Technologies and Multi-Agent System Architectures for Transportation and Logistics Support: An Overview

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Abstract: *This paper is an overview of the problem solving methods in transport and logistics domain. Main attention is paid on the usage of the agent-based technologies. The purpose of this paper is to give a short overview of already proposed multi-agent system architectures and different agent types used in these architectures. First, paper describes existing problems in transport and logistics. Second, the known technologies and methods for solving them are discussed.*

Key words: *Multi-agent systems, intermodal transport systems, intelligent agents.*

INTRODUCTION

A transport and logistics domain is a complex domain with many involved companies. These companies include supply chains, and transport means; they are geographically distributed, and must cooperate in order to achieve the logistics goals. The logistics domain is decentralized, dynamic, where logistics goals, organizations' capabilities and beliefs are continually changing throughout the planning process. Moreover, the logistics domain is an open domain where organizations may enter or leave the system at any time [1]. Problems in this field may be grouped according with different goals or the use of different systems. One can notice a lack of standardization.

This paper is based on the overview prepared as a deliverable of the EC 6th Framework project "Web-based and mobile solutions for collaborative work environment with logistics and maritime applications" (project acronym eLOGMAR-M). The purpose of the work at the project is to analyse different methods and techniques used for problem solving in transportation and logistics, in particular, advanced technologies, such as Web-based, knowledge-based, mobile, etc.

Analysis of the great number of sources reveals that traditional mathematical modelling and simulation techniques dominate for optimisation of solutions. At the same time new approaches start to appear. In this paper we focus on intelligent agent technologies and multi-agent systems as one of the most perspective directions for the development of Web- and knowledge-based systems in transportation and logistics.

Agent technologies start to penetrate into transportation and logistics domain only recently. Intelligent agents represent the organizations within the logistics domain, and model their logistics functions, processes, expertise, and interactions with other organizations. Due to the similarity in characteristics between intelligent agents and organizations, agent technology is an appropriate choice for modelling organizations in the logistics domain [1]. Some agents simulate users involved in traffic; others are means of transport (trucks, trains, planes, ships), or elements of the traffic infrastructure [2].

Multi-agent systems offer such useful features as parallelism, robustness and scalability. They are highly applicable in domains and problems, where centralised approaches meet their limits. Multi-agent based approaches are well suited for domains, which require the integration and interaction of multiple sources of knowledge, the resolution of interest and goal conflicts or time bounded processing of data [3]. Therefore, these approaches allow a distributed modelling and distribution of tasks to be solved within the processing of intermodal transport and intermodal transport chains.

SOME PROBLEMS SOLVED IN LOGISTICS AND TRANSPORTS DOMAIN WITH AGENT-BASED TECHNOLOGIES

Analysis of different information sources allows to conclude that applications of intelligent systems in traffic and transportation covers such problems as multi-agent simulation for traffic modelling, decision support systems for letter transportation, logistics planning, sea freight transportation, vehicle dispatching, railway transportation scheduling, and others [1, 2, 4, 5, 6, 7, 8, 9].

The agent organization is compliant to a socio-technical system, which improves the understanding of decisions taken by agents for actors. These organizing principles are generic for any logistics system and allow fast adaptation to changing conditions.

Intelligent systems, which are able to assist the design-phase (strategic planning) of traffic and transportation systems and/or the management phase (tactical and operational planning) as well, are of special interest in transport and logistics. The purpose of transportation logistics is to design, to organize and to manage transportation in order to meet customer service demands, cost and environmental requirements. In the field of transportation logistics the focus is on the analysis of urban, regional and intercity transportation networks for both passenger and freight transportation as well. Complex *hybrid – type systems*, which include air-, road- and rail transportation are of particular interest [10].

Intelligent systems are designed for real world applications in traffic and transportation. They are built on the basis of an advanced software engineering concept including object-oriented software development and integration with non-standard-databases and GIS. Several so-called intelligent techniques coming from Artificial Intelligence, Operation Research and Computational Intelligence, such as Evolutionary and Genetic Algorithms, Constraint Programming, Agent-Based Modelling and Simulation, Tabu Search Metaheuristics and high performance Optimisation and Simulation techniques are used on the algorithmic side [10]. Models such as modal split models, models of transportation network design, models of vehicle routing and crew scheduling, models for the estimation of future volume of traffic, etc. are developed on the modelling side [10].

