Electronic Communications of the EASST
Volume 37 (2011)

Workshops der wissenschaftlichen Konferenz
Kommunikation in Verteilten Systemen 2011
(WowKiVS 2011)

Indirect Agent Interaction within an Approach for a Robust Transport Control in Dynamic and Multimodal Logistics Networks

Heiko Jung, Samuel Weissbach, and Jochen Kappler

10 pages

Guest Editors: Horst Hellbrück, Norbert Luttenberger, Volker Turau
Managing Editors: Tiziana Margaria, Julia Padberg, Gabriele Taentzer
ECEASST Home Page: http://www.easst.org/eceasst/ ISSN 1863-2122

Indirect Agent Interaction within an Approach for a Robust Transport Control in Dynamic and Multimodal Logistics Networks

Heiko Jung[1], **Samuel Weissbach**[2], **and Jochen Kappler**[3]

[1] heiko.jung@daimler.com, http://www.daimler.com/
Daimler Group Research, Boeblingen, Germany

[2] samuel.weissbach@daimler.com, http://www.daimler.com/
Daimler Group Research, Boeblingen, Germany

[3] jochen.kappler@ch.abb.com, http://www.abb.com/
ABB Turbo Systems, Baden, Switzerland

Abstract: This paper outlines the motivation for a robust transport control in dynamic and multimodal logistics networks. For the accomplishment of this overall goal our current research effort intends to contribute by the development of a decentral and heterarchical organised control approach. This approach is implemented as a multi-agent system. Thereby, a new mechanism combining indirect and direct interaction between transport requesting and offering agents will be studied. This paper presents the blueprint of the indirect interaction. It is realised by a coordination artifact, which incorporates stigmergic mechanisms. This artifact represents a logistics network and is a workspace commonly shared by all agents.

Keywords: multi-agent systems, agent interaction, stigmergy, coordination artifact, transport control, logistics networks

1 Introduction

Logistics systems are non-deterministic. In regard to their input parameters these are characterised by uncertainties, which can be reinterpreted as the stochastic occurrence of disruptions. These induce a constant deviation of the actual from the targeted working progress, which finally causes undesired inefficiencies. Uncertainties are reason for the dynamic behaviour of logistics systems, whereas the degree of dynamics is still rising due to e.g. the tendency of shifting the customer decoupling point to the latest possible time. The complexity of these systems continues to rise due to e.g. a rising number of production plants, which has its main origin in an also rising number of different body variants of cars. This rising complexity increases the necessary time for the determination of reasonable decisions. At the same time the available time decreases because of higher degrees of dynamics [Ble99]. Nevertheless, business partners within automotive logistics networks use exchanged information independently, whereas for the solution of decision problems optimisation, exact, or heuristic methods are typically used within hierarchical information systems. It is a widely spread opinion that due to rising complexity and dynamics this classic procedure is reason for inefficiency [SBF+08].

Drawbacks of the classic procedure become especially apparent within operational transport planning. Thereby, logistic service providers (LSP) are optimising solely their area of responsibility, wherefore e.g. a vast amount of heuristics is available for the NP-hard static route planning problem [Sch08]. By contrast, the occurrence of uncertainties within the runtime of transport systems and the absence of a complete predetermined basis of information require a dynamic decision making. For the accomplishment of e.g. dynamic route planning problems only a small number of heuristics has been developed. These are only capable to handle a specific uncertainty with a specific action alternative for a specific route planning problem.

In practice, this matter of fact causes a mostly manual accomplishment of dynamic operational transport planning, whereby its solution quality depends solely on the business partner and transport specific dispatchers' skills. For this purpose, auxiliaries like blackboards, notes, and spread sheets are used to ensure the logistic efficiency. If the possible multimodality of transports[1] and the variety of possible transport arrangements is also taken into account, it has to be concluded that the applicability and capability of prevailing methods for dynamic operational transport planning is not sufficient. Therefore, methods for the control of complex, dynamic, and multimodal transports have to be developed. In this regard, our research effort intends to contribute towards more robust transport systems[2] by the development of a decentral and heterarchical control approach. The incorporation of these characteristics is promising in order to overcome drawbacks of the classic procedure [SBF+08]. That is, e.g. the capability of the transport control system to cope with not explicitly specified behaviours of the transport system.

