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A Multi-Agent Perspective on Intermodal Transport Chains

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A Multi–Agent Systems Perspective on Intermodal Transport Chains

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Abstract

Modern production and logistics methods, such as outsourcing, depot free production or just in time delivery require efficient transport systems. Inter-connecting different modes of transport, i.e. intermodality comprises the key to this efficiency. We model an intermodal transport chain and the flows of goods within it, using multi–agent technology. Each transport operator is represented by an active software agent, capable of planning, communicating, and co-operating with the other agents in the chain. Vehicles in transit are modelled as holonic agent societies, controlled by a distinguished agent. This agent can dynamically modify existing plans, even during execution time. Intermodal transport orders are planned and monitored by an intermodal planning competence, encapsulated in an intelligent agent. This agent negotiates with the transport operator agents in the chain in order to establish a joint transport and transhipment plan. In addition it monitors the execution of this plan as a mobile agent, migrating through the telecommunications network, as the respective cargo is moved in the physical world.

1 Introduction

"The growing demand for the transport of people and goods in Europe presents transport users, operators and public authorities with increasing problems, notably concerning cost-effectiveness, congestion and environmental impact. Whereas, in the past, we have tended to think about specific modes of transport — road, rail, air and waterborne — there is now growing recognition that sustainable mobility is about inter-connecting transport systems which have to provide a door-to-door service. This is what I call *intermodality*. "[Kinnock 95]

The development of information and communication technology (ICT) supporting planning, optimisation, and monitoring of intermodal transport chains is one of the most challenging application domains for practical computer and business sciences in the transportation sector. The integration of the Trans–European Networks (TEN) of transports and telecommunications, comprising equipment of transport vehicles, departments and companies with telecommunication facilities linked with assistance software for logistics engineers and dispatch officers as well as drivers and transport operators, is a main goal of the next decade. It will provide the fundamental building grounds for keeping the growing trans–european transport demand controllable and manageable: Outsourcing, depot free production, just in time delivery will increase transport intensity. Freight transport within the European Union is expected to grow by another 70% during the next ten years [Carroué97].

The European Commission had recognised that dramatic development and intermodality got a growing interest within European transport politics: The EC Task Force on Transport Intermodality elaborated recommendations for the future development of intermodal transport (Intermodal Freight Village 2000+, Intermodal Freight Network 2000+, Transport Town 2000+, etc.) and several actions have been started addressing different aspects of improving and supporting intermodal transport chains [TaskForce 97]. In the 4th Framework Programme the Commission set-up a number of RTD projects on intermodal transport (COREM, IMPULSE, INTERPORT, etc). One of these projects is PLATFORM some of whose research results we are going to report in this paper.

Most of the European transport companies are small or medium sized enterprises widely focussing on road transportation. They are working in a highly competitive framework still sharpened by the low cost competitors from Eastern Europe during the last years. Rail transportation is yet much to inefficient, in order to be competitive, at least for distances below 700 km. Combined rail–road transportation can become a much more interesting alternative in the near future. However, this requires software products which support dispatch officers in their daily work by providing smooth access to railway time tables and rail-based transport services and — much more important — by allowing for the planning of both, exclusively road-based and combined journeys and showing their cost-effectiveness, where- and whenever possible.

At DFKI we have developed a prototypic software system TELETRUCK [Bürckert+98a, Bürckert+98b] for planning, optimising, and monitoring of road haulage. The underlying approach is based on multi–agent technology. That means in our case, that we model physical objects of the transport domain (trucks together with their drivers, trailers, and load spaces) by active software processes (intelligent agents). Those agents are able to reason and plan on the basis of their individual resources and means provided by the corresponding physical objects. They are embedded in a common environment (a multi–agent system) — potentially distributed in a network of several computers which could be located at different transport departments — reflecting the communication and other interaction structure of the agents.

Currently, in the PLATFORM project, we are extending the TELETRUCK approach for combined rail–road haulage. This extension will be described in the following sections: New agents with intermodal planning and execution competencies are introduced. They are equipped with smooth access to the resources of the two transport means. The different mode operators (road and rail transport agencies) are modelled as agents as well which are responsible both for the intermodal and for the intramodal co-ordination of the transports. Agents capable of planning and supervising the execution of such plans are also able to migrate through the telecommunication network from one mode operator's server to the other's. Thus, we are modelling the accompaniment of the transport flow by the data flow — both during the planning and during the monitoring phases.

