

Föhring, René; Zelewski, Stephan

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Intelligent Exchanges and Coordination in Multimodal Supply Chains

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René Föhring and Stephan Zelewski

Intelligent Exchanges and Coordination in Multimodal Supply Chains



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The prototype ORFE of an Online Rail Freight Exchange was developed as part of the CODE24 project. It demonstrates functionalities for a more transparent communication of available transport services and also supports the configuration of multimodal supply chains. The paper describes the efforts and research outcomes of the implementation of ORFE as well as problems that emerged after its finalization. These problems led the authors of this paper to the draft of a new market place concept: Agent-based Freight Exchanges (AFEX). These yet to be implemented, highly automated and interconnected market places are designed to provide autonomous software agents with the infrastructure to perform contractually binding auctions of multimodal freight transport services utilizing a combinatorial exchange model while addressing problems commonly associated with existing market places.

Keywords: Intermodal Transports, Logistics Modelling, Multi-Agent Systems, Combinatorial Auctions

1 Online Freight Exchanges

Organizing freight traffics more efficiently and sustainably has been an important topic for decades, not only for supply chain managers but the logistics community at large. One idea emerging in this context is the more efficient configuration and coordination of supply chains with the help of freight exchanges.

Freight exchanges are marketplaces where offers for and demands for transport services find one another. Contrary to forwarders, which constitute the classic form of freight mediation between shippers and carriers, they themselves are no participants in the processing of transport services. The majority of the companies specializes in the mediation of truck freights. By contrast, multimodal transports are being mediated fewest of all (Merkel and Kromer, 2002).

Since their origination in the 1970s and 1980s the freight exchanges conducted their business primarily via telephone and telefax. With the advent of the internet in the 1990s and 2000s and the rise of e-commerce platforms, new sales channels opened up and provided a more transparent and comprehensive offer for demanders.

2 Establishment of an Online Freight Exchange within the Framework of the CODE24 Project

The joint project CODE24 has been started in the year 2010. For an overview of the project within the INTERREG-IVB-NWE program of the European Union (EU), it is being referred to Brenieck (2014). The primary goal of the project consists in the integration and advancement of the activities on the

transport axis no. 24, the main railroad line through the Swiss Alps, which connects the harbors of Rotterdam and Genoa.

The challenges here are manifold: Comprehensive and publicly accessible information on how many freight trains will use the corridor is currently missing. It is also uncertain how much this capacity can be improved through a higher utilization of the existing infrastructure. Finally, a considerable market non-transparency exists for forwarders that take a transport by rail into consideration, especially regarding the connection possibilities to freight transports (Endemann and Kasper, 2012).

As a result, a central component of the project is the conception and implementation of an online freight exchange (Endemann and Kasper, 2011). As a first step towards this goal, the Institute for Production and Industrial Information Management of the University Duisburg-Essen systematically ascertained the requirements for an online rail freight exchange by analyzing the relevant literature as well as interviews and workshops with industry experts (Bruns et al., 2010, Habib and Bruns, 2012, Klippert et al., 2013). Further research results regarding user requirements were contributed by project partners (Dörr and Endemann, 2014, Endemann and Kasper, 2012). One of the most important conclusions was that a freight exchange which only supports rail freight traffic has no realistic market potential. A detailed market analysis consequently showed that no such online freight exchange could establish itself on the European transport market in the long term (Klippert et al., 2013). Especially the transport carrier road has to be involved in order to be able to exhaust the potential of multimodal transport chains.

The software prototype ORFE (“online rail freight exchange”) was implemented based on this research. It demonstrates functionalities for the facilitation of contact between potential business partners and the configuration of multimodal supply chains. Since the interviewed experts concluded that future users would hesitate to enter any monetary information, the prototype was built to support the pure mediation between potential business partners. As a consequence, it cannot guarantee contractually binding business transactions as these have to take place outside of the online platform after the contact initiation. For detailed overviews on the concept and development it is being referred to Bruns et al. (2012b) and Föhring and Zelewski (2013).