2 Tasks and Uncertainties

Taking the outlined challenge into account the approach pursues the collaborative integration of the partners' and the transport specific dispatchers' tasks. The considered business partners are LSPs, suppliers, and purchasers. Thereby, as part of operational transport planning the following tasks have to be accomplished:

- the determination of the mode of transport,
- the determination of the means of transport,
- the determination of their loading, and
- the determination of their routes.

These tasks specify entirely the transport movements. Therefore, the approach is called transport control instead of transport planning. The needed transports can only be accomplished by a limited number of means of transport (MOT) and their limited loading capacity. The approach considers different modes of transport in terms of trucks, ships, trains and planes. The creation of transport plans differs between modes of transport, as neither the purchaser nor the supplier

[1] Multimodality is the usage of at least two different modes and means of transport.

[2] Robust logistics systems are able to cope efficiently with uncertainties, which cause fundamental changes of their composition (e.g. varying number of purchasers). Besides, they are stable against minor disruptions (e.g. varying transport times) [Jen05].

are dominant enough to be able to influence the movements of all different modes. The movements of ships, trains, and planes base upon schedules. Their corresponding agents only decide which transport requests meet their schedule. A transport request is an assignment of transport material to a specific destination and time of arrival. By contrast, truck movements are directly influenceable. In this regard, the approach will be able to cope with different types of route planning problems. Within the first implementation trucks will solve a dynamic Pick-up and Delivery Problem (PDP) in which the routes are open and the trucks have a limited loading capacity. It is a dynamic problem as on a daily basis new transport requests emerge.

The constant consideration of uncertainty is crucial for the approach. Thereby, three different categories are considered, implying deviations concerning the:

- supply of materials,
- purchase of materials, and
- transport progress.

The supply and purchase of materials is subject to time- and amount-related deviations. Transport progress is subject to time-related deviations throughout the run-time of transports. By the constant consideration of these uncertainties a robust accomplishment of the named tasks is intended. This finally leads to a logistics system, which operates efficiently for various system states rather then being optimal for a single but possibly never occurring system state.

3 Characteristics

For the accomplishment of the outlined tasks and uncertainties the approach fortifies the distribution of responsibilities to heterogeneous decentral elements. As these elements are interacting, the approach can also be described as a multi-agent system (MAS). Each agent has incomplete information and capabilities. Besides, no global system control exists, data is decentralised, and agent computation is asynchronous [JSW98]. Several agent-based systems have been developed for applications in production and logistics. For transport logistics related problems the approaches Teletruck [BFV00], Coagens [DPR04], and LS/ATN [GDD09] are significant contributions of the last ten years. These are not able to accomplish the outlined field of application (see Section 2). Teletruck does not explicitly take uncertainties into account. Besides, it is only capable to cope with intermodality (trucks and trains) based on a rigid predetermined transport composition. By contrast, the new approach will also determine possible overall and multimodal transport compositions. The focus of Coagens is rather an agent-based realisation of information systems dealing with supply chain management tasks than the development of a decentral approach towards operational transport planning. LS/ATN is an agent-based approach towards dynamic route planning. Thereby, it focuses on the uncertain number of transport requests. LS/ATN as well as Coagens do not consider the multimodality of transports. Furthermore, all three approaches are characterised by a conventional hierarchical organisation, which implies significant limitations of their scalability, adaptivity, ability for self-organisation, and usage of emergent coordination, as e.g. the possible transport compositions are largely predetermined.

Moreover, the new approach differs from already developed approaches with its characteristics, as e.g. a hierarchical organisation between the agents is avoided. Therefore, the system's architecture is heterarchical. The interaction between agents is crucial to avoid the occurrence of undesired global behaviours within decentral and especially heterarchical systems [AHPL07]. It is characterised by the communication and coordination mechanisms used. The proposed interaction mechanism distinguishes between indirect and direct interaction. Both types of communication are employed to exchange information between the agents which represent the MOTs and the transport units (TU). A transport unit represents a predetermined and reasonable transport lot size. A rough description of the interaction follows within the next section.

