SCIENTIFIC PAPER

CYBER PHYSICAL SYSTEMS IN LOGISTICS
This paper on “Cyber physical systems in logistics” discusses the current requirements logistics has with regard to information and communication technologies as well as the potentials of cyber physical systems for the logistics sector in North-Rhine Westphalia.

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I. INITIAL SITUATION

The significance of the internet of things and cyber physical systems in logistics and for logistics

The immense significance of logistics for the German economy is undisputed today, particularly in the light of constantly increasing tendencies towards internationalization and the increasingly complex structures within production, markets and competition. Logistics has developed from being purely about transportation to now play a performance-defining role in global value added networks \(^1\). That means: the production industry is now following logistics – in contrast to the past when logistics followed the production industry’s lead.

In this context, the internet of things and cyber physical systems for logistics are of fundamental importance towards achieving the efficiency required of logistics for individual order processing within global value added networks and towards fulfilling key supply and waste disposal tasks for households, retail and production sites \(^2\).

MANAGING SOCIETY’S CHALLENGES

The central challenges facing society in the 21st century cannot be solved without using core logistics capabilities. In the EffizienzCluster Logistik Ruhr, initiated by Fraunhofer Institute for Material Flow and Logistics IML, logistics addresses the three central challenges which can be deduced from the analysis of the global conditions determining business and society today: protecting the environment and resources, supplying urban systems and preserving individuality. It is the objective of logistics to develop products and innovations to prepare society for changing conditions and to enable society to maintain individual lifestyles.
MANAGING LOGISTIC CHALLENGES

One of the biggest challenges is the growing complexity of logistics concerning the complexity inherent in structures, data and products as well as the complexities of networking and ecommerce. Globalization continues unabated; levels of networking are growing exponentially. The volume of logistics data is increasing by a factor of 1,000 per decade. The desire for individuality is increasing in line with the available possibilities: “batch size one” is already reality. The disproportionately high increase in complexity will cause instabilities in a logistical system that is not (yet) designed for the rapidly changing requirements. The more complex the systems become, the more logistics has to react with decentralization and self-organization.

LOGISTICS IN NORTH-RHINE WESTPHALIA AS A PROBLEM SOLVER

The internet of things and cyber physical systems for logistics play a central role in dealing with the challenges facing both society and logistics. According to the modern perception of logistics, the two are inextricably linked.

Logistics and the internet of things It was logistics that developed the vision of the internet of things more than a decade ago and – under the umbrella of the Fraunhofer Gesellschaft and the Fraunhofer Institute for Material Flow and Logistics IML – made significant contributions towards realizing this vision.

To put it briefly, logistics sees the internet of things as things controlling themselves: intelligent devices should learn to think and goods should organize their own route to the destinations all by themselves. When logistics first expressed this vision it was hardly to be expected that the principle of self-control would lead to a fundamental reorientation of logistics and to a revolution in business.
The statement “The 20th century mobilized the people, the 21st century is mobilizing things”\(^3\) gets to the heart of this development.

**Logistics and the 4th industrial revolution**

The internet of things has become a driver for the 4th industrial revolution which is currently on everybody’s lips as the future project industry 4.0. According to Prof. Dr. Henning Kagermann, president of the National Academy for Science and Engineering acatech, “Industry 4.0 enables batch sizes of one to be produced at the same cost as a mass product, and the requirement-oriented optimization of value adding processes in real time. Active, autonomous and self-organizing production units are replacing passive, plan-oriented production systems. The intelligent product actively supports the production process. Production becomes highly flexible, highly productive, resource-preserving and urban-compatible. The factory of the future will run at the pace of the people.”\(^4\)

**Logistics and cyber physical systems**

Cyber physical systems form the basis for the fourth industrial revolution: informational components (cyber) and mechanical or electronic and sensory components (physical) merge with each other to form an intelligent system, a cyber physical system, in short a CPS.
CPSs are more than an individual sensor application or an individual intelligent assistance system that helps people to perform specific activities (an embedded system). They stand for the networking of efficient intelligent embedded systems, mobile services and worldwide data sources to form complex entire systems.