After the conceptualization and implementation of the ORFE prototype, the project consortium agreed that the final version of the prototype would have to be reimplemented into a commercial software product. Additionally, a viable business model would have to be developed for its operation. For an early review of this work it is being referred to Dörr and Endemann (2014).

It was very important for all questioned project partners and also for other interviewed experts that the future operator of the online freight exchange behaves in an economically impartial way towards all exchange users. This demand can be attributed to the high intensity of competition and mutual distrust in the railway sector (Dörr and Endemann, 2014, Klippert et al., 2013).

Currently there are two potential operators trying to establish themselves on the market (Dörr and Endemann, 2014): “Railcargo-Online” (<http://www.direct.rc-o.com/>), which since its launch has been integrated

into “Cargo Platform” (<http://www.cargo-platform.com>), and “Freit-One” (<http://www.freit-one.de>).

Both companies were given access to the ORFE prototype as a working basis and have started operations in late 2013.

3 Real Problems in Operating an Online Freight Exchange

The research around the CODE24 project revealed further obstacles to the successful establishment of an online freight exchange: If the virtual marketplace fails to reach the critical mass and provide a sufficient mediation rate, forwarders and transport carriers will keep settling their transactions the traditional way. Furthermore, freight exchanges are primarily suited for the mediation of transport services that are dealt with through spot markets, but many transports carried out within Europe are still bound to contracts. Therefore a potential exchange has to either control the existing spot market or strengthen the “spot character” of transport services in general (Merkel, 2002).

The requirement analysis for the ORFE prototype showed that the establishment of an online freight exchange in general meets four central real problems:

The first problem is the need for a business model that enables at least the loss-free operating of the marketplace and specifies a fee for every user of the online freight exchange (Bruns et al., 2012a).

The second problem is the disclosure of competition-sensitive data to the future operator. All participants of a centrally organized marketplace are

required to submit their data to the central operator in order for him to be able to perform his function as an intermediary. This requires a high confidence in the discretion of the operator.

The third problem is the demanded industry experience of the future operator. The role of the operator of an online freight exchange requires intimate knowledge of the respective transport sector. Yet at the same time the potential marketplace members will question his neutrality. It is therefore difficult to find an operator that has the necessary expertise but is not at the same time a participant of the market in any form (Bruns et al., 2012a).

The fourth problem is the consideration of multimodal transports. The ability to configure transports across different carriers is a requirement which can be found regularly in publications on the requirements for an online freight exchange (Endemann and Kasper, 2012, Habib et al., 2012).

The challenge in solving the first three problems lies in the minimization of the costs of operation and participation and the believable guarantee of the neutrality, discretion and expertise of the operator. It becomes apparent that any future online freight exchange should support multimodal freight traffic by taking several traffic carriers into consideration for any given transport. Furthermore, it becomes clear that the first three problems can be attributed to the centralized nature of the marketplace. A single operator has to bear the costs for the provision of the infrastructure and will dispose of the data of all members. Moreover, he would have to reassure potential users about his expertise for the purpose of customer acquisition.

It should therefore be researched if an automated and decentralized approach would be an economically attractive alternative to the so far pursued centralized approaches. The basic premise of this idea is that a network of agents can form an interconnected marketplace in which they participate as equal trading partners. The agents are provisioning the computational infrastructure through the combination of their individual computing power where all agents share the same set of data amongst themselves. A single, central operator would not be needed, alleviating the first three real problems. The support of multimodal traffics would be easier to realize in an automated freight exchange than in an exchange organized in a central and purely contact mediating way, since the coordination could be left to the agents. Finally, an agent-based system could even strengthen the “spot character” of multimodal transport services.

In the following chapter chosen aspects and requirements for the development and implementation of such an agent-based freight exchange are presented.