The paper is structured as follows: In the remainder of the introductory section, we shortly describe our general ideas about intermodal transport chains and select an example to demonstrate our multi–agent perspective onto it. We sketch some multi–agent systems background and then outline the system architecture. In section 2 we present a more detailed description of the TELETRUCK system, a multi–agent system which simulates a forwarding agency. This provides one of the means of transport within the chain. We describe the intermodal planning competence of our new agents in section 3. This competence allows easy planning and execution of intermodal transport orders within intermodal transport chains. Concluding, we summarise our main ideas and provide an outlook onto future work.

1.1 An Intermodal Transport Chain

In general we can define an intermodal transport as any kind of transport, which combines at least two different transport modes and thus a transhipment process between these two. Examples are the combination of road and rail, or the combination of road and waterborne. Usually the precarriage or onward carriage is carried out by road, while the main carriage may be done by the other means of transport, namely train, ship or plane.

In this paper, we focus on a special instance of intermodal transport chains, a combined road–rail transport. The pre- and end haulage is the road based transport, the main carriage is done by rail. Usually rail-based transport imposes the main constraint on the processing of an intermodal transport. It is a time-tabled mode which does not offer much flexibility in terms of pick-up or delivery times of the goods to be transported. These goods, filled in *Intermodal Transport Units* (ITU — it can be any kind of container, semi-trailer or other transport bin), need to be at the intermodal terminal connecting road and rail, in order to be transhipped in time. Thus, the road-based carriages of the intermodal transport have to provide the flexibility required to process the order. Figure1

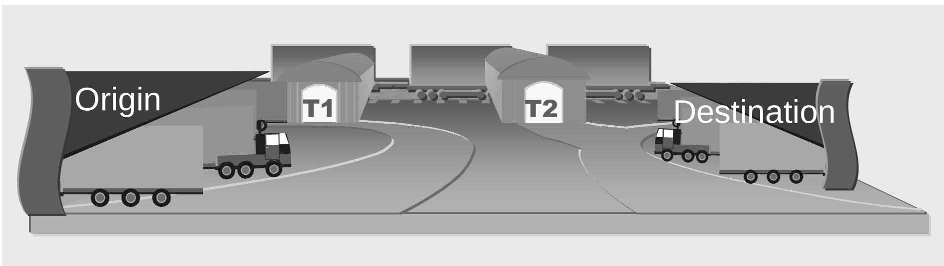

Figure 1: An Intermodal Transport Chain, a combination of road–rail–road

illustrates our instance of the intermodal transport chain. The intermodal terminals, T1 and T2 provide for the inter-connections between the transport means.

1.2 A Multi–Agent System for Intermodal Transport Chains

We model an intermodal transport chain using multi–agent technology. This approach allows for a distributed model and distribution of the tasks to be solved within the processing of intermodal transport orders. The main characteristics of agents are autonomy, pro-activity and the ability to communicate and co-operate with other agents. Besides these features, agents are able to exhibit a certain amount of mobility, that is they can voyage from one hardware or software platform to another one. What makes multi–agent systems so attractive for distributed problem solving is not only the possibility to divide the main task into small subtasks, but these tasks can contain overlapping goals, which require agents to negotiate about their resources and abilities and elaborate co-operative solutions and plans. A more detailed introduction to multi–agent systems can be found for example in [Müller 93, OHare+96] or [Wooldridge+96].