4 Interaction

In the past MAS definitions have been solely agent-centered [PB10]. By contrast, current research work emphasises that the agents' environment is a basic component of MAS as well. In this regard many concepts have been developed. Concerning the indirect interaction within our approach the conceptual framework of Ricci et al. is essential [ROV+07]. Thereby, the use of stigmergy for the coordination of rational agents (e.g. BDI) instead of nonrational agents (e.g. reactive/ant-like) is proposed. It bases upon the use of artifacts, which are essentially an abstraction of an environment and can be any kind of object, tool, or instrument encapsulating local interaction. These artifacts mediate agent interaction and enable emergent coordination by incorporating stigmergic mechanisms, which eventually lead to desired behaviours of the system.

Stigmergy has been originally investigated in studies on the behaviour of insect and ant societies [Gra59]. Within MAS incorporating stigmergy, agents interact with each other by modifying asynchronously a portion of an environment. This leads to an indirect interaction between agents, which constitutes the coordinative influence of stigmergy. Stigmergy promotes the capability of self-organisation enabling system robustness in complex and dynamic environments [ROV+07]. Therefore, the incorporation of stigmergic mechanisms within our approach intends to contribute towards the overall goal of a robust transport control. In previous scientific work pheromone-like markers have typically been used by nonrational homogeneous agents for the modification of spatial environments. That was directly inspired by biological systems.

By contrast, within our approach rational heterogeneous agents exchange information indirectly via an environment model, which represents a logistics network instead of a spatial environment. It is an abstraction of an existing business partner network. It basically consists of the two static object types arcs and vertices. Arcs represent roads, rail-, water-, or airways. Four different types of vertices are considered. Thereby, each vertex can be a supplier, a purchaser, a transshipment, and/or a junction vertex. These structural information determine the possible scope of transport activities. There is no explicit specification of plausible transport alternatives. The environment is currently implemented according to the space concept of Pokahr et al. [PB10] and is part of a workspace commonly shared by all agents. In the next subsection core functionalities of the indirect interaction are described.

4.1 Indirect Interaction

The indirect interaction enables service requesting agents representing TUs to submit information to reasonable service offering agents representing MOTs without using an agent hierarchy or blackboards. It basically consists of two steps: the publication of and the search for information. The information basically characterise transport requests (see Subsection 4.4). Firstly TU agents publish their transport requests by modifying specific elements of the environment (see Figure 1, $\boxed{A}$). Secondly MOT agents search for information on transport requests on specific elements of the environment (see Figure 1, $\boxed{B}$).

