Cargo’s Digital Shadow
A blueprint to enable a cargo centric information architecture

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1. INTRODUCTION
Globalization and social pressure – around for example carbon reduction – forces companies increasingly to collaborate and interact with other companies to gain competitive advantage (Reeves & Deimler 2011). In supply chains, we see the emergence of competing supply chains, and organizing supply chain management. As Lambert (Lambert & Cooper 2000) states: “SCM represents one of the most significant paradigm shifts of modern business management by recognizing that individual businesses no longer compete as solely autonomous entities, but rather as supply chains (consisting of individual businesses, working together).” As such, collaboration becomes part of the company’s core strategy (Cruissen 2006). In parallel, information technology and systems have been, and still are, developing at a fast pace – think about examples such as the Internet-of-Things (Chui e.a. 2010), (Katsma e.a. 2011) and the possibilities and challenges of Big Data (MCKinsey Global Institute 2011).

(Bold & Olsson 2005) identify a long list of challenges and shortcomings with respect to supply chains. Especially waiting time, order changes, and order reception are identified as key issues for improvement. Largest savings can be achieved in the “during transport” phase. Major, more macro-level, challenges to the sector are legislation and regulations, and the troubles LSPs have with IT developments and implementations (in-house, and in the network) (Verwaal & Bedrijfskunde 2005).

Big challenges lie ahead in constructing information systems to support for these increasingly dynamic and agile supply chains. In this paper we introduce an information architecture focusing on cargo centricity to enable flexible interoperability and collaboration between entities across supply chains: the digital shadow. The architectural blueprint is supported by a real-life case study that was performed and evaluated; an application in the railway domain. The paper concludes with a the lessons learned and thoughts on follow up work.

2. METHODOLOGY
The research presented in this paper combines several research methodologies. The paper starts with a brief literature review on the application of multi-agent systems in the inter-organisational supply chain domain. This is followed by design science research (DSR) based on among others (Hevner e.a. 2004). As information systems are constructed from the sum of technology, organizations, and the interaction of people, there is a need for iterative design, as its environment is both complex and uncertain. Part of the design process was a first prototype that was tested and evaluated in a real life case setting for which we followed the case study approach by Yin (Yin 1981). The case, which was executed with one railway operator, operating in different countries (i.e. cross border railway activities), is discussed in the latter sections of the paper.

3. FROM MAS TO DIGITAL SHADOWS
3.1 Multi agent systems
Over the past two-and-a-half decades researchers have been working on a different type of information system architecture, namely multi-agent systems (MAS) (Wooldridge & N. R. Jennings 1995). Different than centralised information systems, such as ERP, MAS consists of many autonomously interacting agents. These interacting agents are small software programs that have a certain level of intelligence and individual behaviour (Schleiffer 2005). Communication and coordination (between agents) are the essential elements in such systems.

The supply chain domain is an interesting candidate for the application of multi-agent systems (Fischer e.a. 1996), (Lack e.a. 2004), (Davidsson e.a. 2005), (Moyaux e.a. 2006). The inter-organisational nature of this domain makes agents logical candidates to meet the heavy interdependence between chain partners which troubles the implementation and utilisation of centralised systems. Fischer et al. (1996) show that MAS have the potential to perform similar to traditional centralised (OR) mechanisms, while providing fundamental advantages such as increased flexibility, and real-time adaptive capabilities. Nevertheless, MAS have not been widely adopted in industry yet (Caridi & Cavaleri 2004), (J. M. Moonen 2009). Chmiel (2005), and Nwana & Nlumu (1999) conclude that most of the current multi-agent system research is far from realistic because its setting are often oversimplified, and designs generally only include a very limited number of agents. They plead to researchers to “start designing and implementing large software systems, consisting of hundreds of agents, and study their behaviour”.

The important characteristics of a multi-agent system are: (1) Agents need each other for completeness of information and
problem solving; (2) No global control system; (3) Data is
decentralised; and (4) Asynchronous computation (Rudowsky
2004), (Caridi & Cavalieri 2004), (Moyaux e.a. 2007) add: (5)
Modularity; (6) The possibility to embed multi-objective
functions; and (7) The fact that design can be a step wise
process, as additional benefits of MAS.