Computer based simulation can provide the decision-makers with the help they need in creating the strategies for the development of intermodal terminals [4]. In situation of hard competition there is a need to enhance the infrastructure of intermodal terminals to make them more attractive for the customers. At the same time very often there are substantial costs associated with these interactions that in their turn dictate a need for trade-offs. So, well-designed investment plans must be designed. Simulation has proven to be a reliable and convenient tool to support the decision makers in the daily operations in many cases [11, 12, 13]. A substantial help to terminal managers can be derive from Decision Support Systems (DSSs) where planning and management techniques, derived from the Operation Research and Artificial Intelligence fields, can be coupled with simulation models and statistical data analysis tools. A well-designed simulation tools can be the middle ground where decision makers compare their own experience with DSS generated management policies and validate them. Major problems in an intermodal container terminal are the following: storing containers on the yard, allocating resources in the terminal and scheduling train, vessel or truck loading and unloading operations. To solve these problems an architecture has been defined that consists of three different but strictly connected modules [14]: (1) a simulation model of the terminal, (2) a set of forecasting models to analyse historical data and to predict future events, (3) a planning system to optimise loading/unloading operations, resource allocation, and container locations on the yard.

This architecture supports the terminal managers [5] in the evaluation of: 1) vessels loading and unloading sequences in terms of time and costs, 2) resource allocations procedures 3) policies for container storage both in terms of space and costs of operations. Simulation tool is based on the partition of simulation objects between simulation agents and simulation components.

The agent-based framework may lead to more effective integration of production, logistics, and trading processes. *Integrated commerce* is an operational extension of traditional e-commerce that entails getting customers more involved in ordering activities so that contractors can more efficiently fulfill orders. I-commerce also entails more effective practical integration of supply-chain processes offering its users several i-commerce techniques (such as mobile timber auctions with integrated support of optimizing logistics) for negotiating, communicating, and exchanging information more effectively [15].

TECHNOLOGIES FOR PROBLEM SOLVING IN LOGISTICS

This section does not include the exhaustive analysis of different technologies already used. Instead, we focus only on the some of them, namely, on those, which are the most interesting from our viewpoint. During a design of agent-based systems for transport a new agent technology has been introduced. It is a holonic agent or a holon [16]. A holon 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 is a single agent. This allows to model several levels of abstraction in a convenient way. In a holon one agent is distinguished as the head of the holon. The head coordinates 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. 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. This approach is successfully used for TELETRUCK system [17]. The TELETRUCK agent society is implemented as a holonic agent system. The TELETRUCK system was designed as an agent-based forwarding system, able to manage the business processes of forwarding companies. Whenever the system plans a road-based transport, the agents representing the involved physical components form a vehicle holon. As a consequence of the domain structure, holons overlap. The agents form holons at the time of planning and can be members in several holons. The intermodal transport unit agents are part of the holon that represents the intermodal order. They belong to two vehicle holons for the initial and the final legs, and to a train holon for the main leg [5]. The TELETRUCK project has an extension – TELETRUCK-CC [18] that allows several independent shipping companies to cooperatively optimise their fleet schedules. Later it has been used as a base for PLATFORM project [6]. The PLATFORM architecture consists of two subsystems:

1) The intermodal transport planner that manages the planning of the whole intermodal transport chain from origin to destination for an intermodal transport unit. The intermodal transport planner plans the whole intermodal transport task thanks to: (1) intermodal planning and execution units (they contact specialized agents for planning, booking, reservation of the initial and final leg on the road and the main leg by train); (2) forwarding agents are responsible for planning of delivery intermodal transport units to and their pick-up from terminals (each forwarder is modelled by such a forwarding agent); (3) booking agent checks for availability of places on scheduled trains, checking which bookings are possible and then chooses the bet and makes the reservation.

2) The simulation system that simulates intermodal transport unit transport process, both assessing the feasibility of the plans generated by the intermodal transport planner and evaluates the performances of intermodal terminals, based on a detailed description of the intra-terminal processes. The simulation system performs the execution of intermodal transport tasks including internal terminal operations to evaluate their feasibility and their performances. It is composed of: (1) road simulator, that simulates the transport of the intermodal transport unit by truck, as delegated to forwarders. It simulates the flow of incoming and departing trucks at each terminal in the corridor; (2) terminal simulator simulates the loading and unloading of intermodal transport units from trucks and trains as well as storing of intermodal transport units in the intermodal terminal; (3) train simulator

simulates the flow of trains within the chosen rail corridor, according to the train time-tables, and the flow of trains from and to the terminals [6].

