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Decentralized intelligence in freight transport—A critical review

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ABSTRACT

The purpose of this paper is to provide a research outlook on the concept of decentralized freight intelligence, i.e. autonomous freight making localized routing decisions. A review of research literature on decentralized intelligence in freight transport serves as the foundation of the analysis. The analysis reveals a scarcity of scientific evidence to suggest a successful introduction of decentralized freight intelligence. Among numerous conceptual findings, the analysis reveals a dearth of research on the clear and present challenges of introducing and adopting decentralized freight concepts in contemporary multi organizational open freight systems. For practitioners this paper provides useful input on future ICT development in the transport field. In particular, due to the lack of guidance on adoption of decentralized freight, a focus on non-networked benefits of information technology is to be recommended. Given the large number of projects, papers and various initiatives related to decentralized freight intelligence, this paper, to the authors' best knowledge, provides a novel technology adoption perspective on decentralized freight intelligence research.

1. Introduction

From their experimental beginnings in the early 90s, the computerization of our material surroundings, or ubiquitous computing [1], has sprouted a wealth of venues for research into radical concepts in various industries [2]. This paper reviews one such concept within the freight industry.

In their quest for higher freight transport efficiency, many authorities and organisations pay increasing interest to Information Systems (IS), Information Communication Technology (ICT) and Intelligent Transport System (ITS) (e.g., [3,4]). An innovative concept that has received a lot of attention is the concept of decentralized intelligence in freight transport. Applying ICT with a higher degree of sophistication than what is currently the standard, is assumed to have large potential on environment and efficiency [5]. Indeed, as early as 2004, Scholz-Reiter et al. hypothesized that "...due to the dynamic and structural complexity of today's logistics systems and networks, central planning and control of logistic processes becomes increasingly difficult. Thus, decentralised and autonomous control of logistics processes is required ([25], p. 357)". Indeed, bold visions of a radically altered future of freight have been following; "In five years time most of the goods flowing through European freight corridors will be 'intelligent', i.e.: self-aware, context-aware and connected through a global telecommunication network to support a wide range of information services for logistic operators, industrial users and public authorities" [6]. This area of research has not passed unnoticed by industry. In a speech about future technology development Leif Johansson (chairman of Ericsson, former CEO of Volvo AB) stated that freight being capable of making decisions will enable higher fill rates and a more efficient freight transport system [7], and he is certainly not alone (see e.g. [8,9]).

Considering the trend of increasing ubiquity of information technology (IT) in transportation [10], is decentralized freight intelligence a preferred direction to increase efficiency in freight transport? By reviewing the research on decentralized freight intelligence, the aim of this paper is to provide a critical viewpoint on the potential of the concept as reported in the literature and to point to some critical areas for future scientific investigations.

We proceed with a definition of decentralized freight intelligence based on current literature and some delimitations. We then describe our research design and analysis of decentralized freight intelligence literature. Following, we discuss the apparent lack of research on decentralized freight intelligence adoption and conclude with some suggestions of research approaches and venues.

1.1. Definitions and delimitations

Over the years concepts related to decentralized freight systems have acquired an extensive nomenclature that includes *Intelligent*

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Cargo, Smart Freight, Intelligent Goods, self-controlling goods and others [11]. While most of them can be traced to e.g. Weiser, we will show some examples. According to the European Commission, Intelligent Cargo implies that "...goods become self-, context- and location-aware as well as connected to a wide range of information services ([5], p. 8)." Intelligent Cargo extends the concept of agent-based autonomous control, encompassing intelligence, i.e., "Cargo is able to invoke services and start processes autonomously in response to predefined events [12]."

As an industrial application of pervasive computing, most research on decentralized freight intelligence use the classifications of *intelligent products* brought forward by McFarlane et al. [13]. Lumsden and Stefansson ([14], p.7) and Meyer et al. [15] (the latter being an intelligent products paper) both use a list of features from McFarlane et al. [13], proposing the following generic characteristics:

- a unique identity;
- the capability of communicating with its environment;
- the storing of data about itself;
- a language to display its features, production requirements, etc.;
- directly participates in or makes decisions relevant to its own routing, etc.

The definitions mentioned above all share the idea of goods processing information and making decisions.[1] Hence an ICT solution using RFID and Barcode tags (simply storing an identity interpreted by an information system), might per definition be intelligent, but in isolation, the individual goods (e.g., shipments, boxes, etc.) are not intelligent. In this paper we will refer to goods without processing as "tagged goods". Solutions and concepts using trailers and/or containers with information processing capabilities [16,17] are likewise considered as intelligent systems with intelligent resources, but still with "tagged goods".

