Whitestein Series
in Software Agent Technologies

Franziska Klügl
Ana Bazzan
Sascha Ossowski
Editors

Applications of Agent Technology in Traffic and Transportation

Birkhäuser

Whitestein Series
in Software Agent Technologies

Franziska Klügl
Ana Bazzan
Sascha Ossowski
Editors

Applications of Agent Technology in Traffic and Transportation

Birkhäuser

Whitestein Series in Software Agent Technologies

Series Editors:
Marius Walliser
Monique Calisti
Thomas Hempfling
Stefan Brantschen

This series reports new developments in agent-based software technologies and agent-oriented software engineering methodologies, with particular emphasis on applications in various scientific and industrial areas. It includes research level monographs, polished notes arising from research and industrial projects, outstanding PhD theses, and proceedings of focused meetings and conferences. The series aims at promoting advanced research as well as at facilitating know-how transfer to industrial use.

About Whitestein Technologies

Whitestein Technologies AG was founded in 1999 with the mission to become a leading provider of advanced software agent technologies, products, solutions, and services for various applications and industries. Whitestein Technologies strongly believes that software agent technologies, in combination with other leading-edge technologies like web services and mobile wireless computing, will enable attractive opportunities for the design and the implementation of a new generation of distributed information systems and network infrastructures.

www.whitestein.com

Applications of Agent Technology in Traffic and Transportation

Franziska Klügl
Ana Bazzan
Sascha Ossowski
Editors

Birkhäuser Verlag
Basel · Boston · Berlin

Editors:

Franziska Klügl
Dept. of Artificial Intelligence and
Applied Computer Science
University of Würzburg
Am Hubland
97070 Würzburg
Germany

Ana Bazzan
Instituto de Informática, UFRGS
Campus do Vale, Bloco IV
Bairro Agronomia
Av. Bento Gonçalves
91501-970 Porto Alegre
Brazil

Sascha Ossowski
Universidad Rey Juan Carlos
Al Group DIET, ESCET
Campus de Móstoles
Calle Tulipán s/n
28933 Madrid
Spain

2000 Mathematics Subject Classification 68T35, 68U35, 94A99, 94C99

A CIP catalogue record for this book is available from the Library of Congress,
Washington D.C., USA

Bibliographic information published by Die Deutsche Bibliothek
Die Deutsche Bibliothek lists this publication in the Deutsche Nationalbibliografie;
detailed bibliographic data is available in the Internet at <http://dnb.ddb.de>.

ISBN 3-7643-7258-3 Birkhäuser Verlag, Basel – Boston – Berlin

Part of Springer Science+Business Media
Cover design: Micha Lotrovsky, CH-4106 Therwil, Switzerland
Printed on acid-free paper produced from chlorine-free pulp. TCF ∞
Printed in Germany

ISBN-10: 3-7643-7258-3
ISBN-13: 978-3-7643-7258-3

9 8 7 6 5 4 3 2 1 www.birkhauser.ch

Contents

Preface

Building effective and user-friendly transportation systems is one of the big challenges for engineers in the 21st century. The rapid change of location, enabled by plane, high-speed rail, sea and road travel, has constantly become easier and more natural. These days we travel without any of the difficulties that accompanied taking a trip less than a century ago. All we have to do is to organize and to pick up the transport mode that comes closest to our objectives. In much the same way, many new opportunities for the delivery of goods are being explored and commercially exploited.

So, it is not surprising that there is the intense need to understand, model, and govern transportation systems at both, the individual (micro) and the society (macro) level. Still, this raises significant technical problems, as transportation systems may contain thousands of autonomous, “intelligent” entities that need to be simulated and/or controlled. Therefore, traffic and transportation scenarios are extraordinarily appealing for Distributed Artificial Intelligence, and (multi-)agent technology in particular.

The papers in this book are revised versions of the work presented at the Workshop on Agents in Traffic and Transportation (ATT), at the International Conference on Autonomous Agents and Multiagent Systems (AAMAS), held in New York on July 20, 2004. The workshop brought together researchers and practitioners working on agent-based tools for modelling, simulation, and management of transportation systems, in particular in traffic and logistics scenarios. All papers have been thoroughly reviewed by renowned experts in the field. In addition, this book contains an invited contribution by Klaus Dorer and Monique Calisti from Whitestein Technologies.