CPSs use the internet as a business web, i.e. as a platform for business co-operations – with the objective of generating added value by means of new applications, new services and co-operations at the complex systems level.

The future of logistics is in the internet of things and in cyber physical systems

In recent years, logistics has developed into a high technology sector with corresponding national, but first and foremost, international opportunities for German suppliers and in particular, for companies from North-Rhine Westphalia. More than 21,600 logistics companies with 274,000 employees generate about 70 billion Euros per year in North-Rhine Westphalia. Including the logistics tasks performed within retail and industry, this sector employs about 600,000 people in this state alone.

Logistics research in North-Rhine Westphalia supports the industry with application-oriented projects: the Fraunhofer Institute for Material Flow and Logistics IML in Dortmund is the first address for all questions regarding comprehensive logistics and works within all the fields related to internal and external logistics. The internet of things is managed by Fraunhofer IML for the whole Fraunhofer Gesellschaft. 160 companies and twelve scientific institutions as well as numerous key players connected with this field are currently working on logistic solutions to face the challenges of the future in 30 projects and six associated projects in the “Leading Edge Cluster” (Spitzencluster). Most of the projects in the EffizienzCluster are ICT-driven.
LOGISTICS NEEDS ICT

The use of the most modern information and communication technologies (ICT) plays a significant role in logistics: you cannot handle today’s logistics with a calculator anymore. Information and communications technology became the trigger and guarantor for efficient solutions and processes. The internet of things and cyber physical systems are heralding another new era in logistics:

- **The Internet of Things** expresses a new form of control and organization for logistical systems based on individual, decentral and autonomous decision-making designed jointly by logistics and ICT.
- **Cyber physical systems** see the internet of things really taking shape. Connecting the virtual world of data with the physical world of goods requires an increasing merging of logistics and ICT competencies and the integration of ICT competencies in logistics.

LOGISTICS USES ICT

Logistics is one of the most innovative and important application industries for ICT and helps to pave the way for information and communication technologies. Intelligent ICT solutions enable logistics to take the lead in efficiency and innovation.

**More efficiency** Together with ICT, logistics in North-Rhine Westphalia wants to use the internet of things and cyber physical systems to make logistics more efficient. The application of ICT with regard to the internet of things and CPS will always be implemented according to the following assumptions:

- The application of ICT is to contribute significantly to change logistics processes and structures.
- The application of ICT is to contribute to reducing logistics costs.
- The application of ICT is to increase the design possibilities of logistics chains and distribution structures.
The application of ICT is to have direct and measurable positive effects.
The application of ICT is to improve the competitive strength of both Germany and North-Rhine Westphalia as logistics locations.5

More innovation  In 2011, Prof. Michael ten Hompel, managing director of the Fraunhofer IML, set the target that logistics companies invest one percent of their turnover in internal and external research and development. Because: with an increased financial contribution to research, companies not only extend their competitive advantages and promote the leading role of the logistics sector, but also simultaneously pay a substantial contribution to solving the future issues facing society. The internet of things and cyber physical systems are suited to inspire research activities by companies in logistics – in particular in cooperation with ICT companies.

Fraunhofer IML and EffizienzCluster Logistik Ruhr, are two organizations/institutions where these research activities have been given the appropriate space and appropriate level of significance.

5 Abstract on the research project “Effects of information and communication technologies for logistics processes and transport” on behalf of the Federal Ministry of Education and Research, Fraunhofer Institute for Material Flow and Logistics (FhG IML), Dortmund, Deutscher Speditions- und Logistikverband, DSLV (German forwarder and logistics association), July 2006.
II. FIELDS OF OPERATIONS AND KEY TOPIC
LOGISTICS DEVELOPS “SMART LOGISTICS” WITH ICT

The internet of things is increasingly developing miniaturized connected systems which result in efficient and reliable organizations for the worldwide goods flow of individual objects and their local distribution. Turning away from centrally controlled processes and steering towards decentralized structures with coordinated and also decentralized processes enables logistics to control increasingly bigger and more complex systems.