4 A Concept for Agent-based Freight Exchanges

4.1 State of Research

There are not many publications on the topic of online freight exchange for transport services in the rail freight and online freight exchanges for the configuration of multimodal supply chains, respectively. The majority of the publications on this topic were published by researchers of the Institute for Production and Industrial Information Management of the University Duisburg-Essen (Föhring and Zelewski, 2013, Klippert et al., 2013, Föhring

et al., 2012, Habib et al., 2012, Bruns et al., 2012b, Bruns and Zelewski, 2011, Bruns et al., 2010). Beyond that, only few publications exist and from these many merely assert the need for such an exchange (Endemann and Kasper, 2011, Scheck and Wilske, 2011).

As a consequence, while there are many publications about electronic marketplaces, the literature about electronic freight exchanges and logistics marketplaces is scarce (Wang et al., 2007). Most publications on multi-modal transports do not focus on the trading of freight transports, but rather deal with their efficient routing and handling (SteadieSeifi et al., 2014). The usage of double-sided combinatorial auctions is discussed elaborately in specialized literature for different markets (Ackermann et al., 2011, Parkes and Ungar, 2001). The same can be said for the usage of multi-agent systems (Davidsson et al., 2005, Fox et al., 2000, Jennings, 2000) and, despite not being the primary focus, the utilization of agent technology for the auction-based negotiation of transport contracts has also already been discussed in the literature (Van der Putten et al., 2006).

The paper at hand suggests the merging of these findings on the requirements for an online rail freight exchange, on the usage of double-sided combinatorial auctions as well as on the organization of autonomous multi-agent systems in order to enable the conception and prototypical development of an intelligent, agent-based freight exchange (or AFEX for short).

The proposed design is an automated exchange in the form of an electronic marketplace. It is organized as a decentralized system which is able to function without a central marketplace operator. The autonomous trade between equal actors is being enabled by the usage of agents that form a

multi-agent system and employ double-sided combinatorial auctions in order to perform auctions of multimodal transport services.

The subsequent prototypical implementation of AFEX will have a graphical user interface through which each human user can control his instance of the agent software. This way, e.g. forwarders can start the software, enter their preferences regarding a freight transport and let the exchange determine the “best deal” in an automated process, which requires no further user interaction.

The following chapters describe chosen aspects and requirements for the development and implementation of such an AFEX system.

4.2 Multi-Agent Systems as Decentralized Electronic Marketplaces

An AFEX-system, contrary to traditional electronic marketplaces, will not require a single operator as central authority. Therefore the system has to be able to organize itself in a decentralized way. This means that, while in case of the central solution all market activity is coordinated by the marketplace operator, the configuration and coordination of the activities in the decentralized version happens by the actors themselves. The marketplace operator is no longer needed as an intermediary; a disintermediation of the trade chain occurs.

In order to develop a multi-agent system that is capable to coordinate itself without a central node, the first requirement is that agents have to be able to locate trade partners. This is a nontrivial problem, as a central authority for mediating the contact between the agents is missing. This “contact problem” can, however, be solved if the agent software enables the manual

entry of agent addresses. These describe the necessary information for making contact with another agent through the internet (i.e. an IP address and a port number).

Every time an agent contacts another agent they exchange all contact information known to them. Through this approach each agent gets to discover the whole network known to the other agent. The agent software then has to save the gathered contact information in a way that enables it to contact the known agents again after a restart.

The contact problem can be solved substantially more user-friendly if other software agents can be discovered without requiring user interaction. For this purpose there should be one or more predefined agent instances on the internet whose fixed contact information is embedded in the agent software. These predefined agents have no trading preference but serve as a kind of beacon, i.e. their sole purpose is to answer contact requests. If a list of these “beacon-agents” is going to be embedded in all agents and stands at their disposal after installation, they can be contacted without intervention of the human user.

Figure 1 illustrates this process: Agent A does not yet know other agents beside the beacon-agent B.

