The Cloud – Logistics for the Future?

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1. Introduction

In 2010, an interdisciplinary working group of the German Logistics Association (BVL) submitted a paper to position logistics as an academic discipline. Based on this positioning and motivated by the fruitful interdisciplinary collaboration, the idea emerged to form another working group[2] "Future Topics of Logistics" with the objective to discuss current and future scientific and business related challenges for logistics as well as possible starting points for their accomplishment. Above all, the question pertaining to whether the existing principles which led to a successful development of logistics for the last three decades continuously apply or whether other innovative and possibly direction giving logistics concepts should be paid attention to in research and practice in the light of current and observable future challenges.

The following paper is based on the results of this working group, which also initiated the focus "Coordinated Autonomous Logistics Systems" of the 6th International Scientific Symposium on Logistics of the German Logistics Association (BVL) in Hamburg, June 13-14, 2012. The paper provides a point of reference and starting point to initiate the necessary changes in both the scientific and business world in order to cope with current and future logistics challenges. The paper is organized as follows: Section 2 structures current and future challenges for logistics in accordance with their (relative) similarity or novelty compared to hitherto general conditions for logistics. In section 3, a new concept denoted as "Cloud Logistics" is introduced and conceptualized. It follows the principal development towards increasingly cooperative, distributed, autonomous logistics systems. The concept adopts the principles underlying Cloud Computing to the domain of logistics with the objective to enable an effective and efficient management of distributed logistics resources, especially in volatile, uncertain and complex environments. An agenda for future research is outlined by means of the challenges ahead towards a further conceptualization and implementation of Cloud Logistics. Section 4 concludes this paper.

2. Current and Future Challenges for Logistics

2.1. Megatrends

Logistics and goods traffic depend on the overall development of the economy and, particularly, on the production and trade of goods which, in turn, are closely interrelated with the megatrends: globalization, demographic development, urbanization and technological innovation, and sustainability. Additionally, governments set a national and international regulatory framework for these developments. Major policies were recently issued in the areas of competition, energy supply as well as environmental and climate

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[2] The working group "Future Topics of Logistics" of the Scientific Advisory Board of the German Logistics Association (BVL) consists of Werner Delfmann, Willibald Günthner, Wolfgang Kersten, Peter Klaus, Ludger Overmeyer, Werner Rothengatter, Michael Schenk and Wolfgang Stölzle

protection. In order to derive the current and future challenges for logistics each megatrend and its influence on logistics is discussed in the following.

Globalization

Globalization describes the process of an increasingly integrated economy in which the procurement, production and distribution of goods are distributed globally with the objective to exploit differences in labor and resource costs, tax or regulatory conditions. The associated increase in the division of labor raises returns of scale and scope and requires (costs) efficient and effective logistics systems. Decreasing transaction costs, in particular for transportation and communication services, in conjunction with stable political conditions, technological development and cheap labor lead to highly dynamic growth in the "BRIC"[3] countries over the last two decades. Despite the recent financial and economic crises, a reversal of the globalization process is only to be expected in case of a drastic change in international political relations. In fact, the endogenous development trend emphasizes a continuation of the globalization process, yet, with lower dynamics for two reasons: First, a fraction of recent growth was attributed to a "globalization bubble" due to unrealistic expectations of returns resulting from globally distributed production networks. Second, returns of scale and scope from globalization are expected to diminish due to an increased development of international locations.

Relevance for logistics: The process of globalization, especially geographically distributed division of labor involves a high number of entities (individuals and organizations) and results in multi-staged, usually highly integrated, logistics systems with "*potentially more delay points, [...] and hence [...] need for greater coordination, communication, and monitoring."* (Manuj & Mentzer 2008) Christopher & Lee (2004) further emphasize that "[m]*anaging supply chains in today's competitive world is increasingly challenging. The greater the uncertainties in supply and demand, globalisation of the market, shorter and shorter product [...] life cycles, and the increased use of manufacturing, distribution and logistics partners resulting in complex international supply network relationships, have led to higher exposure to risks in the supply chain."* Moreover, the global performance of logistics systems, in terms of costs, quality and time, increasingly depends on local conditions as local economic, political and environmental disruptions can cause global repercussions due to integration. To summarize, due to globalization logistics gains in overall importance, but at the same time it is also a critical driver for increased external volatility, uncertainty, and complexity which adversely impacts logistics systems.

Changing Demographics

The global population is projected to continue to grow: from 6bn in 2008 to 8.7bn in 2030. Yet, this growth is not uniformly distributed across regions. The highest growth rates are forecasted for Africa (+55%), Asia (+24%), and Latin America (+23%), India will likely be the most populated country by 2025 if projections become reality (+28% compared with 2008) (Kritzinger et al. 2010). On the other hand, in some developed countries the population stagnates or shrinks and a demographic shift towards a growing elderly population is expected due to declining fertility rates and increased life expectancy, for example, in Japan or Germany. Nevertheless, projections about population growth are significantly dependent on assumptions about migration movements as well as the progress in the prevention and treatment of HIV/AIDS (United Nations, Department of Economic and Social Affairs, Population Division 2009).

Relevance for logistics: A growing world population implies increased economic activity in terms of the production and distribution of goods, which results in a growing demand for logistics services and underlying infrastructure. In particular, the projected population

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[3] BRIC = Brazil, Russia, India, and China

growth in currently developing and emerging regions requires a comprehensive development of local infrastructure, such as harbors, rail and road networks, in order to be able to meet people's needs. Despite this general growth opportunity, producing and distributing goods in these regions entails significantly higher uncertainty than in developed countries due to the potential lack of strong governmental institutions to enforce property rights. Simultaneously in the developed countries, the physiological limitations of an aging population will change the quality of the demand for logistics services, for example, frequent home delivery of perishables may be necessary.

Urbanization

Approximately half of the world population is currently living in cities. By 2050, this share is expected to increase to two-thirds globally and to 84% (72% in 2007) in Europe and 90% in China (United Nations, Department of Economic and Social Affairs, Population Division 2008; European Commission: Directorate-General for Energy and Transport 2009). In the developing and emerging countries, migration to cities led to the development of so called "megacities", for example Shanghai: the population has doubled over the last 50 years and has currently reached 15.7mn citizens, and is projected to reach 19.4mn citizens by 2025 (United Nations, Department of Economic and Social Affairs, Population Division 2008). Thus far, these cities developed rather uncontrolled which led to a high spatial expansion. In order to be able to satisfy the needs of the citizens living in these large cities, a turn towards sustainable urban development concepts is required such as polycentric development along pre-defined axes. Along these axes public transport will serve as the primary means of transportation. Shanghai, for example, has adopted this policy earlier than other cities and has developed a metro system along these axes which is the longest in the world today and is expected to consist of 22 metro lines in 2020.