For the intermodal transport chain introduced, we developed the agent model, which is shown in Figure2. Each transport service is represented by a (software) agent. The Figure shows the physical world in the lower part and its multi–agent model in the upper part. Each transport operator is represented in the agent world as an autonomous agent. The intermodal transport order needs to be planned and negotiated as well as then co-

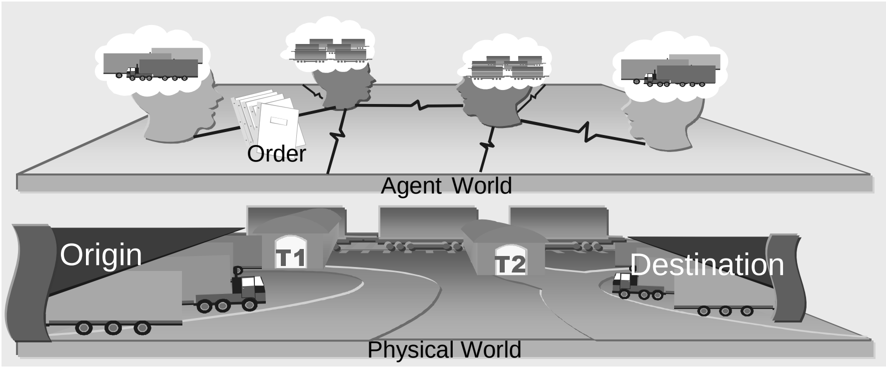

Figure 2: Physical Transport Chain (below) and its representative Software Agents (above)

operatively executed.

The forwarding agents, at the beginning and the end of the chain are instances of the TELETRUCK system, which is described in the following section. The TELETRUCK System was designed as a stand alone agent based forwarding system, able to manage the business processes of forwarding companies.

The terminal agents represent the respective commercial departments of intermodal terminals and are able to manage the business processes of terminal operators: Each terminal agent is able to process booking requests and manage a reservation system for freight trains. Such a system is comparable to reservation systems for passenger transport. Booking and reservation systems, even though less common in today’s freight traffic, will in the future provide essential support for the smooth management of fast loading devices within intermodal terminals such as the Automated Loading System, the Krupp Fast Handling Device, or the Daimler KombiLifter [Funk 98]. As such fast handling devices will ripen from their currently prototypic status to products which will be more common in intermodal terminals of the future, precise management of terminal flows and operations through booking systems will be required.

2 The TELETRUCK System: A Road Haulier Multi–Agent System

The TELETRUCK system [Bürckert+98a, Bürckert+98b] models the business processes of transportation companies, in particular the allocation of transportation requests to means of transportation. A shipping company disposes of a fixed number of transportation units like drivers, trucks, or trailers. The units may differ in many ways: trucks can be classified into pure tractors, those with loading space, and those without, etc. The type and size of the loading space of the containers constrains the type of cargo that can be transported. Also human drivers differ in their supplied working time and the type of cargo he or she may transport depending on issues such as special training or certain licenses, e.g. for dangerous goods. These resources have to be managed in such a way that the transportation tasks at hand can be executed with minimal cost.

In common practice, traditional Operations Research (OR) methods are used to tackle the resource allocation and optimisation problems in the fleet management and vehicle routing domains. However, the underlying problem specification is highly dynamic: new customer orders may be placed and then processed during scheduling or execution time of already accepted orders, thus modifications of scheduled orders may be necessary. Traffic jams or truck breakdowns can lead to the unfeasibility of a plan and enforce online re-planning. Standard OR-techniques are usually applied in an offline planning and optimisation process and can thus hardly cope with the dynamics arising during the execution time of the tour plans since they have do not modify existing solutions, but rather build a new schedule from scratch.

The multi–agent approach used in TELETRUCK partitions the overall scheduling problem into handy sub-problems. Each vehicle's plan is represented separately and can easily be adapted to dynamic changes. A co-ordinated market mechanism is used to realise a global optimisation of the overall solution.

We implemented he TELETRUCK agent society as a *holonic* agent system. A holonic agent or *holon* is an agent that is composed of sub-agents working together in order to pursue a common goal. The users or the other members of the agent society can interact with a holon as if it were a single agent. This allows to model several level of abstraction in a convenient way.

In a holon one agent is distinguished as the *head* of the holon. The head co-ordinates the resource allocation within the holon and controls the communication with the rest of the agent society. The head can be equipped with the ability to plan for the sub-agents.