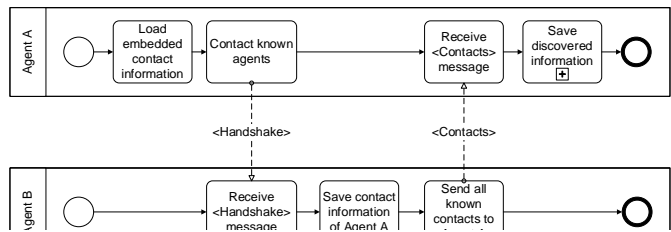


Figure 1 Contact initiation between agents

He contacts agent B and gets further agent addresses from him. Agent A saves the received contacts and can recall them again at the next start and approach them without being dependent on the beacon-agent as a contact mediator.

The advantage of this method is that beacon-agents can be operated, communicated and used independently of each other. They support the decentralized organization of the AFEX marketplace since they solve the contact problem without requiring a user interaction. They are, however, not necessary for operating the decentralized network (as the human users could always build up their own “contact networks” with the manual entry method).

4.3 Capturing Trading Preferences

The agent software has to be usable by a human user. For this purpose an agent’s user can use input masks provided by the user interface to either capture his preferences for an offer or demand for a transport service. This way he specifies similar transport-related preference data (for loading and unloading location, timeframe, etc.) that has also been captured in the ORFE prototype. Figure 2 illustrates this process schematically.

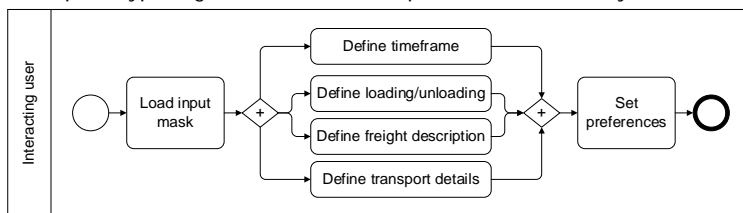


Figure 2 Input process for a demand for a transport service

The difference between the ORFE prototype and AFEX becomes apparent afterwards: The AFEX system does not need further user interaction after the preferences are entered.

4.4 Coordinating Group Formation

Once started with a set of preferences, agents will always advertise the transport services their human user offers and try to buy those transport services which their user demands. For the sake of simplicity, agents that are offering transport services will be called “suppliers” in this paper (and agents that are demanding transport services “demanders”).

All agents know the preferences of all other agents in their network and all preference data is exchanged in a unified format. Therefore it is possible for demanders to determine whether or not the transport services offered by a subset of suppliers can be combined in a way to accommodate at least one of their demands. If this is the case, the demander in question will contact the relevant suppliers and look for a “group” in which the demanded transport services are advertised (which will be called “goods” for the rest of this paper to be consistent with the literature on auctions). If no such group can be found, the demander will ask the suppliers to form one. In this group the agents will be able to submit bids for the demanded goods in an auction. Other agents can find and join the group. A demander might conclude that two groups would have to combine their auctioned goods to be able to accommodate one of his demands. In these cases he can ask both groups to merge in order to form a larger group which addresses more suppliers and demanders. This way, the demanders in a network assist the suppliers in forming the right groups to ensure constant trading.

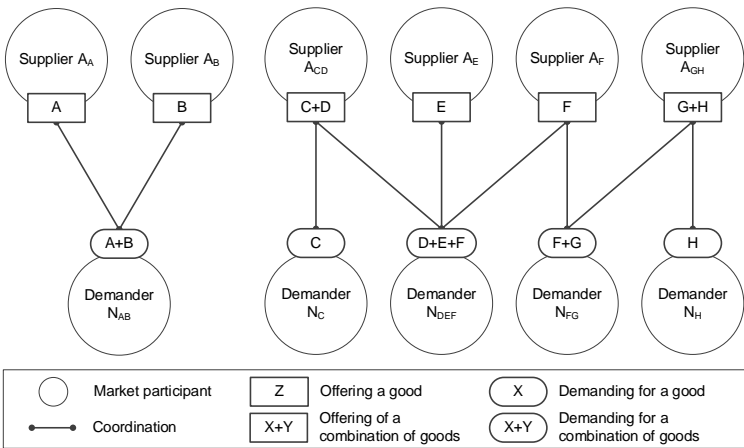


Figure 3 Group formation

Figure 3 shows a schematic representation of a small AFEX system.