Relevance for logistics: Continuously growing cities increase volatility, uncertainty, and complexity for logistics systems due to, for example the overwhelming amount of economic actors and their interactions. The efficient distribution of goods becomes challenging due to unforeseeable traffic conditions while the number and frequency of home deliveries increases simultaneously. Urban development along pre-defined axes facilitates an efficient flow and distribution of goods through utilization of out of town consolidation centers to avoid unnecessary traffic congestion. Already today, logistics service providers collaborate with local authorities to conceptualize and pilot new urban development policies, for example DHL started a pilot in Dubai (DHL Solutions & Innovations 2011). Likewise, the program "Future of Mega Cities" supported by the Federal Ministry of Education and Research (BMBF) focuses on developing sustainable urban development policies, especially pertaining to energy- and climate efficient structures (Federal Ministry of Education and Research (BMBF) 2012). Besides these infrastructural challenges in megacities further challenges arise in already "fully" developed cities, for example Hamburg. The increased turnover of goods in the harbor and the associated in and out flows towards the hinterland reach the capacity limits of existing infrastructure. However, due to spatial constraints infrastructure cannot be further developed in these cases but rather has to be used smarter, i.e. more efficiently.

Technological Innovation and Digitalization

Innovation, especially technological innovation over the last decades, has led to significant productivity improvement and, thus, to economic growth increasing trade volumes and associated logistics activity. Whereas incremental technological innovation has been predicted with some reliability, for example Moore's law, radical disruptive innovations have not so, consider the introduction of the first transistor. This implies that discussions about future technological trends are highly speculative. Nevertheless, Nefiodow (2006) a futurologist, predicts above all technological innovations to happen in the areas of bio or nanotechnology, medical devices, assisting systems, energy and environmental engineering, networks and information technology, knowledge society, and social networks. In the field of energy and environmental engineering, the main challenges can be described with some certainty, namely increased resource efficiency and use of renewable energies. However, so far it remains uncertain whether alternative energy sources such as wind, solar and geothermal heat or alternative (bio) fuels will prevail in the long-run. Similar uncertainties can be observed with regard to transportation technologies pertaining to reducing the emission of greenhouse gases through, for example, electrical engines powered by hydrogen-oxygen fuel cells or batteries. Thus, policy and decision makers face difficult assessments on which technology to invest in.

Technological innovation has also been the enabler for a new recent trend: digitalization. The physical world becomes increasingly digitized. Objects, processes and information are modeled and stored digitally. Examples are: Google literally taking a photo of the "whole" world accessible over the internet as "Google Earth", manufacturing and business processes using computer-aided-design (CAD) or enterprise resource planning (ERP) tools respectively, or digitization of books. As a consequence, gradually a parallel –digital– world is created (Mattern 2003), which in turn results in an overwhelming and constantly growing amount of data as modeling becomes more and more detailed. Moreover, the overall amount of data is also increased by a growing number of physical objects that are able to generate data automatically as they feature tiny computers that are connected to the internet, for example, RFID tagged freight (International Telecommunication Union (ITU) 2005; Fleisch 2010; Günthner & ten Hompel 2010). This concept is referred to as the "Internet of Things" (IOT). (Fleisch 2010), argues that *"the IOT is all about sensing the physical world."* It provides the infrastructure to measure the physical world cost efficiently. In other words, it bridges the media disruption in the "last mile" between the physical and virtual world. Sensing costs are continuously diminishing due to technologic innovations. Thus, when sensing costs fade, sensing efforts will increase in scope, frequency and richness of data (Fleisch 2010). For example, Google Earth was initially released in 2005 providing satellite pictures only. In 2008, the service "Street View" was integrated providing detailed pictures on street level (richness). Over time, Street View will be available for more and more locations (scope) and pictures are likely to be updated more often (frequency). The pace at which additional data is generated has constantly increased so far and is expected to further increase. Despite that the amount of "smart" objects generating data is expected to grow even faster. Thus, questions pertaining to automatic data storage and processing will likely gain in importance.

Relevance for logistics: Technological innovation and digitalization influence logistics manifold. Shorter and shorter product life cycles, especially, of technology intensive products such as mobile phones, flat screen TVs, or laptops require logistics systems to adapt both more often as well as more quickly to new conditions. Technological innovation has contributed to lower costs and higher environmental efficiency, for example through improved routing, reduced aerodynamic drag, alternative fuels or more efficient engines. However, pertaining to fleet renewal policies, decision makers of logistics service providers face uncertainty about whether or not to invest in transportation vehicles with alternative propulsion systems as efficiency gains may not outstrip higher investment costs. Further, technological innovation and digitalization also change how logistics systems are designed and operated. The continuously growing amount of available processing power has been accompanied by research on and development of more and more sophisticated quantitative methods to solve, for example, complex routing problems, which in turn led to highly efficient logistics systems. While these system show good performance under stable condition, performance often declines sharply in case of disruptions, i.e. implying vulnerability (Tang & Tomlin 2008).

At the same time, logistics systems are operated and controlled in an increasingly automatic manner. The Internet of Things provides the conceptual background for this. Data collected from smart objects, for example from pallets equipped with RFID tags, are used as basis to control flows and events in the physical world. In order to allow for an efficient decentralized and partially autonomous control of systems the virtual world needs to be closely synchronized with the events happening in the physical world to provide reasonable input data for control mechanisms as well as requires efficient protocols and rules to govern the large amount of (decentralized happening) interactions (CERP, Cluster of European RFID Projects 2008). Standardized interfaces and data structures are critical enablers for a decentralized system. Simultaneously, the amount of data collected and processed in logistics systems will constantly grow as the virtual image of the physical world increases in detail. As this overwhelming amount of raw data cannot be processed manually by humans, efficient automatic data handling and processing routines will be required to aggregate and present data comprehensible. In future, not only the amount of data as such but also the amount of data which needs to be protected against unauthorized access will increase disproportionately high. Resulting from this increase in data and growing number of interfaces between supply chain partners, data needs to be accessed from multiple entities in different contexts. Thus, an efficient interface-independent management of access rights is required allowing for granular discrimination in data access rights.