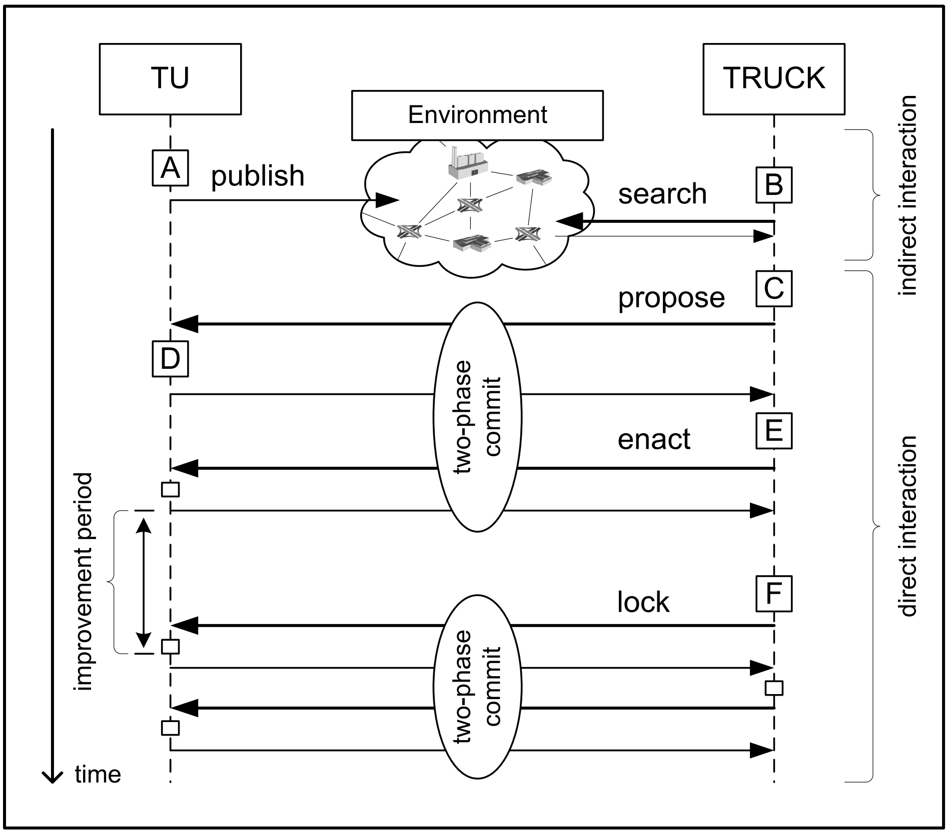

Figure 1: Simplified interaction overview

Thereby, a vast amount of patterns is imaginable. These determine the environment's elements, which are part of the asynchronous modification within either the publication of information or the search for information. The patterns presented in this paper are part of our current implementation work (see Subsection 4.3). The indirect interaction bases upon a network-representing coordination artifact, which corresponds to a specific compilation of patterns, information and the environment model. It determines the MOT's limited insight into the overall system and is solely not sufficient for the coordination of the agents' activities. Therefore, as sketched in figure 1 a MOT agent starts direct interaction with TU agents as soon as it has found at least one transport request. A short overview about the direct interaction is given within Subsection 4.2. It gives the reader a better understanding about the mode of operation of the overall approach and is focused on the direct interaction between MOTs of the mode truck and TUs.

4.2 Direct Interaction

Within the direct interaction truck agents create, assess, and finally try to enact with the concerned TUs transport plans. These core functionalities are processed according to the known transport requests. Therefore, the indirect is a prerequisite of the direct interaction. Trucks use heuristics in order to create transport plans for the known transport requests (see Figure 1, $\boxed{\text{C}}$). Thereby, different heuristic opening approaches will be implemented and evaluated as part of pending simulation experiments. By contrast, trains, ships, and planes only use their predefined route. The assessment of transport plans is based upon the usage of truck and TU specific logistic performance criterias. For the enacting of a transport plan these get consolidated and standardised into utility values, which causes a cooperative coordination between trucks and TUs. Trucks intend to enact transport plans according to the descending sequence of their transport plan specific utility values. As all agents are acting independently and asynchronously, special measures have to be taken to ensure system integrity and to prevent interaction deadlocks or race conditions. This is basically accomplished by the incorporation of the two-phase commit protocol, whereas the truck acts as the coordinator. At first the truck sends the proposal to all concerned TUs in order to assess the corresponding transport plan with the TU specific utility values (see Figure 1, $\boxed{\text{D}}$) and waits for the replies. Each TU answers whether it is still available and returns its for the plan assessed performance criterias. If all TUs are available, the truck evaluates all replies, decides whether to do the plan or not (see Figure 1, $\boxed{\text{E}}$) and finally informs all TUs about its decision. With the incorporation of this protocol transport plan inconsistencies are prevented. Furthermore, communication deadlocks have to be excluded. Therefore, the truck agent is always interacting with the TU agents in ascending sequence of the TU unique identification number. Thus, transactional safety is ensured while using a multi-agent system without hierarchies.

As the trucks as well as the TU might have different transport alternatives a competitive coordination is needed as well. This coordination is necessary as within the approach an improvement period is incorporated, in which the trucks basically search for better transport plans and propose these to the concerned transport units. Therefore, transport plans within the improvement period are not fixed and all involved agents might decide to leave it. For the competitive coordination basically two different alternatives have been developed. Both alternatives determine the validity of an exchange from a current to a possible new transport plan and are part of a truck's decision about the acceptance of a transport plan (see Figure 1, $\boxed{\text{E}}$). They intend to direct local exchanges into a globally desired behaviour. The first one incorporates a multi-criteria function. The course of the function is globally specified and essentially based on the overall utility and urgency of the current enacted transport plan locally parametrised. It specifies an acceptable or necessary change of the overall utility from a current to a new transport plan. The second alternative implements an approach similar to the metaheuristic simulated annealing. A new transport plan with better utility values than a current plan will always be accepted while the probability for accepting worse plans will decrease within the progress of the improvement period.