Agent communication is a field of study situated at the
crossroads of linguistics, cognitive science, artificial
intelligence, formal logic, and computer science. The field of
communication is dominated by both language semantics and
dialogue protocols. Language semantics refer to the meaning
that is expressed in a language or code. A dialogue protocol,
specifies a set of rules that regulate the dialogue between agents
(Endriss e.a. 2003). Coordination among agents in a multi-agent
system is a critically important process to ensure that the system
acts in a coherent manner (Nwana e.a. 1996). For an overview of
developments in coordination schemes, we refer to (Durfee e.a.
1989), (N. R. Jennings e.a. 1998) and (Caridi & Cavalieri
2004). Agents in a multi-agent system coordinate with each other
in order to come up with a solution to the full problem
(Lesser & Corkill 1987).

MAS has roots in computer science with a solution focus on
“coordination through communication” more than on the best
possible algorithms.

3.2 Cargo Centric approach

An agent on every box is an interesting thought to go from
tracking &tracing to sensing &pacing (J. M. Moonen 2009),
which could help in constructing dynamic supply chains.

Do no longer try to control flows of goods from above, through
centralized information systems that have the perception of
knowing what is happening in the supply chain, but put
intelligence in the flow itself, even better: start thinking about
an internet-of-things of intelligent goods.

The cargo (best) knows its destination, its current environment,
its content, et cetera. Why consult a centralized monolithic
system to acquire information regarding a particular container
or pallet while you could also ask the container or pallet
directly? Think about the possibilities this unleashes to create
novel supply chain applications, such as synchronomodality: let
the container itself find its way to its destination, by directly
consulting the different modalities that make it possible to reach
the customer’s destination. Depending upon time, capacities,
and restrictions transport might take different routes (with
different transit times, emissions and cost involved). Also last
minute changes, such as a customer in immediate need of a
container, moving the load forward two days can be facilitated.

If we envision this future, that is what we refer to as cargo
centric information systems. Cargo centricity, directly in line
with the multi agent system designs as discussed above (FP7
EU EURIDICE z.d.).

A related issue which is, to our best knowledge, little addressed
in literature is the question how to operationalize these MAS-
cargo centric concepts in real world settings with challenges
such as being off-line.

For any supply chain application this is very relevant, as cargo
travelling the world, it is likely to have limited network
coverage during large parts of the journey. The cargo centric
agents require communication networks to interact with other
agents. Such communication networks tend to be unavailable
during ocean shipping, while airborne, and also during parts of
inland shipping through modalities such as truck, rail and barge.
The latter caused by a limited reach of transmitters due to metal

environments and movements outside of areas with dense
population and network coverage.

Therefore we recognized the need for a representation of the
physical object in the virtual world where information can be
accessed even if there is temporary no communication with the
object itself. We call this representation a digital shadow,
implemented as a software agent.

3.3 Digital shadows

The term “Digital Shadow” is a metaphor for digital information
related to a thing or being, actively collected, enriched and
guarded on behalf of that entity, available from a single access
point (EURIDICE-1). By definition, the digital shadow fits
perfectly with the “Internet of Things” concept (Atzori e.a.
2010).

The digital shadow provides a digital presence for a thing or
being and collaboration among them. The primary purpose is to
increase the utilization and efficiency of physical resources for
a more sustainable world. As such, the ‘digital shadow’ is a
representation of a real-world object, palette or even an entire
truck load. It reflects their individual shape, history, current and
expected future status.

A digital shadow is a software agent that collects, stores, en-
riched and shares the information like a personal assistant of
the entity it represents. These shadows are first class citizens of
the “Cloud”.

From a fundamental point of view, digital shadows are “entity
centric“, not bounded to a single software process but intended
to be updated by several participating and authorized services
during its lifetime.

Figure 1 gives an example of a digital shadow and the real
physical world. Like a shadow in the real world, the digital
shadow represents a thing or being in the virtual world. Besides
monitoring its real world (physical) counterpart it can also act
as a virtual version of a human personal assistant to serve in
the interest of the entity. A digital shadow is an agent in
cyberspace, not residing on the physical entity itself.