Decentralized production structures (related to *intra-logistics*) can provide a conceptual template to approach these challenges, for example, by means of the specifications stipulated in the Electronic Product Code (EPC). In these systems, data is usually generated during each production step and at interfaces between production steps, material flows are monitored using AutoID techniques. Due to the large amount of data in these systems, data is usually aggregated to meaningful indicators and presented in information dashboards.

Sustainability

The term "sustainability" was coined by the findings of the Brundtland Commission in 1987 and is defined as: *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* (United Nations, World Commission on Environment and Development 1987) Sustainable development encompasses the triad of economic, environmental, and societal development. Environmental sustainability has recently started to gain significant attention as the first symptoms of the anthropogenically induced climate change, resulting from an excessive emission of greenhouse gases, have become evident. In order to counteract the effects of climate change, policy makers started issuing laws to internalize the external effect associated with the pollution of clean air, a public good.

Relevance for logistics: The logistics industry, especially transportation activities, is a significant contributor to the emission of greenhouse gases. With regard to transport policy, multiple challenges have been outlined by the EU Commission, amongst them (European Commission 2011): restrictive CO_2 budgets for the transport sector. In order to achieve the targeted reduction of emissions by 60% in 2050 (compared to 1990 levels) multiple initiatives are proposed, for example funding to foster innovation in transport technologies, strategies for carbon free mobility ("zero-carbon urban logistics 2030") as well as policies to internalize external effects such as emission trading schemes. The European Union Emission Trading Scheme (EU ETS), for example was launched in 2005 and has started to cover the airline industry as of 2012 (DIRECTIVE 2008/101/EC). Even though not all initiatives are likely to be implemented as they require support from all 27 member states of the EU, the strong focus on climate change of the EU Commission emphasizes the increasing recognition among EU industry nations that environmental sustainability will yield a competitive advantage for EU countries on the world market in the long-run. The rationale behind this can be explained as follows: if the EU economy and society succeed in achieving their ambitious climate targets with their own technologies, then EU based companies will have a competitive advantage when more and more countries start to face challenges pertaining to energy consumption and climate change.

2.2. Beyond Megatrends: Structural Breaks and Economic Crises

Structural Breaks

Megatrends induce incremental change in the environment of logistics systems and in logistics systems themselves. Thus, systems can be adapted in an evolutionary manner to changing conditions. In contrast, structural breaks cause abrupt dysfunctionalities and often result in a sudden sharp decline in logistics performance. This raises the question to what extent logistics systems can be prepared for the occurrence of structural breaks as well as which options for adaptability are available. Evidently, scientific literature has not been concerned with structural breaks in a systematic way. Nevertheless, specific problem clusters can be identified: political eruptions as recently observed in Tunisia, Egypt or Libya as well as terrorist action, local military conflicts, and economic downturn may cause global supply chains to fail suddenly and unexpectedly. Similar effects can be caused not only from anthropogenic induced environmental catastrophes such as oil spills, nuclear or chemical accidents but also from natural disasters, for example, earthquakes, tsunamis, floods or volcanic eruptions. Natural disasters or military conflicts often result in humanitarian catastrophes. This cluster has increasingly attracted scientific attention from logistics researchers and is referred to as “humanitarian logistics” (Balcik & Beamon 2008). Albeit the main research focus lies on the efficient deployment of first aid resources or quick reconstruction of infrastructure and does not deal with the adaptability of logistics systems.

Economic Crises

Economic crises are not exclusively caused by exogenous disturbances such as natural disasters or military conflicts as presumed in classic economic theory. It has been accepted at a very late stage in economic sciences that primarily human behavior and decision taking induce fluctuations in the business cycle (Keynes 1994; Schumpeter & Röpke 2006). So far, the most severe crises originated in the financial sector: Mississippi Bubble 1720, Great Depression 1929 and the global financial and economic crisis 2008. While basic influencing factors for the development have been largely explored, it still remains impossible to predict the timely occurrence of crises precisely. This is due to the fact that basic economic parameters as well as group behavior show significantly different patterns prior to each crisis, thus, making existing bellwethers for crises meaningless. Roubini & Mihm (2010) claim that crises will turn out to be more severe the longer the previous phase of prosperity has been. In the case of shorter business cycles, periodic downturns are likely to provide more opportunity for innovation and businesses to change antiquated structures in the sense of “creative destruction” as formulated by Schumpeter & Röpke (2006). Against this background and the recent global financial and economic crisis, different scenarios described in economic long-term forecasts need to be evaluated. Three scenarios are distinguished (Rothengatter et al. 2010; OECD/ITF 2009):

- “Bounce back”, i.e. the global economy returns to its original growth path within five years. This scenario is most desired by the economy, yet also involves the highest risks as it is likely that behaviors remain unchanged, thus, leading to the next crisis.
- “Retrenchment”, i.e. sustained pessimism slows down the economy and process of globalization and associated flow of goods. This scenario only seems likely if international relations drastically change.
- “Schumpeter creative destruction”, i.e. the crisis triggers the development of new market structures including the financial sector and innovation towards sustainable products and processes. Thus, in this scenario firms need to increase flexibility and shorten lead times to be able to quickly respond to changing conditions.

Relevance for logistics: Economic activity drives trade volumes and associated logistics activity. Thus, pertaining to the scenarios discussed one can conclude that logistics activity will increase until the next crisis occurs or that it will decrease due to political disruption and increased pessimism of citizens. In the Schumpeter scenario, logistics activities need to cope with increased fluctuations due to structural changes which would strengthen flexible logistics service providers and question traditional business practice. Irrespective of a concrete scenario, academics and practitioners expect structural environmental conditions to change more quickly, thus, requiring economic actors to have an increased ability to adapt. Rapidly changing economic and environmental conditions result in goal conflicts between long-term commitments allowing for the use of mass capacity means of transport and short term responses to fluctuating demand under the constraint of minimal capital commitment. Thus, it is likely that new types of cooperative logistics will emerge, either on contractual or auctions basis in order to share risks, increase flexibility and maintain service levels.