The duration of the improvement period is not specified globally, as it is dependent on the urgency of the TU. A final enactment by the truck stops the exchange of transport alternatives (see Figure 1, $\boxed{\mathrm{F}}$) and constitutes the end of the improvement period.

4.3 Patterns of Information Publication and Search

The publication of information within the environment model comprises two steps (see Figure 2). The first one publishes information on the arcs of the shortest path to the TU's sink vertex (1st pattern). Within the second step information is published on the arcs to successor vertices of the TU's source vertex (2nd pattern).

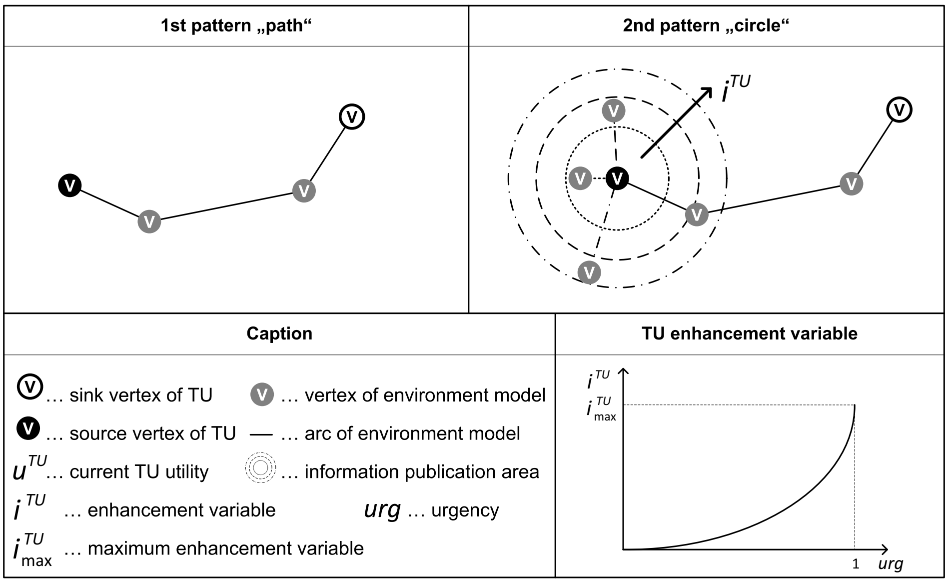

Figure 2: Patterns of TU information publication

The enhancement variable i^{TU} determines the range of the second pattern. It depends on the TU's current urgency urg and its maximum i^{TU}_{max}. i^{TU} refers to the distance between the source vertex and its successor vertices, whereas instead of the euclidean distance the length of the arcs is considered. To ensure operational reliability i^{TU}_{max} has to be specified so high (e.g. based on topological circumstances), that at least some MOT(s) will always be able to find information concerning the TU's transport request. Furthermore, the second pattern is only enhanced when the specific TU currently does not have a transport plan.

The information search with patterns is executed solely by MOTs representing trucks. Trains, ships, and planes only search for information according to their specific route. These routes are predefined as part of the environment model. The information search of trucks within the environment model consists of two steps (see Figure 3). It starts in an enhancing way on their reference point (1st pattern) and continues with the search alongside the routes of according to the 1st pattern found transport requests (2nd pattern). The variable i^{MOT} determines the range of the first pattern. As for the MOT the range can not depend on urgency, i_{Δ}^{MOT} specifies an addition to i^{MOT} which is executed quasi-continuously every t_{up}^{MOT}. It depends on the MOT's current utility u^{MOT} and its maximum $i_{\Delta,max}^{MOT}$. At first a linear correlation is assumed.