APPROACHES FOR SMART LOGISTICS

It is an important task for logistics to guarantee the functionality of globally established production and logistics networks (supply chains). The basis for that is the complete transparency of all material flows in the supply chain which, from now on, can be guaranteed in a new dimension by the internet of things and the cyber physical systems. Such transparency enables products to be traced and therefore leads to sustainability for all the participants in a supply chain – from the supplier of raw materials right through to the consumer.

Smart Reusable Transport Items, or smaRTI for short, are an example of one of the EffizienzCluster LogistikRuhr research projects in the consumer goods industry that is already well on its way to revolutionizing cross-industry and cross-company data and material flows between manufacturers, pallet service providers and the retail business by making use of intelligent load carriers.

In particular, cyber physical systems play an important role in intra-logistics: together with the TU Dortmund University, Fraunhofer IML has developed the intelligent container inBin which is capable of autonomously managing and controlling a complete order picking process. Within the EffizienzCluster LogistikRuhr Cellular Transport Systems research project, real warehouse operations are investigated and practiced in a specially equipped demonstration area in the Research Hall for Cellular Materials Handling (“Zellulare Fördertechnik” (ZFT)). In what is probably the most extensive experiment ever
carried out with artificial intelligence in logistics, 50 innovative autonomous transport vehicles move around between the shelves and the order picking workstations. By utilizing a multi-agent system and with the help of ant-algorithms, “swarm intelligence” is being transferred to intralogistics.

Where individual and business transport are concerned, the principle of the internet of things with cyber physical systems helps to connect all transport processes with the associated information. Thus, control alternatives can be identified and efficiently exploited at any time. The systems have to be combined with new resource-efficient transport technologies such as electro-mobile transportation in urban areas, in order to structure logistics and mobility more efficiently. Further approaches in this field are the shared use of transport and logistics infrastructures (e.g. transshipment areas, distribution transportation, goods transfer systems) by companies and service providers as well as new solutions for “last mile” distribution and goods transfer. Without these it will not be possible to handle the continuous growth of online business in line with acceptable levels of environmental pollution, particularly in cities and densely populated areas.

These considerations result in a plethora of new solutions which could be the impetus for companies in the logistics sector in North-Rhine Westphalia to achieve more through innovation and research.

INNOVATION CORRIDORS FOR INTENSIFIED COLLABORATION BETWEEN LOGISTICS AND ICT

Based on the EffizienzCluster LogistikRuhr key topics that serve as innovation corridors for tomorrow’s logistics, three specific fields of operation can be defined which help cyber physical systems to develop their potential: urban supply, goods transport and changeable logistics systems.
FIELD OF OPERATION: CPS IN URBAN SUPPLY

Urban systems contribute towards improving living conditions. They are driving forces and centers of productivity, yet simultaneously entail social, economic and ecological risks. Optimizing logistics can have a considerable impact here and, in turn, ICT can make an important contribution towards optimizing logistics.

Field of research

The basic idea for CPS in urban supply consists of the constant development of individual modules to form an intelligent urban supply network. This leads to the relevant supply service providers in one city using one shared logistics infrastructure. Such simple and flexible cooperation means goods flows can be bundled at any time. This development can extend so far that central decisions are not necessary anymore in individual cases. In fact, certain supply services can be connected with each other ad hoc in terms of the highest efficiency. This decision is made autonomously and decentrally.

In the same way that smart grids can work as intelligent electric power grids, a smart grid for urban supply can be understood to be the networking and control of intelligent suppliers, consumers and services in an urban infrastructure. This enables the partners connected in a network for urban supply to provide optimized bundled logistics services. The aim is to guarantee supply based on efficient and reliable system operations and the convergence of the end-customer’s different supply requirements. Convergent supply is understood to be the merging of day-to-day requirements (e.g. food, nursing care, cleaning, etc...).

