Semantic Data Integration for Ubiquitous Logistics
An Approach Supporting Autonomous Logistics in Urban Environments

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Keywords: Autonomous Logistics, Ubiquitous Computing, Semantic Data Integration, Interoperability.

Abstract: This paper introduces an approach for seamless plug & play data integration in a novel urban logistics concept. The logistics concept is called ubiquitous logistics and contains an agent-based perspective on shared logistics resources. Each private and public vehicle participating in the concept, as well as parcels, features an intelligent agent that may request (or offer) information services to other agents or legacy systems. The technical approach of this paper suggests that each of the heterogeneous data sources delivers additional information that is used to virtually integrate the data in an automated way. This additional information concerns, the authentication, data structure and sequence – information that have to be provided manually nowadays. The technical approach is explained using a typical situation from the future urban logistics concept. This situation represents an intelligent agent trying to deliver small goods along a stream of urban commuters.

1 INTRODUCTION

The exchange of goods between companies and the delivery of final products to consumers requires considerable logistics capacity. The planning and realisation of both the transport and storage of goods need to take into account time, cost and quality constraints. Changes in customer behaviour, such as an increase in importance of individualised/ personalized products compared to mass-produced ones (Kumar, 2007), challenge these activities. This demand for individualised products, combined with the growing popularity of online shopping and the customers' desire for same-day delivery cause a reduction of delivery lot size, in turn increasing the overall amount of deliveries (Ickert et al., 2007). This growth of delivery volumes puts urban traffic and logistics systems under additional stress causing congestion, limited parking space, pollution and infrastructure deterioration (Müller et al., 2006).

An approach to reduce these negative impacts caused by increasing delivery volumes is the ubiquitous logistics concept as presented in (Wellsandt et al., 2013). Cornerstone of the approach is to describe urban freight transport as a system of shareable logistics resources managed by collaborating intelligent agents. Agents continuously request and offer information services while each service is connected to a data source.

One of the most significant problems in this environment is the seamless exchange of information from distributed, heterogeneous data sources. Intelligent agents and data sources like traffic management systems, logistic infrastructure and other systems have a need for actual information about relevant system states to make a sustainable decision. Nowadays, there are several approaches to establish the communication between different data sources featuring different information structures and information meaning. One of these techniques is the approach of the *virtual data integration*. The main advantage of this approach is the delivery of information on demand without the need for an additional data storage device like a data base.

The paper aims to describe an approach enabling automated virtual data integration in urban logistics. For this purpose, section 2 will explain existing research on the fundamental topics of this paper. Section 3 will cover the technical approach that is explained using a guiding example. Section 4 concludes the described approach.

2 RELATED WORK

This section covers existing work related to the core

Wellsandt S., Klein K., Franke M., Hribernik K. and Thoben K..
Semantic Data Integration for Ubiquitous Logistics - An Approach Supporting Autonomous Logistics in Urban Environments.
DOI: 10.5220/0004961206520656
In *Proceedings of the 4th International Conference on Cloud Computing and Services Science* (CLOSER-2014), pages 652-656
ISBN: 978-989-758-019-2

ideas of this paper. The section will explain the concept of ubiquitous logistics and its preceding background. Furthermore, the section will cover aspects of data integration that are reused in the introduced approach of this paper.

2.1 Autonomous Logistics

Interpretation of logistics as a multi-agent system (MAS) is discussed in literature for several years (Moore et al., 1997). In 2005, Davidsson et. al. published a survey about the use of MAS in transportation and traffic management (Davidsson et al., 2005). Findings indicate that many logistics problems have characteristics similar to those of agent-based systems. A similar argumentation is suggested for the collaborative research centre 637 for autonomous logistics in Bremen, Germany (Scholz-Reiter et al., 2004). According to (Gehrke et al., 2010), autonomous logistics can be enabled by *situation-aware agents*, actively gaining information about their surroundings. Based on an agent's observations, decisions can be made about logistics processes. An example for the implementation of situation-aware agents in logistics is the intelligent container that is described in (Lang et al., 2011). A comprehensive study on multi-agent coordination enabling autonomous logistics is provided by (Schuldt, 2012).

The argumentation of autonomous agents in logistics offers far reaching possibilities for future urban freight transport. In order to utilize possibilities, the focus of planning and control of urban transport needs to shift from a centralized perspective towards a decentralized one. At the same time, efficiency in urban freight transport is increased by taking into account all available logistics resources an urban environment provides.

2.2 Ubiquitous Logistics

In the ubiquitous logistics concept, public and private transportation means that are able to transport goods (parcels) within a city are considered as *logistics resources* of that same city (i.e. private vehicles, trucks, trams, buses, etc.). Primary objective of the concept is to avoid additional traffic for freight transport by utilizing existing logistics resources best.