From a technical point of view, the digital shadow is a semantic
communication framework. The information stored in a single
electronic register and described with use of a knowledge base
containing definitions of concepts and relations. Some of these
corresponds represent conditions and rules. Actions are performed
by fixed but small set of hard-coded basic functions as part of
the digital shadow access point.
Digital shadows are event driven and the rules stored in its knowledge base define the response on new information aka digital shadow events. These events are either being disposed or remembered as immutable facts just like the concepts in the knowledge base. This means that all information remains available during the life cycle of a digital shadow. Depending on the extensiveness of the used knowledge base, the actions of a digital shadow are more or less based on understanding instead of spelling out each step. This allows users to instruct digital shadows without the need for translation of functional requirements into a technical programming language. The actions of a digital shadow are limited to a combination of the implemented functions. For sake of simplicity, extensions of functions is not supported as a design decision. Additional functions should be implemented as a higher level framework on top of the digital shadow framework. Each shadow represents exactly one entity and is implemented by one software agent. Since these software agents make use of functional descriptions and instructions stored in a knowledge base, they are referred as semantic software agents.

The digital shadows live in a semantic multi-agent environment, also known as the digital habitat. This environment is managed by a supervising semantic agent which can be instructed and configured in the same functional and flexible way as its inhabitants, the digital shadows. The main tasks of the supervising agent is to handle the access control for the habitat as a gatekeeper, to control a common knowledge base and to control the lifecycle for the inhabitants, the software agents.

The main difference with traditional information systems (process and organisation oriented approaches) is the entity centric approach. The paper describes in detail the multi-agent system approach and the connection with the current legacy systems. The framework offers a secure, scalable and distributed solution for cross chain collaboration using an inter-organisational system.

The digital shadow was originally created during the EURIDICE\(^1\) project to provide an easy way to connect and interact with goods to optimize the supply chain.

### 3.4 Semantic model and knowledge base

In analogy with the human brain, a digital shadow has three types of memory: long term or semantic memory, a periodic memory containing events in chronologic order and a short term memory.

The semantic memory contains information that is not entity specific. In nature, the selection of semantic information is part of the human learning process but not expected nor intended as objective for the development of digital shadows in the near future.

Organizations often adopt and implement different technological solutions to achieve their specific goals. However, these organizations also share common goals and need to communicate with each other in order to synchronize their efforts. Therefore, there is a need for semantic interoperability among organizations with heterogeneous information systems in order to facilitate the communication, understanding and exchange of resources and information.

A first step towards semantic interoperability consists of developing a semantic model that describes the core elements used in the logistics domain. This model should provide a common understanding for a large amount of actors participating in global logistic networks. In other words, a semantic model shall enable parties to interpret the meaning of the exchanged information across business domains.

In our case a semantic model is a conceptual data model to describe the relevant business objects and their interactions that enables parties to interpret the meaning (semantics) of the exchanged information.

A semantic model describes business objects and their relations but doesn’t contain information about individual instances. For example, a truck will be describes in terms of its characteristics with attributes like the license plate for identification and a position to specify its movements. The semantic model will not contain license plates nor real GNNS positions of trucks but will describe how a position is expressed for a specific business process or business domain.

In iCargo (iCargo z.d.) a semantic model and knowledge base are synonyms but used for different occasions. The term semantic model will be used in a functional context to define a common understanding of the business processes while the term knowledge base will be used in a technical context referring to an instance of a specific version of a semantic model compiled for a specific business application.

### 3.5 Digital shadow event

Information that is exchanged between the digital shadows and (internal) software components is based on a generic and uniform information structure called the digital shadow event. New information enters the digital shadow as a fact which has at least the following attributes:

- **Subject**, a reference to the entity most likely the identification code;
- **Source**, a reference to the origin of the information (originator of the incoming received message);
- **Content**, a reference to the type of information;
- **Time**, the timestamp that is applicable for the information and is not the time that the information has been received;
- **State**, a reference to a business process state;
- **Place**, a reference to a relative or absolute location;
- **Value**, the information itself which can be a single element or a complex data structure. The content attribute should give already a clue how to process this value.

These attributes were proposed by the EURIDICE project and derived from the Event messages of EPCIS\(^2\).

The authentication of the source/originator of the new information will first be verified. Only known and authenticated sources are accepted and will put the received fact into the cache which is equivalent of our short term memory.

The combination subject, source, content is used to determine how to process the received information and to move all valid facts from the cache into the periodic memory in chronological order of occurrence based on the time attribute. Facts can be received asynchronously and therefore the sequence of receiving information can differ from the actual occurrences of the facts. The periodic memory builds a history rather than a logbook. The place attribute relates a fact to a geographical location but to avoid duplication of information, the fact is not stored in a spatial memory. The trail of a digital shadow can easily be deduced from the period memory.