The idea of smart grids for urban supply can make a considerable contribution to guaranteeing urban supply – also under tightening transport restrictions (traffic jams, city toll, prohibition on entry for delivery transports).
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FIELD OF OPERATION: CPS IN GOODS TRANSPORT

The demand for goods transport has been increasing steadily over the last few years. Transports exceed the capacity of the present traffic infrastructures. However, by using intelligent goods transport management, logistics makes a decisive contribution towards a sustainable improvement of the overall traffic situation. In particular, it is about using the existing infrastructures more efficiently – in both transport routes and logistic facilities. The focus is on the development of supporting software systems that put logisticians in a position to make the right decisions to achieve an acceptable use of resources.

Research requirement

Setting up a smart grid in an urban region means having to develop and implement widely distributed supply structures to create the infrastructure for a supply network for urban areas with which all supply requirements can be covered ad hoc and flexibly.

The intelligent inclusion of individual customers’ requests sent using mobile applications is a fundamental condition for recording the required times in real time.

To achieve this aim, research is required to develop concepts strictly according to the principles of service-oriented architectures in logistics. Furthermore, it is necessary to meet the demand for real-time-capabilities in logistic process configuration in order to achieve intelligent autonomous decisions. Merging individual applications in a smart grid for urban supply means there is more need for research and experimentation.
**Field of research** Means of transport and load carriers as CPS become intelligent logistics objects in goods transportation. At the very least, in future these will help to better prepare decisions for planning and controlling a process chain. This is done by automatically collecting, processing and transferring all the information relevant for logistics. But it is to be expected that these logistical objects will use this information together with information from similar objects in order to make decisions autonomously and locally. In simple cases this leads to reactions to disturbances, in more complex cases ongoing logistics chains are planned decentrally and dependent on desired target figures.

This means logistics objects recognize their environment and their own situation and develop their behavioral strategy on that basis. The exchange of information occurs decentrally via the latest near field communication processes. Parallel to this, CPS also contributes information to upstream cloud-based structures. Surrounding systems – themselves again to some extent CPS – in logistics facilities, factory premises and transshipment terminals, harbors or goods transport centers can make contact with the units. Thus, they can on the one hand support the processes of these logistics objects and, on the other hand, gather information to improve the processes in the logistics facility.

That also results in interactive information exchange between downstream transport systems and infrastructures (provision of information about transport flows, traffic situation, etc.). At the shipments’ place of origin and destinations, in particular, existing resources can only be used efficiently in future if there are cooperative structures and communication can take place between the logistic units and the surrounding systems. Limited space (traffic and transshipment areas) and time (pick-up and delivery times in industry, retail and final consumer) can thus be put to sensible use. Urban networks become balanced and are integrated in the logistics systems.
Research requirement ▶ Using CPS as a matter of course in goods transport is just getting started. Technologies have to be further developed and designed with regard to logistical utilization. There are numerous logistics companies in North-Rhine Westphalia such as the harbors, most of all Duisburg Harbor, important producers and retailers with their distribution centers and warehouses or logistics service providers, which, because of their strong economic development, ideally need new and more efficient means for processing their logistics. The potential users must be in a position to test and evaluate such possibilities step by step in order to extensively shift processes and facilities to full-scale utilization of CPS.

In practice it would be interesting to have a research project on autonomously controlling flows between the logistics park Westfalenhütte and logistics terminal Dortmund Harbor (perhaps with a similar parallel project at Duisburg Harbor)

▶ Cyber components: cloud-based environment for merging participants’ data, providing logistics-related services (booking logistics services, searching for partners/bundling, designing logistics chains) and as information back-up for the physical components
▶ Physical components: intelligent means of transport and load carriers for the decentral organization of the upstream processes (loading, bundling, preparatory transport)
▶ Cyber physical systems: automated design, processing and control of a limited part of a logistics chain

In connection with CPS in goods transport, fundamental questions first have to be solved in various areas. These include the handling of large amounts of data (big data), guarantees for data security (security), the standardization of enabling technologies and processes, the integration of human participants and the integration of other software elements as well as costs and energy efficiency.
FIELD OF OPERATION: CHANGEABLE LOGISTICS SYSTEMS

Change has always been a definitive feature of this world. Many areas of our life are subject to serious changes in ever shorter cycles – driven by increasing complexity and acceleration. There is hardly an area in business, science or society that is not affected by the challenges resulting from this change. They all share the fact that logistics plays an increasingly important role. In recent years it has proven to be the engine and pace-maker for sustainable and efficient design in business and society and its adaptability is the key for that. Optimizations in logistics are always based on new technologies and standards that create conditions and give impetus towards organizing processes more efficiently. The intelligence for controlling logistic processes is still based within central processors today, whereas in future it will move into the load carriers themselves. Uniform basis structures for informative mobile networking between infrastructure, material flow technology and goods are an essential condition for the adaptability of logistics systems.