The first contribution to this book, by Davidsson et al., provides a survey of existing research on agent-based approaches to transportation and traffic management. Perugini et al. present an provisional agreement protocol that facilitates the planning required in transportation scheduling problems. Dorer and Calisti put forward an agent-based approach to solve dynamic multi-vehicle pickup and delivery problems with soft time windows. The work by Ossowski et al. reports on an abstract architecture for traffic management, and its application to two real world domains. Yin and Griss describe SCATEAgents, an agent-based intelligent, flexible, and context-aware multi-modal traveller information system. Bazzan and Klügl show how the Braess Paradox, a well known phenomenon in transportation engineering, can be overcome by means of information manipulation. Yamashita et al. analyse the effect of route information sharing on traffic congestions. Katwijk et al. report on a test bed for multi-agent road traffic management systems. Conde et al. focus on the problem of effective real-time traffic light control using agent technology. Hallé and Chaib-draa present a collaborative driving system using teamwork for platoon formations. Marchal and Nagel propose a simulation model to account for the effect of secondary activities on route choice. Rindsfüser et al. describe a multiagent simulation for the generation of individual activity programs. Rossetti and Liu report on how the abstraction approach of multiagent systems can be used to represent the complexity inherent in the urban traffic domain. Finally, Gloor at al. present a message-based simulation framework for different kinds of mobility simulations.

We are grateful to all these authors for contributing their latest and inspiring work to this book, as well as to the members of the ATT Program Committee, and the external reviewers, for their critical reviews of submissions. Finally, a deep thanks goes to each of the brave members of the AAMAS-2004 local organization team for their hard work in providing (not only) the ATT-2004 event with a modern, comfortable location, and social program.

We hope you will enjoy reading this book and find inspiration for your own work!

October 2004 Ana Bazzan, Franziska Klügl and Sascha Ossowski

Agent-Based Approaches to Transport Logistics

Paul Davidsson, Lawrence Henesey, Linda Ramstedt,
Johanna Törnquist and Fredrik Wernstedt

Abstract. This paper provides a survey of existing research on agent-based approaches to transportation and traffic management. A framework for describing and assessing this work will be presented and systematically applied. We are mainly adopting a logistical perspective, thus focusing on freight transportation. However, when relevant, work of traffic and transport of people will be considered. A general conclusion from our study is that agent-based approaches seem very suitable for this domain, but that this still needs to be verified by more deployed system.

1 Introduction

The research area of agent technology continues to yield techniques, tools, and methods that have been applied or could be applied to the area of traffic and transportation management. The aim of this paper is to present a consistent view of the research efforts made in this area.

We are mainly adopting a logistical perspective, thus focusing on transportation rather than traffic, and on freight rather than people. In particular, we will not survey the extensive work on agent-based modeling of driver and commuter behavior. Also we will not consider approaches to supply-chain management.

In the next section, the areas where agent technology may be useful will be identified. We then present a framework that will be used to classify and assess the research in the area. This is followed by a systematic survey of the work found in the literature. Finally, we analyze our findings and present some conclusions.

2 Background

The development of distributed and heterogeneous systems, such as software for automation of, and decision support for logistics management, poses significant challenges for system developers. *Agent technology* [73], [75] aims to provide new concepts and abstractions to facilitate the design and implementation of systems of this kind. Parunak [51] lists the following characteristics for an ideal application of agent technology:

- *Modular*, in the sense that each entity has a well-defined set of state variables that is distinct from those of its environment and that the interface to the environment can be clearly identified.
- *Decentralized*, in the sense that the application can be decomposed into stand-alone software processes capable of performing useful tasks without continuous direction from some other software process.
- *Changeable*, in the sense that the structure of the application may change quickly and frequently.
- *Ill-structured*, in the sense that all information about the application is not available when the system is being designed.

- *Complex*, in the sense that the system exhibits a large number of different behaviours which may interact in sophisticated ways.

As most transport logistics applications actually fit Parunak's characterisation rather well, this would suggest that agent technology indeed is a promising approach for this area. However, it is not suitable for all applications. For instance, in applications that are monolithic, centralized, static, well-structured, and simple, agent technology will probably not provide any added value, only unnecessary complexity.

3. Evaluation framework

For each paper surveyed we describe the problem studied, the approach taken to solve it, and assess the results.

3.1 Problem description

Each problem description includes the following three parts: the domain studied, the mode of transportation, and the time horizon considered.

3.1.1 DOMAIN We have chosen to divide the problem descriptions into three domains: *transport*, *traffic* and *terminal*. A transport is an activity where something is moved between point A and B by one or several modes of transport. Problem areas that fall under the category transport are e.g. route planning, fleet management, different sorts of scheduling, i.e., functionalities that takes place to support transportation.