In Figure 3, two groups have formed:

In group 1 two suppliers are offering two goods to one demander, in group 2 four suppliers are offering six goods to four demanders. The necessary coordination steps as described above are shown as edges between the agents.

This group concept not only enables agents to frame the coordination of their efforts but also ensures that all participants in a group are interested in the offered goods. These aligned interests are a prerequisite for the negotiation of prices.

4.5 Using Double-sided Combinatorial Auctions for Price Negotiation

The pricing between buyer and seller is a challenge any marketplace faces.

Three pricing models can be made out (Grieger, 2003):

The bulletin board model that serves primarily for the publication of advertisements and as a pure information and contact platform (this variation was implemented in the ORFE prototype).

The fixed price model in which case the supplier and demander specify the final price for the service being in demand or offered.

Virtual exchanges made possible by the internet that offer its members a dynamic pricing with the help of auctions.

For the design of an AFEX system, the chosen concept should ensure an efficient auction of the traded transport services. From the three mentioned alternatives, this requirement can be only met by the dynamic pricing through auction. The choice of auction form is crucial for the efficiency of the auction execution (Ausubel et al., 1998, Krishna and Perry, 1998). There are two reasons why the employment of the double-sided auction form, in which case the auction participants can appear as buyer and as seller, is reasonable: Firstly, many exchanges and resource markets in the real world are organized as double-sided auctions (Yang, 2003). Secondly, the participants are not assigned dedicated roles ("supplier" or "demander") but can act as both, demanding and offering goods according to their preferences. In order to be able to depict multimodal transport services in an auction, other dimensions next to the price have to be taken into account when computing the optimal allocation of goods. Multidimensional auctions

promise a high allocative efficiency despite the possibly complex preferences of the participants concerning the traded dimensions. Combinatorial auctions, sometimes also called combinatorial exchanges, are very well researched multidimensional auctions that make it possible for participants to submit bids for indivisible combinations of goods and only win the bid if they receive exactly the desired combination (Bichler et al., 2005).

Resulting from these considerations it becomes clear that a double-sided combinatorial auction model meets the previously mentioned requirements. But while double-sided combinatorial auctions have major economic advantages, their computational complexity is a well-documented challenge that can be seen as a disadvantage (Sandholm et al., 2002). This complexity largely stems from the fact that each participant in a combinatorial auction has to submit bids for all relevant combinations, which means that the number of bids grows exponentially as the number of participants increases.

An AFEX system mitigates this issue by pre-selecting the participants of each auction through the previously described formation of groups and the concept of “ad hoc auctions”.

4.6 Ad hoc Auctions

The auctioneer plays an important role in the trading process as he performs the auction and decides on the final allocation of goods. The fact that an autonomously coordinated exchange without a central operator lacks this central figure constitutes a design challenge: The agents do not only have to find each other and form groups based on their preferences but

also have to coordinate the initiation and implementation of auctions by themselves.

After a group has formed and a sufficient number of suppliers and demanders have joined, the group is declared “complete” and the auction starts. For this purpose the agents carry out a spontaneous “ad hoc auction”.

The difference between ad hoc auctions and “normal” auctions in centralized marketplaces is that the auctioneer is dynamically selected from the crowd of suppliers in a group. The role of the auctioneer falls to the supplier that tries to sell the highest number of goods or, if several suppliers make an equal number of offers, that supplier which entered the group first.

The auctioneer carries out a double-sided combinatorial auction according to the auction model and subsequently specifies the final allocation of goods within the group. After all participants agree to this new distribution the group dissolves.

This approach pairs well with the concept of loosely-coupled groups described before: Groups are not only a way to frame the context of an auction by ensuring that all participants are interested in the offered goods but also limit its complexity by limiting the number of participants. Handing the computationally expensive calculations needed to perform the auction to the supplier side is a design decision based on the assumption that suppliers have a natural interest in providing a solid technical foundation in order to enable auctions of the goods they offer.