The TELETRUCK system comprises holons of several types. For each transportation device of the forwarding company as well as for each of its drivers there is an agent, which manages the resources of the device or the driver. These agents have their own plans, goals, and communication facilities in order to provide their resources for the transportation plans according to their role in the society. They can merge together with a *Plan'n'Execute Unit* (PnEU) and form a holon which represents a complete vehicle which is actually capable of executing transportation tasks. For example such a vehicle holon may consist of a PnEU, a driver, a truck, a trailer, and two containers.

The PnEU is the head of the vehicle holon, represents it to the outside world, and is authorised to reconfigure it. A PnEU plans the vehicle's routes, loading stops and driving time and therefore is equipped with planning, co-ordination, and communication abilities, but does not have its own resources. Each transportation holon that has at least one task to do is headed by such a PnEU. Additionally, there is always exactly one idle PnEU with an empty plan that co-ordinates the formation of a new holon from idle components if needed.

The vehicle holons are internal sub-holons of a super-holon which represents the entire transportation company. This holon that subsumes the complete agent society is headed by a *company agent*. The company agent announces and distributes the incoming orders, gives the acceptance of the tenders, controls global optimisation, co-ordinates the execution, and channels all communication of the system with the user, i.e. the dispatch officer. Hence, the company agent represents the society to the user — and to partner companies to be represented also by such company agents [Bürckert+98c], or here, in the intermodal framework, the company agent represents the company to the terminal agents in the transport chain. The company agent also co-ordinates the internal co-operation and interaction between the PnEUs.

For the formation and co-ordination of a holon we have chosen an extension of the contract net protocol [Smith 80]. It allows not only to assign a task to a single vehicle, but — in case of a large amount of cargo, that cannot be hauled with one truck — to split the task into sub-tasks and assign them to several vehicles [Fischer+96]. A co-ordinated market mechanism, the *Simulated Trading* procedure [Bachem+92] is used to optimise the vehicles' plans iteratively. In the multi-staged simulated trading procedure the truck agents submit offers to sell and buy tasks to the company agent which matches them such that the global solution improves. In analogy to simulated annealing mechanisms the company agent accepts a worsening of the solution in early stages in order to leave local optima in the solution space. Nevertheless, optima that are left are saved. This decentralised approach is well suited for this complex setting since local information is sufficient for globally efficient resource and task distribution. The model has been implemented and tested in co-operation with a haulage company [Bürckert+98b].

3 Extension to Intermodal Planning and Execution

For the extension of the TELETRUCK approach to intermodal transport, we model the intermodal terminals in a similar way: An intermodal terminal is represented by an agent (see Figure2), which actually stands for a holonic agent society of terminal service agents. However, the fine grained agentification of resources in terms of modelling trains or its wagons as autonomous agents is currently not required for terminal services. Thus the holonic terminal agent society consists of the *terminal agent*, which is the head of the society and a *booking agent* managing the booking requests for the trains handled in the terminal. This agent comprises the heart of the terminal services for the negotiation and planning of intermodal transport orders.

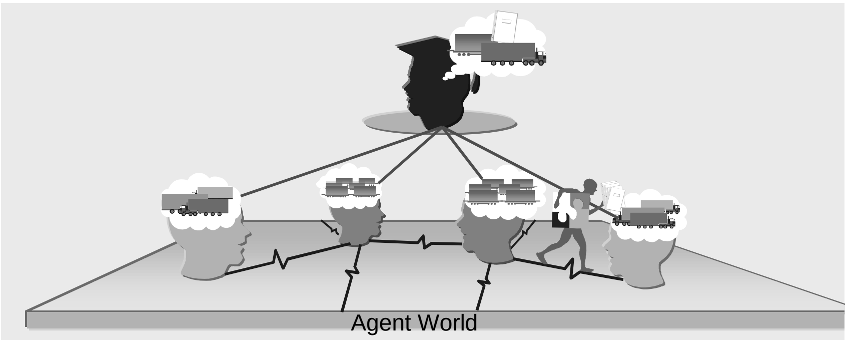

Figure 3: The IPnEU planning and migrating

3.1 An Agent for Intermodal Planning and Execution

Inter-connecting the two transport modes in the agent world, and thus allowing for intermodal transport orders, requires more sophisticated planning competencies and execution processes. Such intermodal planning competencies are usually managed as a hands-on-process either by the client requesting the order herself or by the expeditors of transport operators, e.g. terminals, providing pre and end haulage for rail-based transports. We cluster and concentrate knowledge and competence of intermodal transport planning for each transport operator, by encapsulating these into a new intelligent agent. This agent is integrated in the respective holonic agent societies which allow it smooth access to resources of the respective transport agency.