In order to manage the multitude of logistics resources within a city, transported parcels feature an autonomous, situation-aware agent that can be human or artificial. The agent collects information and takes decisions required to complete the scheduled transportation task for a certain parcel. The decision process each agent has to perform is based on a multi-criteria problem. The problem concerns the selection and realization of an optimum route from the current location to a target destination within a dynamic environment. Potential routes are created and destroyed dynamically based on the availability of local logistics resources. A situation-aware agent picks logistics resources in order to make progress against its scheduled transportation task. Completion of a transportation task might require taking different logistics resources (i.e. vehicles or transportation modes).

The assignment of parcel and resource depends on criteria like transportation time, load efficiency, service level, stock level, as well as transportation and storage cost (Nyhuis and Wiendahl, 2013). Furthermore, environmental dynamics need to be taken into account including for instance traffic condition, delivery order changes, weather conditions, and availability of logistics resources.

The decision process requires large amounts of most recent information from distributed sources like other agents, traffic management systems and logistics providers. Therefore, the underlying information infrastructure needs to be capable of handling several thousands of decentralized information requests and offers at the same time. In this infrastructure, each information offer is represented by a specific *service*. Services can be provided by different organizations with different data source structures. Complex decisions require that several information services are requested and integrated.

2.3 Data Integration

Information services are based on data sources. From a technical point of view, significant data sources in logistics are data processing systems, data storage systems and sensors deployed in the field. The *data processing systems* are decision making agents, infrastructure management systems and other necessary systems to handle processes in logistics. *Data storage systems* are used to aggregate data in logistics. This includes for instance generic data bases, data warehouse systems, warehouse management systems and product lifecycle management systems. *Sensors* are typically used to collect field data. This data may contain measurements like temperature, light intensity and mechanical forces. The described data is allocated in different ways, for instance as a CSV file, text file or database. It can be accessed by using HTTP (hyper text transfer protocol), web services or industrial standards like EDIFACT or EANCOM. The data is transmitted as a stream or in a structured way by, for instance services, cloud applications, data gathering modules and data warehouses.

The concept of the *semantic mediator* developed to fetch data on demand based on the mentioned virtual data integration approach is used to retrieve data from sensors and data storage systems (Hribernik et al., 2010). This concept abrogates the persistence of the data from each data source in one huge data warehouse. The implementation of the virtual data integration concept retrieves only the needed data on demand. The binding module to resolve a query is implemented by a wrapper, depicted in Figure 1.

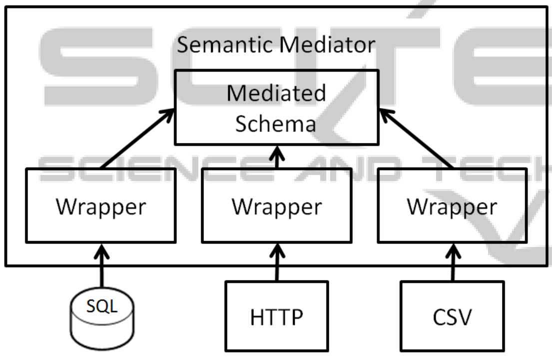

Figure 1: Integration module concept (semantic mediator).

The wrapper contains the communication interface between the data sources and a semantic mediator. Nowadays, the wrapper modules have to be adapted for new data sources manually. The mediated schema remains untouched by this adaption. The wrapper modules abstract the data sources and all users query the needed information over the wrapper. Here, the data from the particular data sources will be transformed into a global representation. The data sources are represented in the figure by SQL, HTTP and CSV modules.

The following information in the data integration domain need to be implemented manually: (1) the access method; (2) the sequencing of the data access and exchange; (3) the adaption to the structure of the data sources. Related to the seamless integration of information service in ubiquitous logistics, there is a high demand for the automated handling in the mentioned three points. Otherwise, the dynamic integration of, for instance logistics resources (and their related agents), is too time and cost intensive.

3 APPROACH

The technical approach of the proposed solution aims for seamless (plug & play) integration of data from different sources, in order to facilitate a collaborative service infrastructure in urban logistics. For this purpose, automated binding of heterogeneous data sources that leaves only a few activities up to the user is targeted in this paper. The technical foundation of the approach is explained in the next section, followed by a guiding example consisting of a small situation.