While transport refer to the movement of cargo from one point to another, traffic refers to the flow of different transports within a network. One train set is thus a transport, or part of a transport, that takes part in the train traffic flow. Hence, a transport can be part of several traffic networks (air, waterborne, road, rail,) and a traffic network constitutes of several transports. Typical traffic activities are traffic flow scheduling such as railway slot allocation, air traffic management, and railway traffic management.

Within for example a transport chain where the cargo is transported by truck, rail, ship and truck again, there are interfaces between the different modes. These interfaces represent nodes for re-loading and are referred to as terminals. Terminals can be any fixed place where the cargo is handled and require access to different kinds of resources. Typical terminal activities are resource allocation and scheduling of cranes, forklifts and parts of a facility.

3.1.2 TRANSPORT MODE There are five basic modes of transportation: *road, rail, air, water,* and *pipeline* [64]. Although the use of pipelines often offers the cheapest method in transporting bulk fluids in long distances, we will in this paper not regard this modality.

The water transport via sailing vessels offers one of the most used and less costly means of transporting bulk goods. The use of rail is often associated with bulk items transported less costly than road to far distant markets. The flexibility and often-inevitable use of road for the beginning or final transport mode in a transportation chain makes this the most often used form of transport. Road transport is often associated with faster delivery in short distances and is attractive to shippers and customers that demand choice and flexibility in scheduling. Finally, air transport mode offers the fastest means of transport and usually the most expensive. This mode is usually reserved for high-valued goods that need to be transported across large distances. The use of air is also considered in short supply times, as in the case of disaster relief.

All freight transport modes can include, for example, fleet management techniques, route and maintenance planning, on-board loading/unloading techniques and on-board computers. In all cases, the emphasis will be on the impact on organizational costs and service levels. Usually in freight logistics, transportation represents the most important single element in logistics costs for most firms [5]. Transportation is a key decision area within logistics due to, on average, a higher percentage of logistics costs associated with this activity than any other logistics activity [5]. The selection of which mode of transport is to be used is dependent on several factors associated with the type of cargo/goods, e.g., requirements on speed, handling, costs, distance, flexibility etc.

Intermodal transportation, refers to "movement of goods in one and the same loading unit or vehicle that uses successively several modes of transport without handling of the goods themselves in changing modes" according to the definition of The European Conference of Ministers of Transport [24]. The definition is valid also for personal travelling that includes two or more different modes of transportation.

One of the primary challenges in intermodal transport management is to coordinate several inter-dependent activities within the transport as well as the communication between the multiple actors involved.

3.1.3 TIME HORIZON Historically, the term logistics referred mainly to issues regarding technical and physical flows of products on an *operational* level. Today, the term includes both strategic and tactical issues beside the operational ones and includes the information flow connected to the physical flow. Therefore, the applications and concepts studied and presented are divided into levels of time perspective; *strategic*, *tactical* and *operational* level of decision-making. This is an established classification that is widely used. It can also be seen as a hierarchy in decision time [61]. We will here by *time horizon* refer to at what stage in the decision-making process the application is used, or is intended to be used. There are two dimensions often distinguished, the level of decision-making and its time frame. There is no definite line of separation, but strategic decision-making typically involves long-term decisions concerning determining what to do, while tactical deals with medium-term issues of setting up an action-list, and operational how to conduct the work set out in more specific terms, i.e. short term issues [61]. The time horizon for these levels is highly domain dependent.

In this study we also include the execution of tasks and real-time controlling functionalities within the operational decision-making. For a transport operator, as an example, a strategic issue to address would be where to locate distribution centres, while a tactical issue would be to tailor the vehicle fleet to satisfy the customer demands, and the operational level would involve scheduling of each and every transport and the controlling function with monitoring and ad-hoc planning if necessary.

As can be seen there is no established definition on time frame or content in the different planning hierarchy, and it is highly dependent on what type of business that is addressed.

3.2 Approach

Each approach is described by the following three parts: the intended usage of the agent system, the type of agents used, and the type of coordination chosen.