In the road based TELETRUCK approach the PnEU represents the road trains during planning and execution time. For intermodal transports, we introduce an *Intermodal Plan 'n' Execute Unit (IPnEU)*. Like the PnEU, it is equipped with planning and communication skills and there will always reside an idle IPnEU with an empty plan ready to start the processing of an intermodal order. Unlike the PnEU, it is not the head of a vehicle holon; it is associated with an intermodal order. This means the IPnEU plans and executes the plans for all the goods comprised within the order and not only for one ITU. An order may consist of one or several ITUs. If the order contains more than one ITU, it may be splitted over several trains or road trains. Still only one IPnEU is supervising the transport execution. The IPnEU plans and negotiates the intermodal transport of the ITUs it represents and then monitors the execution of the plan by migrating on the software side, while the ITUs are in transit. This implies, that the IPnEU has on the one hand smooth access to the respective transport operators in the transport chain for the negotiation and planning of an intermodal transport order. On the other hand it is a mobile agent, which accompanies its cargo in the agent world, while the goods are shipped in the physical world. Figure 3 illustrates this: the intelligent agent on the top is the IPnEU during the *planning and negotiation phase*; the walking agent is the vehicle holon during the *execution and monitoring phase.* The small puzzle in the body of the walker indicates the holonic agent society. The black piece stands for the IPnEU's participation in it. The phases are modelled differently, though we are able to mix them freely and thus provide for emergency replanning during execution or due to newly incoming orders, their dynamic insertion into consisting plans.

The announcement of an order triggers the inactive IPnEUs (the active IPnEUs are by definition busy with either planning or executing an order) to enter the planning and negotiating phase. The planning phase itself is divided into a *negotiation phase* with preliminary commitments to the services requested (road based transport, rail based transport and terminal services) and a *final commitment phase*, where the information gained during the negotiation will be used in order to place bookings on trains and provide pre and end run by trucks. The preliminary commitments are level commitments, which serves two purposes: reserve resources during planning and negotiation and provide a decision and planning basis for service providers within the intermodal transport chain.

3.2 Communication and Co-operation: Negotiating Intermodal Orders

The details of the negotiation and planning phase is shown Figure 4. The partners in this phase are customers and transport service providers. The customer at the origin sends an order to the forwarder of her choice. She may announce the order to several transport operators in order to receive and select the most competitive offer. The forwarder recognises that the order requires an intermodal transport and activates an IPnEU agent to provide for intermodal planning. The IPnEU splits the order into three parts: the *rail-based main run order* which constrains the *road-based initial and final run orders*. The main run order is passed to the booking agent of one or more terminals, who then engage in main run planning. The result of this activity, the main run plan is communicated back to the IPnEU. If the IPnEU has contacted several terminals, it sends one of them a preliminary commitment and adjusts the initial and final run orders to the chosen main run plan (latest arrival time at the terminal gate, earliest pick up time at the destination terminal). Other main run plans are rejected. Planning of the initial and final run can be done concurrently. In the protocol this is indicated by dashed arrows. Initial and final run planning involves the usual TELETRUCK planning and scheduling activity, which results in a holon for every road train. With the information on the whole transport, the IPnEU can then tell the forwarder which are the times relevant for the customer, that is pick up time (possibly interval) at the customer's site and delivery time (possibly interval) at the final destination. The *Intermodal Planning and Negotiation Protocol* is an application-specific extension and nesting of several classical Contract Net Protocols.