\(^1\) http://www.euridice-project.eu/

\(^2\) http://www.gs1.org/gsmp/kc/epcglobal/epcis
4. CASE STUDY: RAIL TRANSPORT

4.1 Setting the case

A prototype was build to address the inter-organisational problem mentioned earlier. A semantic model was used to overcome the differences in terminology and to combine the information from multiple sources. The rail transport case required an individual scheduling and monitoring of wagons which made this case a good candidate for using software agents. Therefore we base the prototype on a multi-agent system (N. Jennings 1999). Semantic software agents were deployed for communication across business domains. Two out of a total of 200 railway wagons were equipped with a GPS device to report its position via GPRS-based mobile communication every hour. Later this was brought down to twice a day to be more energy efficient and to reduce the costs of communication. The prototype was a federation of systems fully distributed by design without the need of a central system or organization. Using semantics for the description of business objects and business rules for their operations enabled a functional configuration of the system instead of a hard-code implementation of all the required parameters and functions.

The objective of the Intermodal Operator pilot was the investigation of potential improvement in efficiency and utilisation of railway wagons of the intermodal operator SeaRail. A pilot application has been developed and used to enable efficient planning, monitoring and management of intermodal operations. Continuous real-time access to all relevant transportation information is a key feature of the system.

4.2 Objectives

The objectives were achieved through:

1. Facilitation of an automated wagon selection proposal to optimise the utilisation rates;
2. Automated alerting and event information about the wagon situation;
3. Automated calculation of utilisation rates. The goal is to monitor wagon utilization based on the load-factor in order to have necessary data for decision-making to, e.g. increase the turnaround of the wagons.

The Intermodal Transport pilot used a wagon-centric-approach to organise the data, instead of the “cargo” centric one. Technically there is only a semantic difference between both approaches. Therefore a more generic “entity-centric approach is being used in the succeeding iCargo project. In fact, entities can also be “abstract objects” like a transport order.

A request for transport from the paper factory was the starting point of the process. A coordinator had to manually update the current status and location of the wagons before he could assign and allocate the wagons to an order and the requested destination. During transport the acceleration was being measured and a notification was sent when a shock exceeded 2.4 G. Due to new legislation in Finland, Intermodal Operators are required to register the kilometre usage per axle. Since axles need to be changed per wagon when entering or leaving Finland due to different track sizes, the distance travelled by wagon is not the same as the axles.

4.3 Implementation

The Intermodal Transport pilot was depending on cooperation of multiple systems from different business domains. The yellow blocks in figure 3 represent the initial pilot specific implementations. The Smart Gateway in the middle collected all the information with use of semantic software agents. Later a digital habitat (blue in figure 3) has been added to experiment with a semantic supervising agent to create a more flexible multi-agent environment.

Two wagons were equipped with NavMaster devices from Eureka AG to determine their GPS positions every hour. One wagon was equipped with a G-shock sensor and the other one has an axle counter to register the mileages of axles. A ferry was used for the transport of wagons between Finland and Sweden. The position of the ferry was collected via Marine Traffic based on the Automatic Identification System (AIS). Information from the RailTrace system of the Finnish Railway was used to trace the wagons without a device in Finland. Based on an automatic and up-to-date overview of the available (empty or becoming empty) wagons in Finland, an automated wagon selection proposal was generated by a Cargo Intelligence service; designed, implemented and provided by the Jožef Stefan Institute (JSI) in Slovenia.

The dotted lines (interfaces) were outside the scope of the original project and implemented by manually uploading the required information. For example the information from the ERP system has been substracted with queries as spreadsheets and imported manually into the system. Information about the wagons handled by Green Cargo could not be extracted automatically without significant development effort from GreenCargo who was not involved in the EURIDICE project.

The user interaction was primary via a web-browser. A more detailed description of the technical infrastructure can be found in D24.2 – Pilot Application prototype and D11.3 (FP7 EU EURIDICE z.d.).

Due to the prototyping nature of the pilot, only a few sensors could be used in the field. Therefore the pilot application had to be used in parallel to the daily business, which caused the overall operational handling to basically remain the same. As a consequence no actual business improvements could be measured for the overall business. Nevertheless clear differences between the “as-is” and “to-be” situation were measured.