3.2.1 USAGE The applications studied can be classified, according to this paper, as either to serve as an automation system, or a decision-support system. An *automation* system can be defined as "having a self-acting mechanism that performs a required act at a predetermined time or in response to certain conditions" [46]. In this context it refers to a system's ability to act upon its decisions, i.e. it has a direct influence on the controlled environment and there is no human involved. On the contrary, a *decision-support system*, DSS, has only at most an indirect impact on the decision-making. A DSS is a system that provides output of some specified type to support the decision process for the user. The user, i.e. the decision-maker, takes the suggested decision(s) into consideration, and then acts. Thus, the final decision is made by a person, not the software system.

3.2.3 COORDINATION (CONTROL, STRUCTURE AND ATTITUDE) Researchers in many fields including computer science, economy, and psychology have studied the area of coordination, which can be viewed as "managing the interdependencies among activities" [45]. In any environment where software agents participate, the agents need to engage in cooperative and/or competitive tasks to effectively achieve their design objectives. From the multi-agent systems perspective coordination is a process in which agents engage in order to ensure that a community of individual agents acts in a coherent manner [48]. Coordination techniques are classified here according to the three dimensions control, structure and attitude.

We capture the authority relationships between agents in the dimension of *control*, which is either centralized or distributed (decentralized). The *MAS structure* corresponds to the set of agents constituting the MAS, their roles, and the communication paths between agents. The structure is either predetermined, i.e., static (the set of agents or their roles do not change during the execution), or is changing dynamically. Finally, the *agent attitude* dimension captures the behavior of agents, which is classified as either benevolent (cooperative), i.e., they will comply with social laws and global goals, or selfish (competitive), where the agents' individual goals, e.g., in a market-based economy, will govern their behavior.

3.3 Results

The main classification of the result of the approaches will be in terms of maturity of the research. However, we will also try to assess the performance and the limitations of the approaches.

3.3.1 MATURITY Agent applications can have varying degree of maturity, i.e., how complete and validated an application is. According to Parunak [52], the description of the maturity of an agent application helps the users to assess how much work that remains to carry out the implementation of the agent application. Furthermore, Parunak has suggested a number of degrees of maturity which formed the basis for our refined classification.

The lowest degree of maturity in the classification is *conceptual proposal*. Here the idea or the principles of the proposed application is described with its general characteristics, e.g. if the model is simple or complex. In the literature the term *conceptual model* is quite well-established and well-defined. However, we prefer the more open term conceptual proposal since it otherwise could be more difficult to fit in all applications according to the classification.

The next level in the classification is *simulation experiments*. Here the application has been tested in a simulation environment. The data used in the simulated experiment can either be real data, i.e. taken from existing systems in the real world, or data that is not real, i.e. artificial, synthetic or generated. Further, the type of data has been divided into limited/partial or full-scale data. The full-scale data represents data for a whole system, while the limited/partial data only covers parts of the system.

Field experiment indicates that experiment with the application has been conducted in the environment where the application is supposed to be applied. As in the simulated experiment, the field experiment is also divided into limited/partial and full-scale. The final level, *deployed system*, indicates that the system has been implemented in the real world and also has been or is in use. This is the most mature type of agent applications.

3.3.2 EVALUATION COMPARISON If a new approach is developed to solve a problem which has been solved previously using other approaches, the new approach should be compared to those existing approaches. Such an evaluation could be either *qualitative*, by comparing the characteristics of the approaches, or *quantitative*, by different types of experiments.

3.4 Summary of framework

Table 1 on the next page summarizes the framework for describing and assessing the agent-based approaches to logistics. The Appendix provides a table listing the published work in the area of agent-based approached to transport logistics that we have encountered is classified according to this framework. The papers in the table are first sorted according to domain and then according to mode of transportation. In the case where several papers have been published regarding the same project, we have chosen the most recent publication and/or the most widely available.

	Aspect	**Categories**
Problem description	Domain	1. Transport 2. Traffic 3. Terminal
	Transport mode	1. Air 2. Rail 3. Road 4. Sea 5. Intermodal
	Time horizon	1. Operational 2. Tactical 3. Strategical
Approach	Usage	1. Automation system 2. Decision support system
	Control	1. Centralized 2. Distributed
	MAS structure	1. Static 2. Dynamic
	Agent attitude	1. Benevolent 2. Selfish
Results	Maturity	1. Conceptual proposal 2. Simulation experiment 2.1. artificial data 2.1.1. limited 2.1.2. full-scale 2.2. real data 2.2.1. limited 2.2.2. full-scale 3. Field experiment 3.1. limited 3.2. full-scale 4. Deployed system
	Evaluation comparison	1. None 2. Qualitative 3. Quantitative

Table 1. Classification framework.