3. The Future of Logistics: Adopting the Cloud Paradigm?!

3.1. The Impact of Limited Predictability on Logistics Systems & Strategies

Megatrends, structural breaks and economic crises increase volatility, uncertainty, and complexity and, thus, limit logistical predictability. Nevertheless, the leading design principle for logistics systems over the last two decades has been (costs) efficiency, not the least enabled by quick developments of information technology (Christopher & Peck 2004). Tang & Tomlin (2008) argue that *"executives strived to improve their financial performance, [...] implemented [...] initiatives to increase revenue (e.g. increase product variety, frequent new product introduction), reduce cost [e.g. reduce supply base, just-in-time (JIT) system, vendor-managed inventory (VMI)] and reduce assets (e.g. outsourced manufacturing) [...] [which, added by author] created longer and more complex global supply chains, which are more vulnerable to business disruptions."* Furthermore, Tang (2006) argues that costs efficiency is accompanied by high hidden costs incurring in case of a disturbance (Lee 2004). More and more frequent business disruptions due to economic crises, political unrest, volcanic eruptions, earthquakes and tsunamis motivated academics and practitioners to develop strategies to maintain supply chain performance even in volatile environments. The most prominent strategy proposed is Risk Management.

Miller (1992) and Juttner et al. (2003) define risk as the unpredictability or variation in corporate outcomes, for example supply chain performance. Uncertainty about external variables which influence corporate outcomes increases risk. Risk management has the objective to reduce risk either by reducing its probability or impact, or both. Miller (1992) suggests 5 organizational responses to uncertainties of which 4 are relevant to logistics: [4] avoidance, control, cooperation, and flexibility. Enterprises can avoid supply chain risks, for example, by discontinuing business relations with unreliable suppliers or control risk by integrating vertically. Alternatively, companies can sign multilateral long-term cooperation agreements which results in a *"transfer of risks between the companies; it may decrease some risks and increase others"* (Hallikas et al. 2004). However, alliances are usually established rather slow, incur costs to set up, may require a partial integration of organizations and are usually long-term commitments, thus, reducing flexibility in some cases. Supply chain flexibility can also be improved by, for example, increasing the number of suppliers for a particular input factor or decentralized warehouses which enable a quick response to local demand fluctuations. Tang (2006) summarizes the risk management process in the following steps: identification, assessment (probability and impact), and development of mitigation strategies. Zsidisin et al. (2004) provide, for example, an elaborate overview of techniques to assess supply risk. Nevertheless, in an uncertain, complex and volatile environment not all risks can be identified, assessed and mitigated

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[4] Miller (1992) also proposes imitation as an organizational response to reduce risk. However, imitation seems not to be an appropriate response to reduce supply chain risk.

in advance. Moreover, Tang (2006) argues that *"[w]ith inaccurate estimates of the probability that a major disruption would occur, many firms find it difficult to perform cost/benefit or return on investment analysis to justify certain risk reduction programmes or contingency."* As a consequence, alternatives to risk management have been proposed.

"Robust" supply chain strategies enable firms to efficiently manage regular fluctuations under normal circumstances and help them in sustaining their operations if a major disruption occurs (Tang 2006). Robustness can be achieved by designing supply chains in a particular way, for example, through strategic stock, additional de-coupling points, or postponement. Furthermore, robust strategies can also contribute to building resilient supply chains. Christopher & Peck (2004) define supply chain resilience as *"the ability of a system to return to its original state or move to a new, more desirable state after being disturbed."* Resilience can be improved through: design principles "keeping options open" or the use of "selective slack", collaboration along the supply chain, and supply chain agility. Agility enables firms to quickly react to changes in demand and supply conditions through end-to-end visibility of, for example, up- and downstream inventories as well as through minimal lead times along the supply chain. To summarize, robust and resilient strategies are an appropriate answer to an increased volatile and uncertain environment. Nevertheless, re-examining the "efficiency vs. redundancy" trade off may turn into a hard sell in some cases. Moreover, establishing overarching (global) supply chain visibility may be challenging and requires more and more advanced communication and information technology since *"traditional supply chains have been transformed into global "supply networks."" (Wind et al. 2009)*

Surana et al. (2005) and Choi et al. (2001) take another perspective and argue that supply chain networks can be recognized as complex adaptive systems (CAS) with intense communication and inter-dependencies among its entities, processes and resources. Associated system characteristics are: non-linearity, complex multi-scale behavior, evolution and self-organization driven through its structure and function, thus increasing complexity. Consequently, management and control of these systems becomes difficult. Even though recent developments of communication and information technology contributed significantly to supply chain integration and visibility, current technologies lack the ability to achieve, for example, adaptive and collective behavior in autonomous decentralized distributed systems due to, for example, missing coordination and decision mechanisms. Similarly, Windt & Hülsmann (2007) argue that inherent complexity in today's supply chains can no longer be achieved through centralized planning and control systems. Consequently, they emphasize the need of a paradigm shift in logistics system design towards *"decentralised control of "intelligent" items in heterarchical structures"* instead of today's *"centralised control of "non-intelligent" items in hierarchical structures".* Notwithstanding that this paradigm shift constitutes a non-negligible reorientation of logistics system design; multiple research approaches investigating the design and performance of complex, adaptive, autonomous, cooperative, and decentralized systems in distributed environments can be considered a first point of reference. Surana et al. (2005) model and analyze supply chain networks by means of CAS concepts, tools, and techniques such as dynamical systems theory, models from observed data, and network dynamics. Also Choi et al. (2001) recognize supply chain networks as CAS and propose that these systems rather emerge than result from deliberate design. Managers, thus, need to balance between how much to control the network and how much to let it emerge in order to allow for network innovation and flexibility. Windt & Hülsmann (2007) study autonomous cooperation and control (which is related to the idea of self-organization) in logistics processes and discuss respective drivers and enablers such as RFID technology. Um (2010) simulates supply chains by means of multi-agent technology and proposes a new agent negotiation algorithm improving supply chain performance. Using holonic multi-agent technology, Dominici (2010) introduces the concept of "capacity" describing the agents' know-how and Rodriguez et al. (2006) propose a collaborative negotiation approach for a holonic production system in their simulation respectively.

In conclusion, efficiency focused design principles make logistics systems vulnerable to disruptions. In the light of an increasingly volatile, uncertain and complex environment with limited predictability, the question to revisit current mainly efficiency focused design principles needs to be raised. Efficiency focused principles allowing for high performance under stable conditions need to be complemented with principles that maintain performance – even in the case of disturbances. In order to achieve this, strategies to provision for the occurrence of disturbances need to be further refined on the one hand. On the other hand, future design principles need to shift the focus towards effectiveness. Thus, robust and resilient design principles will gain in importance in future considerations. The trend towards increasingly integrated, thus interdependent, multi-staged, and slack-free systems needs to be superseded by a trend towards more and more decentralized, autonomous, cooperative, and de-coupled system constellations. These systems need to employ an appropriate amount of "slack" in order to ensure stable performance after disruptive events. This extended design philosophy does not only apply to micro-logistics systems but also to macro-logistics and infrastructure systems which are subject to similar challenges. Against this background, questions pertaining to a reasonable degree of outsourcing, centralization of production and distribution systems, number of suppliers and production locations, selection of transportation modes, routes and associated gateways as well as network structures of logistics service providers need to be reconsidered. These design challenges seem to resemble implications resulting from climate change considerations and increasing energy costs which also suggest a trend towards more and more de-coupled and decentralized logistics systems.

