution of orders in the planning phase between trucks of the same company, while our system is concerned with automating the negotiation over loads between different companies in a supply chain.

The system proposed by Magenta Technologies [5] uses a multi-agent system to provide intelligent support for transportation scheduling. At the core, the system also relies on a virtual market engine to distribute loads. One feature of the MAGENTA system not currently considered by us are the semantic representation capabilities, as provided in the Ontology Management Toolkit.

Another set of solutions which address problems very similar to the ones described in this paper are provided by Combinenet [14].

Combinenet aims also at capacity optimization, by allowing more expressive bidding and scenario generation. We assume most of their solutions are based on efficient algorithms developed, in fundamental research by Sandholm and collaborators (reported, for example, in [11]). The main difference with the approach discussed in this paper, these solutions rely mostly on combinatorial auction algorithms to compute efficient bundle allocations.

Finally we should point out that there are also several electronic freight exchange sites, such as Teleroute [15] and Transporeon [16]. Teleroute (which is also currently used by VLO for their open market operations) acts more as a platform on which carriers and shippers advertise their order and transport capacity, but any negotiation and matching is done by human through the phone. Transporeon is another platform that provides a slightly more advanced functionality, such as bidding and order matching, yet well short of what can be achieved through automated agent-based solutions. Nevertheless, Transporeon has been used in daily operations by other partners of VLO, with considerable savings.

In comparison to these approaches, we focus mostly on the order allocation between several companies, more specifically on the order allocation between a 4PL and several 3PL companies. Our approach allows parties to discover optimal allocations in an iterative way, without revealing private planning information except to their own negotiating proxy agents. We envisage our tool being used as a human decision support tool, which allows human negotiators to investigate different scenarios, by changing the constraints, information shared and negotiation parameters of their agents. Humans are then free to accept/reject the proposed allocations, or re-run the negotiation in a new scenario.

Finally, our paper would not be complete without outlining some of the challenges we face in getting a pilot project on automated negotiation actually working at a company such as Vos Logistics. In general, in order for such a system to be adopted in practice, we need to show that the profit margins which can be achieved from adopting the new technology must be sufficiently high to warrant the effort and costs. Also, in our case, due to the fact that the system automates the interaction between several companies ("actors") in the supply chain, each of these must be willing to use this technology. Finally, the integration of automated planning of orders for each company with the negotiation proxy agent would be desirable in order to fully exploit the capacity of our system. Even if it is true that some of the companies use automated planning systems, we cannot assume this is necessarily the case for all companies in the supply chain. An alternative would be to allow humans to specify bids and offers, such as in an auction like protocol.

Despite the above challenges, our results from the approach so far have been very well received and a full scale pilot project is under way to apply such techniques in the daily outsourcing processes at Vos Logistics Organizing.

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