3.1 Technical Foundation

In order to realize an automated binding of different data sources, each source is able to describe itself. Key information concerns the authentication, sequence and structural characteristics of a data source. Each of these three descriptors is explained briefly in the following:

- **Authentication** – concerned with the security aspects of the access process of the particular service. The information ensures subsequent access authentication to eligible machines, services and persons.
  The authentication is typically based on username and password. More sophisticated methods are also possible. Moreover, the protocol for the authentication can differ from the essential data exchange protocol. It can happen in one or more steps.
- **Sequence** – typically, available data exchange processes are conducted in multiple steps. Up to now, implemented approaches don't consider information flows in more than one step. Especially the data access over web services proceeds during several steps. Moreover, the most data accessing procedures happen in one session with a recurrent sequential pattern of "data access" and "data processing". This pattern is common in authenticated sessions in which the subsequent data query has to carry the secure token.
- **Data structure** – describes what information and what kind of data model the data source uses. Furthermore, it contains information how certain integration problems related to the data structure can be solved. The data structure problems that need to be solve are: (a) different names for attributes with the same meaning; (b) different data representation (describes how data is conceived, manipulated and recorded); (c) use of different data model; (d) data sources cover

different attributes.

The data sources send the information about their authentication process, sequencing information and the data structure information to the virtual data integration module (semantic mediator) described in section 2.3. The authentication and data structure information relies on ontology models, located in the mediated schema, describing the needed information semantically. Ontologies lack the ability to describe sequencing. According to this fact, the description of the sequencing information is modelled by means of sequence diagrams which are part of the Unified Modelling Language (UML).

3.2 Guiding Example

The following example (see Figure 2) will be used to explain how the integration of data might work in the ubiquitous logistics concept.

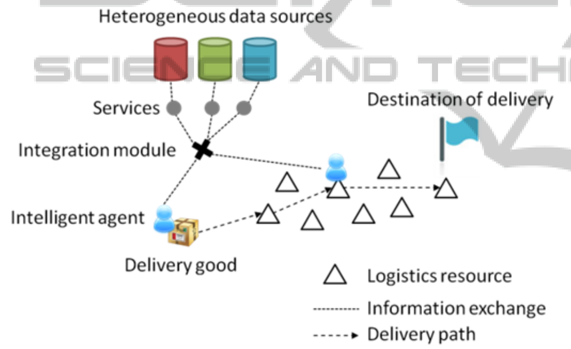

Figure 2: Illustration of the guiding example for data integration in ubiquitous logistics.

A hypothetical stream of daily commuters (logistics resources) will be exploited to transport small sized goods within a city. In order to keep the delivery time and cost low, delivery paths (routes) are decided by an intelligent. The agent utilizes based the information extracted from heterogeneous data sources. These sources concern for instance weather and traffic data from the field (sensor data). In addition, information about the delivery order needs to be taken into account. These information concern for instance the delivery destination (address), expected delivery day and pricing information. Each commuter's agent offers a service for its location and delivery status. Due to the underlying agent-based network in ubiquitous logistics, each parcel's agent has to integrate the distributed information for decision-making.

The necessary data exchange process for the decision making happens through the proposed approach. According the described situation the following data integration process flow is conceivable:

1. An intelligent agent needs additional traffic information because a scheduled delivery route collapsed. This might happen, for instance if a commuter leaves her daily travel route and another logistics resource has to complete the delivery.
2. The intelligent agent sends a request for additional routing information. The integration module (e.g. semantic mediator) looks up for the particular service(s) which can deliver the requested information from a data source.
3. The integration module asks for the particular authentication data and sequence models the intelligent agent can use. After that the authentication process between the requested service and the intelligent agent proceeds.
4. The next step is the exchange of the existing data structure model and the sequencing model for the data exchange. After that, the data exchange process proceeds.
5. The final logout process is part of the authentication process. The necessary information for this step has been exchanged in the third step.

According to this brief example the data from different sources can be integrated by the intelligent agent automatically. The agent can request the needed information services in order to manage the delivery of the parcel. In case an additional service provider (and the related data source) becomes available, the new wrapper for the data source does not need to be implemented manually but receives relevant information from the data sources.

4 CONCLUSIONS

This paper presents an approach allowing intelligent agents within an urban logistics scenario to integrate heterogeneous information services and their related data automatically. The paper starts with a brief overview of autonomous and a future urban logistics concept, as well as an overview of data integration. In the following, the technical foundation of the approach is outlined and explained through an example. The example represents a typical situation potentially occurring in ubiquitous logistics.

Benefit of the proposed approach is the reduction of time and cost for manual adaption of data integration tools. Additionally, it allows the integration of data for distributed agents, reducing the need for maintaining local data bases. This will become especially useful in the mentioned concept for ubiquitous logistics that is grounded on agent-based decision making based on numerous distributed data sources. Dynamically changing sources, especially related to logistics resources, can be seamlessly integrated through the introduced approach.

ACKNOWLEDGEMENTS

The paper is based on research that is done in the research project “CyProS”, funded by the German Federal Ministry of Education and Research (BMBF) within the Framework Concept ”Research for Tomorrow’s Production” (fund number 02PJ2461).

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