En route towards innovative logistics systems: Delfmann et al. (2010) argue that logistics is interdisciplinary academic discipline and, thus, uses and adapts methods from other research fields, such as mathematics or engineering, which could provide a conceptual template to overcome current and future challenges for logistics. Cloud Computing seems to a promising method originating in the field of computer sciences.

3.2. Paradigm Shift:

Transferring the Cloud Paradigm from Computing to Logistics

Cloud Computing denotes a novel currently emerging model to provide and consume computing resources "as a service", based on "Service Level Agreements" (SLA). Thus far, a myriad[5] of definitions has been proposed. Among the most common ones are those proposed by Vaquero et al. (2008) who define that *"[c]louds are a large pool of easily usable and accessible virtualized resources (such as hardware, development platforms and/or services). These resources can be dynamically re-configured to adjust to a variable load (scale), allowing also for an optimum resource utilization. This pool of resources is typically exploited by a pay-per-use model in which guarantees are offered by the Infrastructure Provider by means of customized SLAs."* and by the U.S. Department of Commerce National Institute of Standards and Technology (NIST) (2011): *"Cloud Computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model is composed of five essential characteristics, three service models, and four deployment models."* An abridged description (based on the NIST definition) of these elements is provided in the following three paragraphs.

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[5] Vaquero et al. (2008) provide an overview of recent definitions and differences between Grid and Cloud Computing

- *On-demand self-service* allows consumers to unilaterally request and use computing capabilities without having human interaction with their service provider.
  Broad network access allows users to consume computing capabilities over the internet by means of thin or thick client platforms such as mobile phones or notebooks.
  Resource Pooling: Each Cloud Computing provider's resources are pooled in order to fulfill the service demand from multiple consumers. To match consumer demand, the provider dynamically assigns and reassigns physical and virtual resources to consumers. Consumers generally have no control or knowledge about the detailed location of resources assigned.
  Rapid elasticity of Cloud Computing results from the ability of providers to add and release resources quickly in order to match changes in consumer demand effectively. This happens without the consumer noticing, thus, computing capabilities appear to be unlimited and available at any quantity at any time. Kuperberg et al. (2011) analyze this characteristic in more detail and explicitly distinguish between scalability and elasticity. Scalability means that a system *"maintains its performance goals/SLAs even when […] its workload increases (up to a certain workload bound)."* An elastic system dynamically adds or releases more resources when service demand increases or decreases respectively. *"Thus, elasticity adds a dynamic component to scalability."* System elasticity depends on the following variables: "trigger and reconfiguration points" define time instants when resources can be added to a system and when they become effective respectively. The "temporal distribution of reconfiguration points" describes the density of reconfiguration points over time. The "effect of reconfiguration" is the amount of resources added or released; in particular, this defines the granularity of reconfigurations possible. Finally, the "reaction time" denotes the time interval until the system has adapted to a new stable state after a reconfiguration has been triggered. In terms of a mathematical optimization problem, elasticity implies the relaxation of a previously binding constraint.
  Measured Service: In order to automatically control and optimize the use of resources a suitable metering capability for each service is deployed. Service utilization is monitored, controlled, and reported. As a consequence, both providers and consumers have transparency on actual resource usage, thus, allowing a pay-per-use model.
- Cloud Computing services are categorized according to the type of capability provided to the consumer into three *service models*. *Infrastructure as a Service (IaaS)* comprises the provision of fundamental computing resources, such as storage or processing power, on which arbitrary software, for example operating systems, can be deployed and run by the consumer. *Platform as a Service (PaaS)* provides an application-hosting environment to consumers in which they can deploy applications created using a specific programming language, for example, Java or Python. Finally, *Software as a Service (SaaS)* allows consumers *"to use the provider's applications running on a cloud infrastructure."* (U.S. Department of Commerce National Institute of Standards and Technology (NIST) 2011) These applications are usually accessed via a web browser or other thin client interfaces and (mobile) devices.
- Four *deployment models* have been defined for Cloud Computing; the distinctive feature being who is entitled to consume underlying cloud infrastructure resources. In *private clouds*, cloud infrastructure is provided for the exclusive use of one organization as opposed to *public clouds* which openly provide infrastructure to the general public. The case in which cloud infrastructure is provided to a specific community of organizations that have shared concerns is denoted as *community cloud*. The infrastructure of a *hybrid cloud* is a composition of at least two distinct cloud infrastructures that are connected through an interface which, for example, allows the portability of data and applications. This requirement is also referred to as interoperability between clouds.

In other words, one could argue that the Cloud Computing model solves the fundamental logistic problem of providing the right commodity or service, in the right quality & quantity, at the right location & time, to the right customer, at the right price for, say, computing resources. Nevertheless, the model and its associated characteristics, service and deployment models described above can also be interpreted in more abstract terms with the objective to identify the concepts underlying. To illustrate, Cloud Computing utilizes three service models which are compiled by applying the concepts of resource abstraction, virtualization and subsequent encapsulation in services. From an abstract point of view, these concepts could be applied to any type of resource. In the following, this set of underlying concepts of Cloud Computing will be denoted as the "cloud paradigm".

Switching the order of the previous argument: Cloud Computing solves the fundamental logistic problem of the provision of computing resources by means of the cloud paradigm. Thus, it seems to be a self-evident idea to adopt this paradigm to other domains dealing with logistics problems such as the distribution and warehousing of goods. To clarify explicitly for the context of this paper, adopting the cloud paradigm to other domains does *not* denote the implementation of a Cloud Computing solution in the target domain to provide domain-specific computing services. It, in fact, denotes the interpretation of the target domain –itself– including its specific characteristics through the lens of the cloud paradigm. Consequently, adopting the paradigm necessarily entails a critical assessment of whether it is reasonable and feasible to actually adopt the paradigm as well as whether cloud characteristics can be preserved in the new domain.