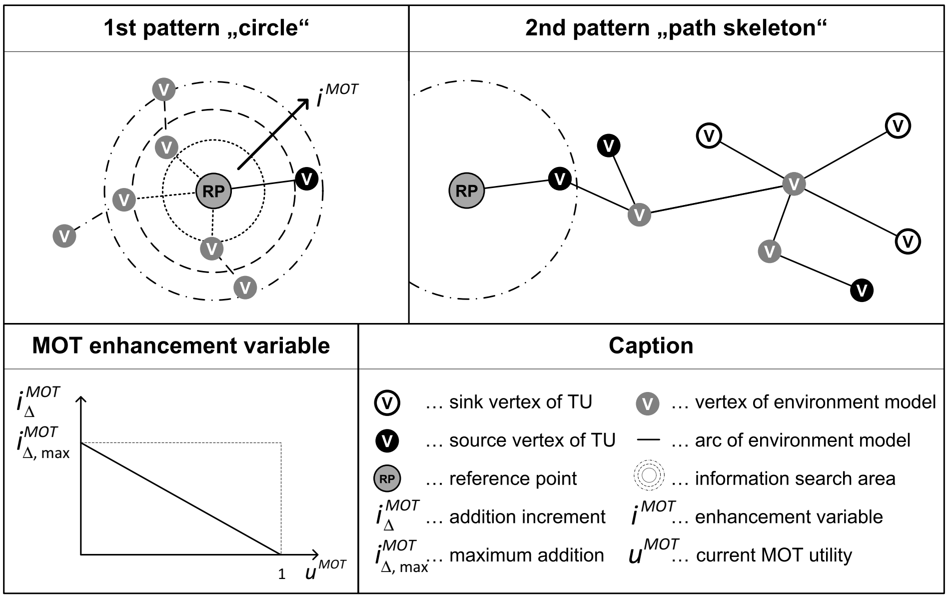

Figure 3: Patterns of truck information search

The outlined indirect interaction provides trucks with the knowledge of promising transport requests. That is, transport requests are according to their geographic location e.g. close to each other or close to the trucks' reference points. This creation of the trucks' limited insights into the overall system corresponds to the coordinative influence of the coordination artifact used.

4.4 Information

As outlined the approach incorporates a network-representing coordination artifact. Thereby, in contrast to stigmergy within biological systems no pheromones are published and searched. The information characterise the TU's transport request. Thereby, the overall goal of reducing unnecessary multi-lateral communication between MOT and TU within the direct interaction is considered. The information are e.g. the source vertex, sink vertex, information concerning time-related, and capacity-related restrictions. In contrast to pheromones these information do not have a dynamic behaviour. Therefore, TU agents have to publish and delete information directly within the environment model. The deletion of the information is processed when a transport plan is enacted. For a consistent identification of the information the bijective identifier of TU agents is used. The following subsection outlines specific characteristics of the indirect interaction concerning the consideration of different modes of transport.

4.5 Transshipment

Up to this point, the focus of the paper has been on transports, which are processed in direct relations. In these a variation of the used MOT does not exist. By contrast, multimodal transports are not processed in direct relations. The transshipment from one mode to another is executed at specific transshipment vertices. The existence of these results mainly from different transport times, costs of the modes, and in topological circumstances. Besides, transports including transshipments between means of transport of the same mode exist as well. In this paper, these transports are called unimodal. The unimodal transshipment is typical for parcel services. Within the automotive industry it can be part of the processes of an area contract freight forwarder.

For the consideration of different uni-, or multimodal transport alternatives TUs have to identify and assess a set of reasonable overall transport alternatives. For this purpose, the determination of the shortest paths is based upon different arc rating criterias. These are distance, time, cost in relation to distance, and cost not in relation to distance. In this way, TUs determine in analogy to navigation systems the shortest, fastest and cheapest route to their sink vertices. An explicit specification of reasonable transport alternatives is avoided. Unimodal transports are identified by the criteria cost not in relation to distance, as these alternatives are typically by far cheaper. Furthermore, it is also necessary to identify different overall transport alternatives, which are characterised by a similar transport composition (e.g. multiple transatlantic ship routes). Therefore, the shortest path has to be determined multiple times on the basis of the concerned arc rating criteria. This multiple determination is executed whenever transshipment vertices are part of the shortest path. Prior to this multiple determination of the shortest path an elimination rule is considered, which basically determines that the arc(s) of the main run has(have) not to be considered within the next shortest path determination. The multiple execution of the elimination rule in combination with the shortest path determination stops when abortion criteria are met. All identified overall transport alternatives are potentially subject of TU's information publication. In our current work we focus on different alternatives of the main run within multimodal transports. Therefore, only train-, water-, and airways have to be considered.