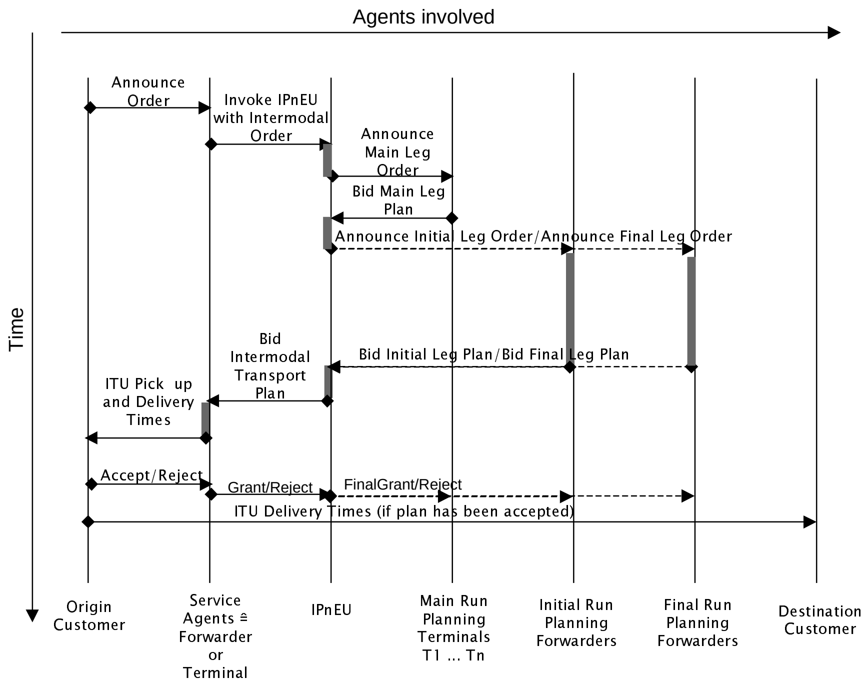

Figure 4: An Intermodal Planning an Negotiation Protocol

3.3 Results of the Negotiation and Planning Phase

The negotiation and planning phase generates an intermodal transport plan. Such a plan is a composition of plans for the different transport runs. The intermodal plan is composed of two road-based transport plans and a rail-based plan. The road-based plans realise the TELETRUCK approach, that is, for each road train, a software representative, namely a holonic structure is generated. Each structure is dominated by a PnEU. The IPnEU is participating in each of these holonic structures. This is possible, because an agent can be part of several holons at a time.

The protocol described here is a prototypic reference example. It is not the only way an intermodal transport, and thus an IPnEU, is activated. We provide each service within this transport chain with the ability to accept intermodal transport orders. That means, our customer at the origin may also contact the intermodal terminal which she may want to use directly, or the forwarder at the main run destination. The IPnEU therefore gives the respective carriage (pre-, main, or end) to the service provider that invoked it. In contrast to the other negotiations, there is no competition of service providers along this carriage.

The protocol presented here has a very static structure. The time-tabled railway transport constrains the remainder of the intermodal transport and therefore leads to the protocol structure as it is: the time-tabled, less flexible carriage needs to be planned (and booked) first. The more flexible road transport can be scheduled according to the needs imposed by the rail terminal. This idea can be easily transferred to combining other modes of transport, such as airborne or waterborne with road. Like in combined road–rail transport chains, there is a smooth combination of a less flexible, time-tabled mode and a more flexible, namely road based transport mode.

Within the protocol we use a preliminary commitment, which depends on the acceptance of the intermodal plan by the customer. If the customer does not agree to the plan, the terminal and forwarders get retract messages. Otherwise, after a certain delay (e.g. 60 minutes) the transport operator can either use the reserved resource differently or charge the cost of the transport to the client, or even both. This serves both sides: service providers reserve their resources for the client and do not loose to much time or money, if an order is then retracted. Clients have a certain planning security within the negotiation process and enough time to find out about cheaper means of transport.

3.4 Execution of Intermodal Transport Plans

One goal of the PLATFORM project, is the implementation of a prototypic simulator for intermodal transport and transhipment. With this simulator, we simulate the execution of intermodal transport plans. The intermodal transport plan contains the executable schedule for the three transport runs. For the road-based runs of the transport the holonic approach is used. This means that for each road train to be generated, a holon is composed during planning time. The road holons start their respective operations as planned. Within each road holon the IPnEU associated to the order is a sub-agent, thus accompanying the cargo in transit. On reaching the terminal gate, the road holon splits: The IPnEU clones itself and migrates from the software system of the forwarder to the software system of the terminal. The remainder of the road holon continues its plan, which may consist of picking up a new ITU at the current location or move on to a different target.