Xu (2012), for example, adopts the cloud paradigm to the manufacturing domain. Whereas the concept of Cloud Manufacturing is new, it builds on recent trends to move from production-oriented to service-oriented manufacturing as well as on existing manufacturing approaches for distributed resources *"encompass[ing] technologies such as networked manufacturing, manufacturing grid (MGrid), virtual manufacturing, agile manufacturing [...]".* Compared with existing approaches, Cloud Manufacturing particularly improves the coordination between the resource service provider and demand through centralized service management. The service model of Cloud Manufacturing covers the whole product life cycle: product design, manufacturing, testing and managing all other stages. However, compared with Cloud Computing, the process of resource virtualization and encapsulating them in cloud services is more challenging due to the higher heterogeneity of physical resources and manufacturing capabilities. Liu et al. (2011), for example, propose a method to describe heterogeneous manufacturing resources as well as their capabilities in an isomorphic manner utilizing, for example, semantic web concepts.

Cloud Manufacturing is closely related to another research field commonly referred to as *intra-logistics* which primarily focuses on organizing, controlling and optimizing (raw) material flows on the premises of a firm, for example, within a factory building. The basic properties of material flow systems are outlined by Overmeyer et al. (2009). Functionalities cover basic transport or sorting functions. Planning and coordination is achieved by means of a central control unit. Challenges arise, for example, from different sizes of materials to be transported. As a consequence systems have been customized to match the requirements of a specific use case, thus, system reconfigurations involve significant effort and costs. In order to increase flexibility of these systems, for example, to cope with shorter product life cycles more cost efficiently, Overmeyer et al. (2009) propose to use "intelligent" small scale transport modules. Modules can be easily combined in order to be able to transport, for example, larger goods. Coordination of modules is achieved in an autonomous decentralized way. Communication among transport modules as well as between materials and transport modules is achieved through RFID technology.

Similarly, Günthner et al. (2010) argue that mechanical components of manufacturing systems have been largely modularized, but modules are still controlled centrally. This increases operational risk as systems become increasingly complex due to, for example, the trend towards individualization (ten Hompel (2010). Thus, a paradigm shift within intra-logistics is needed. Innovative material flow systems need to consist of intelligent infrastructure, small scale transport modules and need to function in a similar way as computer networks: decentralized, cooperative, adaptive, and free of hierarchy. The Internet of Things provides a conceptual template for these systems.

Scholz-Reiter et al. (2007) further argue that there is no need for full self-control within each logistics system. The optimal degree of self-control is a rather function of: logistics performance targets, complexity and degree of self-control. Especially in complex systems, logistics performance increases if the degree of self-control increases, reaches a maximum, and then starts to fall again if self-control is further increased.

Furthermore, new manufacturing techniques such as 3D printing are likely to make manufacturing more flexible in future (The Economist 2012). 3D printing is an additive manufacturing technique, in which thin material layers are successively added until a solid object emerges. Each layer is cured, for example by exposure to ultraviolet light. In other words, compared to regular office printers, 3D printers use (raw) materials as ink. 3D printers are ideally suited for mass customization of finished parts or low-volume products as there are almost no economies of scale so far. Additive manufacturing increases flexibility and shortens the time to market as printers can manufacture any kind of product without reconfiguration at decentralized locations. In this case only raw materials need to be distributed to manufacturers, the digital copy, i.e. the plan, of the product is available in an online library. As a consequence, the protection of intellectual property will be challenging as digital things can be copied easily. Also the risk of going to market is decreased by additive manufacturing as entrepreneurs are able to test and modify their ideas before scaling up production.

3.3. Adopting the Cloud Paradigm to Logistics:

Conceptualization and Critical Appraisal of Paradigm Adaptability

Similar to the example of Cloud Manufacturing, the idea of adopting the cloud paradigm to logistics builds on existing logistics strategies, integrates and complements them with the objectives to overcome current limitations and, thus, to improve logistics performance in volatile, uncertain and complex environments. The adoption of the cloud paradigm to the logistics domain will be denoted as "Cloud Logistics".

The definition of Cloud Logistics is still in its infancy. No generally accepted definition exits thus far, but constructive proposals can be found in the literature. The working group "Future Topics of Logistics" of the Scientific Advisory Board of the BVL defines Cloud Logistics as *"an environment of "virtual" systems that facilitate supply chains' overall coordination and use of distributed resources, capacities, processes, and services from supply chain partners. These systems are based on advanced information and communication technologies that leverage modern Internet services."* (German Logistics Association (BVL) 2012) Under the term "Supply Chain as a Service", Leukel et al. (2011) provide a more detailed conceptualization of Cloud Logistics, covering, amongst others, a model to describe a supply chain exclusively through services, cloud scalability and potential constraints resulting from the physical heterogeneity of logistics resources, and the role of SLAs. The conceptualization of Cloud Logistics proposed in this paper picks up on these contributions. It details them further and, more importantly, discusses whether the characteristics of Cloud Computing can be preserved in the logistics domain – explicitly taking into account the specific properties of logistics, say, the flow of physical goods in physical networks. The following discussion is structured along the elements (i.e. essential characteristics, service and deployment models) of the NIST definition of Cloud Computing.

A necessary precondition for Cloud Logistics is the feasibility of abstracting, virtualizing and encapsulating logistics resources (e.g. trucks, trains, vessels, airplanes, warehouses incl./excl. inventory) and associated operational capabilities (e.g. as (un-) loading transportation vehicles, freight commissioning and de-consolidation, placing and removing goods from stock in warehouses, or handling freight documents) in services. With regard to transportation resources, already today, a high level of abstraction can be observed. This can be illustrated with the ocean freight business: logistics service providers commonly take an intermediary role between shippers and ship operators and broker "abstract" transportation capacity (e.g. FCL or LCL) on a particular trade lane from X to Y instead for capacity on a particular type of vessel. In general, complexity of abstraction and virtualization depend on resource's properties which need to be described in an isomorphic manner in order to utilize this "class of resource" as a service. Consequently, the abstraction and virtualization of, for example, warehouses designed for a specific type of good is likely to be more complex than of transportation resources. With regard to describing logistics through services: the logistics function is often outsourced to specialized service providers. The underlying outsourcing relationships are commonly structured by means of Service Level Agreements (SLAs) which describe logistics activities in terms of services already today. Leukel et al. (2011) propose a "service-based" supply chain model focusing on the description of services and their relations. In particular, the problems of service composition, i.e. forming a new service by combining at least two other services, and service coordination, i.e. finding the best composition of services, are raised. Service composition requires that services are interoperable (which can be achieved through the use of semantic web services) and is a prerequisite for service coordination. An initial evaluation of the proposed supply chain model (focusing only on service composition) by means of a supply chain system for ground handling operations at airports was successful and, thus, provides first evidence that the cloud paradigm can be adopted to logistics. In summary, it can be argued that above stipulated precondition for Cloud Logistics is generally fulfilled for logistics.