3 http://www.euridice-project.eu/index.php/web/pubdocs/58

Figure 2 Intermodal Transport Shadows
4.4 Pilot realisation & results

The pilot application demonstrated an increased supply chain visibility by providing more information in real time. Also daily manual effort was reduced which enabled the intermodal coordinator to focus on optimising the use of wagons instead of acquiring information manually from scattered sources.

The estimated time of arrival and deviations on schedules were automatically available to optimise the planning process and the quality of service.

The impact of the research had three practical contributions:
- An overview of available wagons and automatic scheduling suggestions based on the order coming from legacy system and wagon status, condition, position and prediction of estimated time of arrival;
- Automated alerting and event information about the wagon situation. System follow-up wagon movement and situation and created notification or alert if the conditions inside the wagon were not within the predefined limits. In this case the acceleration (G-shocks) were measured
- Automated calculation of utilisation rates for decision-making purposes.

The digital shadow concepts were used for wagons, the ferry, the cargo and the axles.

5. DISCUSSION

5.1 Concluding remarks

This paper introduced the digital shadow concept, a design metaphor to construct cargo centric information systems, utilizing multi-agent systems that can handle the offline character of many logistical applications – hence ocean shipping, and rural environments with little network connectivity. Digital shadows can help construct a new generation of systems, unleashing the full potential of an Internet-of-Things, thinking bottom-up. This makes whole new applications possible.

The paper also reports on a first pilot were the digital shadow concept is used in a railway setting in the Nordics. In this pilot, the use of digital shadow events have proven to simplify the processing and storage of information.

The use of semantic models are required to share information instead of data, across different business domains.

5.2 Lessons learned

The technical complexity can be bundled in a digital shadow and the functional complexity (the business logics) has been concentrated in a black-box called knowledge base.. The technical structure of such a knowledge base is not the problem but defining the content is the challenge. The theoretical top-down approach has not been successful in our case. Assisting tooling and domain expertise are prerequisite. During the case we used a more pragmatic bottom-up approach for constructing the semantic model. Starting with nothing and every time a new type of fact appeared a (human) engineer determined if and how the knowledge base needed to be extended. This kind of automated learning intelligence is not expected in the first generation of digital shadows nor for the near future.

Also the awareness that semantic software agents could also be used to facilitate abstract objects like a transport order and for managing a multi-agent environment (digital habitats), were valuable insights.

5.3 Future Work

The development of supporting tooling to build and maintain semantic models will continue in the iCargo project. But also the organisational aspects of constructing common semantic models for stakeholders in the same supply chain need to be explored. To meet a high level of dynamism in logistics value chains (with ever changing relationships between parties), the dynamic configuration of business communities is expected with closed user groups. The purpose of these business communities is to exchange information more efficiently and effectively with each other by creating and using a common terminology, set of rules and business message protocols on how to cooperate with each other.
A community might be for example a group of organization operating in a particular port, a group of suppliers to a specific large shipper, or any other group of cooperating organizations. Most likely, an organization will be a member of multiple communities and will join and exit communities over time, as business conditions change. (eFreight 2012) This topic will also be further investigated within the iCargo project.

The first pilot was promising, but limited to a small number of agents to proof the feasibility of combining semantics and software agents. For large scale implementations, performance will definitely become a practical constrain. Processing a knowledge base stored as an ontology consumes a lot of computational resources and deterministic behaviour is not easy to verify. Therefore, Dalmolen, Stoter and Cornelisse (ICAART 2011) have investigated the possibilities to compile ontologies into finite state transition tables. Although it is still a challenge to compile a knowledge base automatically, the rise of functional programming languages like Scala and Haskell might come to the rescue here.

We think that semantic models as integral part of software agents can enable large scale implementations of multi-agent systems. Semantic software agents can make it easier to manage software agents as described in the concept of digital habits.

Within Logica, Digital Shadows has become part of our Intelligent & Sustainable Enterprise vision. A vision about a decentralised ICT infrastructure that allows real world objects, new planning services including CO2 calculation capabilities and existing systems to co-exist and efficiently co-operate at an affordable cost, not limited to logistics but for all kind of business. For Logica, this is the next generation of system integration.

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