5 Summary

This paper roughly outlined the motivation for a robust transport control in dynamic and multimodal logistics networks. It described tasks and considered uncertainties of an approach being developed at the time of the papers' creation. Besides, it presented conceptual work for the incorporation of stigmergy. The approach will be implemented within an agent framework. On this basis simulation experiments will be conducted. These enable the assessment and finalisation of our conceptual work. Thereby, especially the alternatives within the direct interaction and the parametrisation of the indirect interaction are predominant parts of the simulation experiments. In the context of first simulation results, a more detailed description of the approach's functionality will be presented in future scientific publications.

Bibliography

[AHPL07] F. Armetta, S. Hassas, S. Pimont, O. Lefevre. Towards the Control of Emergence by the Coordination of Decentralized Agent Acitivity for the Resource Sharing Problem. In *Engineering Self-Organising Systems*. Lecture Notes in Computer Science 4335, pp. 132–150. Springer Verlag, Berlin Heidelberg New York, 2007.

[BFV00] H. J. Bürckert, K. Fischer, G. Vierke. Holonic Transport Scheduling with Teletruck. *Applied Artificial Intelligence* 14(7):697–725, 2000.

[Ble99] K. Bleicher. *Unternehmerischer Wandel: Konzepte zur organisatorischen Erneuerung*. Gabler Verlag, Wiesbaden, 1999.

[DPR04] W. Dangelmeier, U. Pape, M. Rüther. *Agentensysteme für das Supply Chain Management: Grundlagen - Konzepte - Anwendungen*. Deutscher Universitäts-Verlag, Wiesbaden, 1. edition, 2004.

[GDD09] D. Greenwood, C. Dannegger, K. Dorer. Dynamic Dispatching and Transport Optimization: Hawai'i International Conference on System Science. Waikoloa, 2009.

[Gra59] P. P. Grassé. La reconstruction du nid et les coordinations interindividuelles chezBellicositermes natalensis etCubitermes sp. la théorie de la stigmergie: Essai d'interprétation du comportement des termites constructeurs. *Insectes Sociaux* 6(1):41–80, 1959.

[Jen05] E. Jen. Stable or Robust? What's the difference? In Jen (ed.), *Robust design : a repertoire of biological, ecological, and engineering case studies*. Pp. 7–20. Oxford University Press, New York Oxford, 2005.

[JSW98] N. R. Jennings, K. Sycara, M. Woolridge. A roadmap of agent research and development. *Autonomous agents and multi-agent systems* 1(1):7–38, 1998.

[PB10] A. Pokahr, L. Braubach. The Notions of Application, Spaces and Agents: New Concepts for Constructing Agent Applications. In Schumann et al. (eds.), *MKWI: Multiagent Systems: Decentral approaches for designing, organizing, and operating information systems*. Pp. 159–170. Universitätsverlag, Göttingen, 2010.

[ROV+07] A. Ricci, A. Omicini, M. Viroli, L. Gardelli, E. Oliva. Cognitive Stigmergy: Towards a Framework Based on Agents and Artifacts. In Weyns et al. (eds.), *E4MAS 2006, LNAI 4389*. Pp. 124–140. Springer Verlag, Berlin Heidelberg New York, 2007.

[SBF+08] B. Scholz-Reiter, C. de Beer, M. Freitag, T. Hamann, H. Rekersbrink, J. T. Tervo. Dynamik logistischer Systeme. In Nyhuis (ed.), *Beiträge zu einer Theorie der Logistik*. Pp. 109–138. Springer Verlag, Berlin Heidelberg New York, 2008.

[Sch08] A. Scholl. Optimierungsansätze zur Planung logistischer Systeme und Prozesse. In Arnold et al. (eds.), *Handbuch Logistik*. Pp. 43–57. Springer Verlag, Berlin Heidelberg New York, 2008.