Cloud Computing offers *broad network access* as well as *on-demand self-service* to computing capabilities. However, these characteristics can be partially preserved only for Cloud Logistics. Logistics capabilities (services) cannot be accessed or provided over the internet but are always associated with a physical flow of goods in physical networks. Nevertheless, the business initiation, definition of scope of services and contract closure can be performed online, for example, via an electronic data interchange (EDI) or via a specialized Cloud Logistics platform. With regard to on-demand provision of logistics capabilities, Cloud Logistics preserves the characteristic of Cloud Computing with the minor difference that the time gap between service request and provision may be larger in Cloud Logistics. Moreover, on-demand provision of logistics capabilities is common business practice if procured from an external provider, for example, a pick-up by an express courier can be scheduled on needs basis. However, logistics capabilities cannot be provided as a self-service. Human interaction between the shipper and the respective logistics service provider or sub-contractor will always occur.

Cloud Logistics generally preserves the characteristics of *scalability and elasticity*. Scalability arises from the property that without adding additional resources, service levels (e.g. delivery times) can be maintained in case of (small) demand fluctuations. The capacity of a logistics resource is larger in this case than the capacity needed to fulfill an additional service request, for example, partial container loads are consolidated. Elasticity is preserved as logistics resources can be added or removed dynamically, for example additional trucks can be allocated to an unforeseen capacity-intensive transportation service request. However, Leukel et al. (2011) emphasize that elasticity may be lower compared to Cloud Computing due to an increased time necessary for resource reconfiguration. Time may be required to overcome physical distances between the current resource's location and its targeted deployment location. In order to ensure sufficient elasticity this implies that there may exist an upper bound for the geographical coverage of a logistics cloud which depends on the respective resource type. Also Leukel et al. (2011) argue that there may be only a very limited set of resources with required properties available. Thus, constraining elasticity may be further. Finally, the temporal distribution of reconfiguration points may be much lower than in Cloud Computing. Pre-determined flight schedules or sailing lists will likely reduce elasticity.

Cloud Logistics preserves the characteristics of *resource pooling*. Yet, resources can be pooled in considerably different ways:

- In the first pooling scenario one logistics services providers operates a pool of resources in order to fulfill the service requests from multiple customers. The logistics service provider will realize efficiency gains resulting from economies of scale and scope through pooling. This resembles the general Cloud Computing pooling scenario in which one provider pools resources and assigns them dynamically to serve multiple customers.
- In the second pooling scenario at least two logistics service providers pool their resources in order to serve their combined customer base or customers of a third party. Providers will decide on those resources or services that will also be accessible to other providers. As a consequence, resource pooling requires horizontal cooperation between logistics service providers. Yet, this type of cooperation does not imply an ongoing commitment between suppliers as in, for example, strategic alliances. It is rather a transient short-term cooperation which ends automatically after an agreed service has been fulfilled. To add, cooperation in Cloud Logistics differs from sub-contracting in such a way that terms and conditions are predefined, use utility prices and are not subject to (constant re-)negotiation between providers. Anticipated efficiency gains will then arise from the improved utilization of currently underutilized resources of the cooperating logistics service providers. This scenario can be considered as an extension to the first as it implies that each cooperating logistics service provider already operates an own resource pool and it emphasizes the principle of "self-similarity" of logistics (Delfmann et al. 2010). As multiple companies have already outsourced logistics to specialized service providers this precondition seems to be generally fulfilled. Thus, Cloud Logistics offers a potentially interesting method to improve efficiency through cooperation.
- A third way to pool resources arises if arbitrary companies in an arbitrary industry cooperate horizontally and share resources which are directly connected to logistics resources, for example inventory in warehouses. Cooperating companies may have either outsourced the management of the associated warehouse or manage it themself. Zhao et al. (2005) *"analyze a decentralized dealer network in which each independent dealer is given the flexibility to share his inventory […] each dealer faces his own customer demand with high priority, and inventory-sharing requests from other dealers with low priority."* Dealers' sharing behavior and system performance is analyzed pertaining to incentives, subsidies and transshipment fees. Thus far, the authors of the paper in hand are aware of one example in apparel industry in which this type of resource pooling has been implemented successfully. Consider this simplified workflow of order generation, handling and invoicing: A shoe manufacturer operates an online shop, incoming orders are offered to the dealer located closest to the customer, the dealer accepts and delivers the shoes; the manufacturer pays the dealer and invoices the customer.

Charging logistics services on *pay-per-use basis* by means of SLAs is common business practice in the logistics industry. However, the concept of Cloud Logistics heavily builds on the commoditization of logistics services. As a consequence, Leukel et al. (2011) emphasize that the adoption of the pay-per-use model in Cloud Logistics depends largely on whether logistics services can actually be transformed into a utility. Another prerequisite for a successful adoption is the ability to precisely measure service delivery and actual resource usage. Due to the physical characteristics of logistics, this is more challenging compared to Cloud Computing, nevertheless feasible. Precise measurement requires close synchronization between the physical and virtual world which generally can be achieved by deploying sensors at all relevant points in the logistics system as emphasized by the Internet of Things (Fleisch 2010). Ideally this measurement happens automatically, for example, through RFID technology. However, the penetration of these technologies in logistics systems is rather low today but is likely to further increase over time with falling prices and technological innovation. Cloud-wide data compatibility of these sensors is a critical enabler for integrated service measurement. Furthermore, a conceptual challenge arises from the fact that the actual costs incurred from service delivery or resource usage may not be quantifiable in a straight forward way. Consider the case in which a provider delivers one incremental shipment using a truck loaded with own shipments. Hence, transparent price setting mechanisms and fair allocation rules of efficiency gains are essential. One possible way to overcome this challenge would be to auction off services on a Cloud Logistics platform.

In Cloud Computing three distinct service models have been proposed. Thus far, no comprehensive service model for Cloud Logistics has been proposed. Service models generally depend on the resources types and their capabilities. Consequently, the Cloud Logistics service model covers basic transportation, warehousing services, but also associated value added services such as packaging or customs clearance. These services usually require some sort of physical handling of goods. Yet, also services without direct physical manipulation are conceivable; hence some of them may be accessible over the internet. Information or financial services such as shipment tracking or billing belong to this class. However, information and financial services cannot be provided standalone, i.e. detached from or without an underlying physical flow of goods. In fact, these services build on their measurement. Thus, again a close synchronization between the physical and the virtual world is a necessary prerequisite for these services.