This paper focuses on efficiency aspects of decentralized intelligence in freight transport, i.e., societal, security and safety aspects are not addressed. Goods transport by road, rail, sea or air was in focus, i.e., local movement of goods within one facility (e.g., literature on Automated Guided Vehicles (AGVs)) was excluded.

We include virtual decentralized freight intelligence, e.g., freight making decisions with a local scope through an enabler (e.g., an on-board unit of a truck) in our definition of decentralized freight intelligence, whereas trucks and load-units (e.g., trailers and containers) containing sensors and carrying e.g., RFID-tagged goods [18], are per se not viewed as decentralized freight intelligence.

Concepts associated with decentralized freight intelligence are by no means synonymous to it. E.g., *Intelligent Cargo* is increasingly used to denote tagged goods with freight information services associated to it, i.e., a virtualization of LSP services and Smart Goods often refer only to RFID-tags [19]. As Intelligent Cargo frequently denotes "intelligent" systems using tagged goods rather than actual decentralized decision capabilities, the authors would like to strongly emphasize that this paper is solely intended to address decentralized freight intelligence in transport operations, e.g., goods with actual or virtual information processing capabilities.

The concept of *Intelligent products* have been addressed by several authors and evolved over the past decade (e.g., [18,20–22]). Early papers on the concept (e.g., [23]) encompass the idea of some degree of autonomous control [15]. In research described in e.g. Främling et al. [24] and Holmström et al. [17], prototypes and tests of business models have used RFID tags containing a numeric ID and in some cases other data and no decentralized decision-making on product level. In the roadmap for future research by Holmström et al. [18] as well as in other recent publications on intelligent products, the researchers do recommend using agent technology for linking tracking applications but highlight that the major challenge for intelligent products lie in solving the interoperability standard issues. The challenge of multiple information systems needing to communicate to enable advanced applications of Intelligent products was further highlighted by, e.g., Främling et al. [22].

[1] Actual intelligence as what is sought by e.g. artificial intelligence clearly lies beyond the scope of this terminology. However, we will utilize terminology that exists in our target literature: intelligent cargo.

2. Research design

The introduction outlined several labels used over the past decade to denote conceptual systems using decentralized freight intelligence. To find relevant literature, the authors used Google scholar and extensive discussions with some 30 researchers and practitioners from both information systems and logistics and transport sciences. In the literature review, the authors extensively applied the ancestry approach to existing literature sources, in particular to papers referenced extensively (e.g., [25]). The focus of the literature review was on selecting peer-reviewed literature (i.e., journal articles, edited book sections and peer-reviewed conference proceedings). A minor number of other publications were included, due to being either extensively referenced, used as evidence for the feasibility of decentralized freight or for giving a more detailed description of the concept and its design. Decentralized freight capabilities have received attention in several countries and the literature review revealed publications written in English, German and Swedish. We found a number of phrasings specifically addressing decentralized freight capabilities:

- *Autonomous [Logistics/Transport] Processes* [25–33].
- *Intelligent Cargo* [8,9,21,34].
- Intelligent Freight Objects [35].
- *Intelligent Goods* [36–40].
- Intelligent Parcel [31].
- *Selbststeuernder logistischer Objekte* [41–44].
- *Smart Goods* [11,45–47].
- *Smart Freight* [14,48–55].
- *Smart Parts* [56,57].

The analysed decentralized freight intelligence papers are listed in Appendix A. In addition, all the analysed papers on decentralized freight intelligence are part of the list of references. The papers were classified based on their research approach.

The authors of this paper are coming from the supply chain management and information systems (IS) disciplines respectively. Both have been heavily involved in and financed by research projects on decentralized freight intelligence.

3. Literature review

Reviewing the literature, we found six variants of methodological approaches; non-empirical conceptual, numerical experiment, prototype study, case based conceptual, case/interview based conceptual, and interview based conceptual quantitative. The distribution of research approaches and outlets are shown in Table 1. Conceptual research is clearly dominant and empirical approaches are, in particular those employing actual tests or prototyping, though present, less commonly employed.

The remainder of this section is structured as follows. First we give an outline of the literature on decentralized freight intelligence. Since the focus of this paper is on the feasibility of the concept, particular attention is paid to the anticipated effects on