Figure 4 depicts an AFEX system of 24 agents, six of which formed a group based on the principles described above.

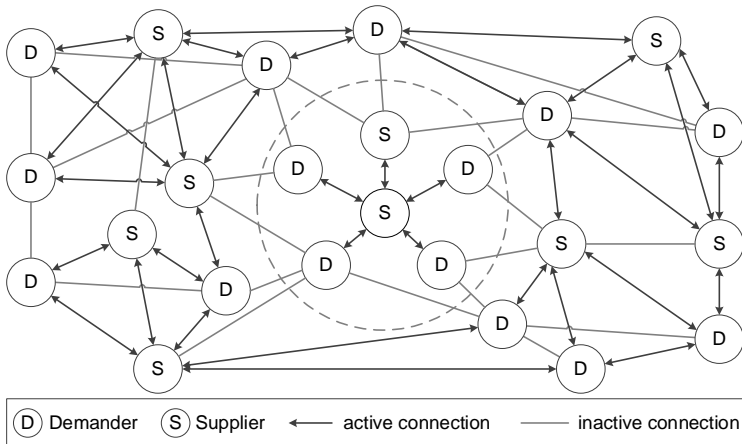


Figure 4 Ad hoc auction inside an AFEX system

The dotted circle in the middle indicates that the group currently performs an ad hoc auction. The figure also illustrates that not all of the agents are maintaining an active connection to each other all the time, e.g. agents currently participating in an active auction are not maintaining any active connections except the one with the auctioneer.

4.7 Critical Reflection

The outlined marketplace concept AFEX should provide three implicit advantages in contrast to conventional approaches:

Equality – all members of the market are subject to the same rules of action. Although agents are started with individual preferences, they cannot deviate one-sidedly regarding their strategy, which is deposited in the software.

Efficiency – the usage of the double-sided combinatorial auctions allows for optimal solutions for pricing through the deployment of mathematical

models. The efficiency criteria can be specified in a goal-oriented way during the design phase.

Transparency – from the point of view of the software agents the conditions of the market and the market activity are completely transparent: all agents make contact among themselves and exchange their trading preferences.

In addition, the described approach provides a realistic modeling of the roles played by the members of the marketplace. Agents do not only act explicitly as supplier or demander but also play either the role dependent on the context. However, the described concept also has implications which can be seen as disadvantages:

Transparency – in traditional negotiations, there are often information asymmetries that benefit one or more participants. Therefore, while also an implicit advantage, this aspect can be a disadvantage regarding the acceptance of a completely transparent marketplace.

Social norms – automated negotiations lack the personal element that face-to-face business provides. The world of logistics is just slowly discovering the advantages of automated negotiations and decision support systems.

The kind of automation AFEX aims to provide should therefore not be expected to establish itself in the short-term, but rather seen as a major trend shaping the next decade.

5 Summary and Outlook

This paper described the efforts to establish an online freight exchange for the mediation of multimodal transport services within Europe. The research on online freight exchanges, the development of the prototype ORFE and the challenges that any new freight exchange will face have been described.

The investigation of these problems resulted in the draft of an innovative marketplace concept: AFEX, an online freight exchange that is based on autonomous software agents. Selected requirements for the development of these decentralized and autonomously trading agents have been outlined. It has been described, how these proposed multi-agent systems differ from existing solutions in that they will form intelligent exchanges, which will be decentrally organized, i.e. not require a central authority or operator, and utilize two-sided combinatorial auctions to perform fair, efficient and transparent auctions of transport services within an automated marketplace environment.

The next steps are the development of an adaptive agent behavior that is able to adjust to different situations, a generic traffic route notation for the description of transport routes and a description language for the offer and demand for transport services within auctions.

The last step will be the combination and implementation of all mentioned aspects into a prototypical agent software.

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