The deployment models used in Cloud Logistics significantly depend on the type of resource pooling employed. The first pooling scenario seems to resemble a *public cloud* with regard to transportation resources. Pertaining to warehousing resources it may rather resemble a *private cloud* as warehouses are in some cases provided exclusively for one customer. The second pooling scenario resembles a *hybrid cloud*. The interoperability of services between the individual resource pools (or clouds) is a precondition for successful implementation. Coordination of resource deployment will likely be achieved through a common IT platform. The third pooling scenario resembles either a *hybrid* or *community cloud* – depending on the legal relations and the existence of a "shared concern" between the organizations involved. Furthermore, if the cooperating companies have outsourced the operation of their warehouses to a common provider, it is likely that this provider will evolve as a cloud operator and coordinate resource usage. Alternatively, the coordination can be achieved through the manufacturer of the shared inventory as outlined in the example above.

To summarize, the provided conceptualization and its critical appraisal emphasize that the cloud paradigm can be adopted to the logistics domain. The most important cloud characteristics, i.e. resource pooling, scalability and elasticity, can be preserved in the logistics domain which is characterized by the physical flow of goods in physical networks. Scalability and elasticity make Cloud Logistics systems robust against supply chain disruptions, volatile and uncertain demand. Cloud Logistics systems are also resilient: geographically distributed resources can be re-configured, added, or removed from the cloud, thus, allowing the cloud to dynamically move to a previous or new more preferred state. In other words, Cloud Logistics systems can be expected to outperform conventional logistics systems in volatile, uncertain and complex environments.

3.4. Towards Cloud Logistics: the Challenges Ahead

The cornerstones to conceptualize Cloud Logistics have been set. Yet, without doubt, various unsolved challenges remain to implement successfully a true Cloud Logistics system. In the following, potential fields for future research are briefly outlined.

A comprehensive service model based on logistics resources needs to be developed. Service compatibility, especially with regard to data interfaces, will be critical to ensure that services from more than one logistics provider can be combined to solutions. Existing concepts, for example, from Cloud Manufacturing are likely to be applicable to logistics too. In light of this service model, it needs to be understood if and how logistics providers need to adapt their current service portfolios to offer Cloud Logistics services.

Cloud Logistics uses subject to the underlying resource pooling scenario a different deployment model. In case of a *hybrid* deployment model logistics service providers need to cooperate (horizontally). Future research needs to investigate what preconditions need to be fulfilled for this type of cooperation to happen and how these relations can be governed effectively and efficiently. In particular, the potential need for a neutral "cloud operator" needs to be evaluated, which, for example, coordinates and moderates between suppliers or defines, manages, enforces common policies for data interfaces, service standards, performance measurement or policies that ensure data privacy if sensitive customer information is shared during service delivery. Further questions pertain to coordination mechanisms to match service demand with supply including prioritization rules in case of resource shortages, transfer pricing models for rendered services, and allocation rules for cooperation gains. Moreover, rules for quick supplier qualification are essential to allow for elasticity. Nevertheless, this will increase risks resulting from a high number of potentially unknown suppliers. Thus, questions concerning the assurance of service quality, liability management and security of freight need to be considered.

Logistics service providers are currently using heterogeneous, sometimes archaic IT systems with various data standards and interfaces. Towards implementing a Cloud Logistics IT platform, questions regarding the definition of a common data model and interfaces need to be addressed. Further, it needs to be understood who, for example a dedicated institution, will drive this definition process.

Another field of future research focuses on how Cloud Logistics could influence the role of logistics service providers. Zacharia et al. (2011) argue that *"the role of 3PLs has evolved from a provider of logistics services to that of an orchestrator within the supply chain. Orchestration can be defined as the activity of managing, coordinating, and focusing the value-creating network."* Acknowledging their orchestration role, does this imply that 3PLs are tending to move into a "cloud operator" role? The same argument can be made for 4PL businesses which have, by definition, a neutral arbitrating role; integrate and coordinate the services rendered by other providers. Will these "service integrators" finally emerge in Cloud Logistics, providing end-to-end solutions? Will there be a difference in how small and medium sized logistics service providers will be affected compared to globally operating ones? Furthermore, in Cloud Computing, providers tend to specialize with respect to the three service models. Will a similar specialization happen in Cloud Logistics, i.e. with generally non-customer facing infrastructure and customer-facing service providers (Leukel et al. 2011)? Also some providers could specialize in IT solutions enabling Cloud Logistics.

The effects of Cloud Logistics on end customers need to be understood in detail. Customers will only support and request the implementation of Cloud Logistics if they can benefit from, for example, improved service levels and/or lower costs. If this assumption holds, will customers need to adapt their procurement strategies for Cloud Logistics services? Will customers accept that their goods are transported by potentially unknown suppliers? Further, which industries are likely to be early adopters of Cloud Logistics? For instance, in the fast moving consumer goods industry already today manufacturers and retailers closely collaborate (Christopher & Peck 2004). To add, will companies agree to share critical resources (e.g. inventory) with direct competitors? If yes, under what conditions?

Thus far, Cloud Logistics is a theoretical idea which cannot be observed empirically. Consequently, the actual performance in volatile, uncertain, and complex environments has not been evaluated. Nevertheless, some currently existing 3PL/4PL structures, freight exchanges, partial load and line based cooperations with and without a parent company share concepts with Cloud Logistics. Leukel & Kirn (2011) propose to utilize the theories of New Institutional Economics, say transaction costs theory, agency theory, and property right theory to evaluate "Cloud Value Systems". Applying these theories to existing 3PL/4PL structures could be a starting point to understand the performance of Cloud Logistics in a real business environment.

4. Conclusion

An adequate answer to the challenges for logistics arising from an increasingly complex, uncertain, volatile and less predictable environment seems to be found in principle by means of adaptive, coordinated, distributed, autonomous logistics systems based on decentralized self-control mechanisms in sense of Cloud Logistics. Nevertheless, it remains a long way to go until a first successful system implementation will be achieved. The variety of the generically outlined challenges ahead emphasizes the manifoldness of this research field for academic research but also for successful business implementation. The methods available in related research fields show that there is no need to start from scratch when approaching this task but rather that there exists a fruitful basis from which future research can set off. This certainly ushers in another important chapter in history of logistics.

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