Field of research ▶ One of the clear trends we can already see today which is pushing changes of value added systems forward is “cellular logistics”. Logistics systems based on cellular logistics become adaptable, flexible and needs-oriented. Decentrally-organized swarms of vehicles and networks adapt to the constant changes in their environments like a living organism. So, cellular logistics takes the long-term demand for flexibility and changeability into account, particularly in intralogistics.
In order to bring logistics systems “to life”, a whole range of different developments are necessary: physical and information services have to be available on demand according to the principle of everything-as-a-service. That makes it possible to enter into business relations on demand, adjust and close them again without having high transaction costs. It is necessary to develop economically sustainable solutions, for example for contract logistics that achieve solutions with a high degree of automation by using cellular transport systems despite contract periods becoming shorter. The enablers for this include innovative sensor concepts that make it possible to achieve three-dimensional area monitoring and predicative algorithms that enable efficient collaboration between various transport entities.

**Research requirement** The internet of things and services will only become reality if we enable the machines to achieve autonomous decision-making and communication and at the same time create people-oriented, ergonomic technologies. Here, logistics has to take on a decisive, active role. This is the only way to achieve “enterprise integration” and future-oriented development of the value added system. Following on from the mobilization of people, this century will continue with the mobilization of and cooperation between machines. To achieve this, technological developments such as autonomous networked vehicles and intelligent load carriers will have to become less expensive, more robust and more efficient. It will have to be possible to construct, start up, extend and dismantle transshipment hubs quickly and simply. So, all individual logistical systems will have to be equipped with standardized interfaces (software and hardware) and be adaptable.
Cloud computing – in other words the virtualization of hardware and software – will have a much bigger impact in logistics than outsourcing IT services. It will change the way we control and organize our systems.

**Research area** The advantages of cloud computing are obvious: compared to conventional systems they help to save costs by doing away with one’s own software and hardware resources and outsourcing them to a specialized provider. Thanks to the high flexibility of scalable clouds, sufficient processing power can be provided even when there is peak demand. There are particularly large potentials for saving within logistics where all systems continuously have to offer maximum availability even when often only a fraction of it is really required. Performance could be increased considerably if the required IT was provided by a specialized company.

**Research requirement** This means that cloud computing provides a substantial basis for the implementation of cyber physical systems. There is a need for research in application areas for production, logistics and retail. Before cloud computing is widely implemented, various challenges have to be solved. These challenges focus mainly on the areas of

- standardization and modelling as well as
- information and data security

This describes the specific needs for research.
IT services are being offered and made usable on the basis of public and private market places, so called Public and Private Malls. Standardizing services, communication objects and methods for modelling enable free exchange and competition between different providers in the market place. Furthermore, new processes have to be developed for IT security in connection with the logistics services being provided. Data security aspects are also very important particularly in distributed supply chains that go beyond company boundaries.

The Fraunhofer Innovation Cluster “Cloud Computing for Logistics – Logistics Mall“ has already developed concepts and a commercially implemented platform for cloud-based market places and made that available to the industry. Logistics Mall has been developed by the two institutes, Fraunhofer IML and Fraunhofer ISST, and forms the basis for numerous EffizienzCluster LogistikRuhr projects such as the central trading and implementation center for logistics software and logistics services in the internet. This solution “made in NRW” stands for a new dimension of flexibility and efficiency in logistics and sets new international standards. Experts speak of a revolution in logistics IT. This work forms the basis for continuing standardization and modelling and for focusing on raising security standards.