Since the IPnEU is associated with an order, which may consist of several ITUs, cloning becomes necessary on the software side: not all ITUs belonging to an order may reach the terminal at the same time. So cloning guarantees that the IPnEU is still part in all road holons in transit, while already accompanying ITUs on trains. A similar mechanism is at work at the destination terminal: The IPnEU clones itself as soon as the first road train of the end run is formed and becomes part of the respective vehicle holon.

While the planning phase can be compactly described with the protocol illustrated above, the execution requires some more elaborated methods and competencies. The execution itself can also be described in a protocol-like diagram, where messages about the result of the execution are communicated (see Figure 5). Within this Figure also the grey arrows indicate the transport control or supervision by the IPnEU. The simulation of the intermodal

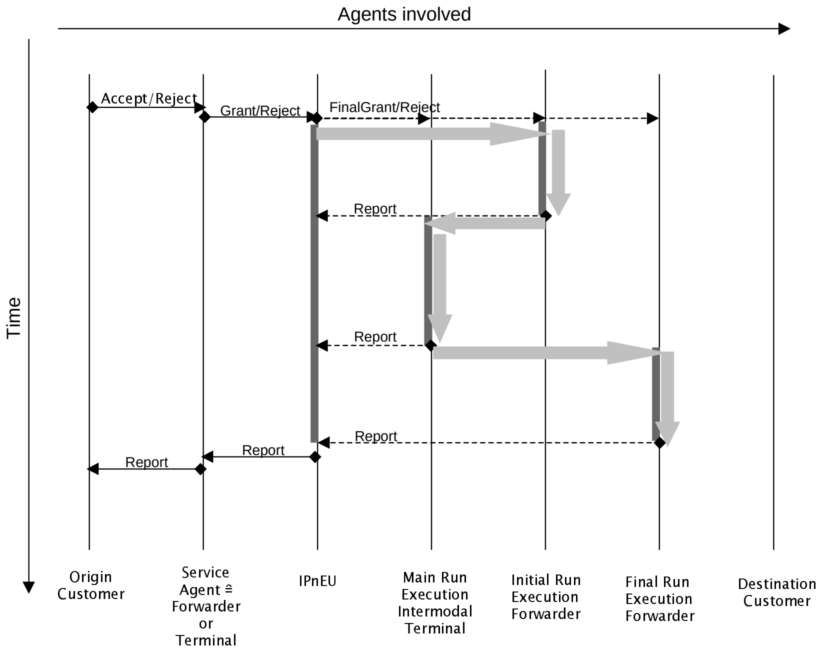

Figure 5: Execution Protocol of an Intermodal Order, flow of messages and control

terminal operation in the transport chain is in itself an important and nontrivial task. The transhipment of the ITUs inside the terminal, effects of the application of fast handling devices on the transhipment processes, yard management and storage policies as well as other important issues connected to terminal management is investigated and implemented by our partners in the PLATFORM consortium [Gambardella+98].

4 Conclusion

We have presented our multi–agent perspective onto intermodal transport chains. For the demonstration of our approach, we chose a combined road–rail transport. In the intermodal transport chain, each transport operator is represented by a software agent, thus we established a communication network within the chain. The network is used to negotiate and plan intermodal transport orders. Monitoring of the execution of joint transport and transhipment plans is guaranteed by the IPnEU agent, which is able to migrate inside the network as the goods it represents are moved in the physical world.

In this paper, we focussed on a combined road–rail transport. However, in our future work we aim at extending our ideas to a more generic model, where the user will be able combine arbitrary means of transport in a chain. The first step towards this, is the distinction of transport modes according to their time-tabled — and thus less flexible — character in contrast to more flexible modes such as road. We are developing a theoretical framework for holonic agent societies [Gerber+99], and will aim at applying it to other logistic management issues. The investigation of variations of the Intermodal Transport Negotiation Protocol is an other long term commitment for future research. The simulation of the execution of intermodal transport plans comprises other challenges, such as delay communication policies or the efficient management of peak traffic at terminal gates.

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