Another kind of holonic agent as a software agent is realized in the Casa ITN system [15]. Each member of participant groups (producers, buyers, retailers, and logistics companies) is represented with an appropriate *holonic agent*. Holonic agents accomplish complex (mostly hierarchically decomposed) tasks and resource allocations in the selected application scenarios. They also coordinate and control the activities and information flows of their subagents. This holonic technique lets personal assistants that represent human users act on behalf of their users even if those users are offline. A corporation holon consists of several holonic agents, each of which represents a special department and its corresponding tasks and services.

DIFFERENT AGENTS FOR INTELLIGENT TRANSPORTATION SYSTEMS

From a logistics management perspective agents taking responsibility in fulfilling the operational goals as well as agents supporting these tasks in a computational way are needed. These considerations motivate the introduction of two *generic meta-types of agents* in the logistics domain. *Management agents* pursue goals with respect to their environment and their defined action space, whereas their contractors, the *service agents* solve well specified tasks autonomously [19].

Management agents are the central part of a management system. In logistics they are software entities for meeting operational goals on behalf of a human actor or another managerial agent with some degree of independence or autonomy, and in doing so, employ some knowledge or representation of user's goals or desires. Management agents are goal directed, pro-active, take goal responsibility, make decisions, and have a model of their environment. They act autonomously, but the actions are constrained by the provided information and models (e.g. from a *supervising agent*). A management agent needs the following information: a goal to pursue, its skills and behavior, model of its environment, its role in the agent community (e.g. supervising agent, its sub-agents, collaborating agents), communication and co-operation protocols. In a logistics domain, where the co-ordination of joint actions play an important role, a management agent must exhibit the following properties: act in a collaborating manner, apply various problem solving strategies, manifest communicational abilities, use methods for solving conflicts among its sub-agents, and show capabilities for goal and model building, which are used by its sub-agents.

The design of DIAL system (Distributed Intelligent Agents for Logistics) is based on a multi-agent framework where a customer's problem can be decomposed and assigned to one or more (as needed) intelligent agents, which together generate a logistics plan [20]. Intelligent software agents are built on the top of simulation models to communicate among themselves and to generate or assist in generating a correct course of actions. These software agents must have sufficient reasoning power to understand each other's messages and actions as well as their own objectives in generating a complete plan.

The role of intelligent agents is as follows [7, 8]:

1) a *priority agent* prioritizes cargo based on unit's Latest-Arrival Date, the Available-to-Load Date at the port, and the size of the unit;
2) a *unit integrity agent* provides Integrated Computerized Deployment System with a list of items that meet the unit integrity rules;
3) an Integrated Computerized Deployment System *interface agent* passes Port Simulation Model a per-stow plan for use in staging area setups;
4) a *timing agent* passes Port Simulation Model packages of data in each 24 hour time period based on the outcome of Force Flow Model that provides time-phasing information for cargo from the installation to the port;

5) a Port Simulation Model *interface agent* passes Integrated Computerized Deployment System a list of items for the final stow plan that meet all the combined rules of unit integrity, Force Flow Model, and Port Simulation Model.

Previously mentioned kinds of agents are used in the DIAL project [21], which is an open system architecture that allows existing models to interface and communicate in a distributed network environment to evaluate and develop logistics plans.

In case of intermodal transport an intermodal terminal is represented by a *holonic terminal agent society* consisting of the *terminal agent*, which is the head of the society, a *booking agent* managing the booking requests for the trains handling in the terminal, and *locomotive agents* which represent the trains. Inter-connecting the two transport modes allowing for intermodal transport orders requires more sophisticated planning competences and execution processes [6]. In intermodal transports an *Intermodal Plan'n'Execute Unit* is introduced that plans and executes the plans for all the goals comprised within the order. The *Intermodal Planning and Negotiation Protocol* is an application-specific extension and nesting of several classical Contract Net Protocols [9, 22].

CONCLUSIONS AND FUTURE WORK

Our work based on analysis of different sources of information allows to conclude that at least two different multi-agent architectures has been worked out and used in real life problems within the transportation and logistics domain. These architectures are holonic agent technology and an open system architecture. Multi-agent or agent-based systems that mainly are used to solve typical problems in the transportations and logistics domain are decision support systems, logistics planning systems, and simulation and modelling systems, which support both decision-making, and planning.

The future work is connected with collection of more information about specific multi-agent systems and their applications in the transportation and logistics domain. More detailed analysis of existed solutions is also needed to define urgent issues for the development of agent based collaborative work environment for transportation and logictics.

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