

LOGISTICS 4.0: SMART INFRASTRUCTURE

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Abstract

The theoretical foundations of Logistics 4.0 are being researched at the OVG University of Magdeburg and the University of Miskolc. The model of the Smart Logistics Zone, which was jointly developed in Magdeburg by the Fraunhofer Institute IFF and Otto von Guericke University at ILM, can be used to describe logistics solutions. At its core, it differentiates between logistical objects, logistical processes, logistical systems and logistical infrastructure. The logistical infrastructure is currently gaining great importance. In the article, some important basics of infrastructure planning and current trends and developments are considered. The objectives are to characterise infrastructure holistically, to define new developments and to pose current research questions related to infrastructure.

Keywords: Logistics 4.0, Smart Logistics Zone, smart infrastructure

1. Introduction

Physical infrastructures are currently coming more into focus in politics, business and the media. This is supported by major investments worth billions, such as in the new Silk Road and the US infrastructure programme. In the scientific world of logistics, on the other hand, infrastructure has so far tended to lead a shadowy existence. This article is dedicated to the infrastructures used by logistics. Based on the analysis of current literature and own empirical knowledge, a scientific analysis of logistics infrastructure will be conducted, with a focus on smart infrastructure. The literature analysis is deliberately carried out primarily on the World Wide Web, as many infrastructure measures are published in political programmes, daily news and popular science articles. The goals of the scientific investigation are to record and systematise the existing knowledge in the field of logistics infrastructure and to derive recommendations for action for the logistician.

2. Smart Infrastructure: goals, term and relationship to Smart Logistics Zone

First, the question of how a smart infrastructure is defined and what all belongs to a smart infrastructure is clarified. For a better understanding of the term, a smart infrastructure will be characterised in the following.

Current trends and developments form the starting point. Two major trends are Industry 4.0 and sustainability. They allow properties as well as target and evaluation variables to be derived, such as digitalisation and networking, economy, ecology and social aspects. Many current infrastructure measures such as the preparation of 5G and the modernisation of the rail network can be classified here. As a cause of and affected by climate change, logistics also has major tasks ahead of it, especially in the area of infrastructure. Other important current objectives and thus also evaluation parameters relate to resilience, reliability and security.

Infrastructure is a "system of facilities, equipment and services necessary for the operation of an organisation" (DIN EN ISO 9000, 2015). In the logistics context, infrastructures are to be understood as a required necessity and basis for the performance of logistics services. The logistics infrastructure fulfils basic tasks of energy, information and material supply and disposal. Infrastructure are "the basic physical and organizational structures and facilities (e.g. buildings, roads, power supplies) needed for the operation of a society or enterprise". (Stevenson & Waite, 2011) Simply speaking, "Infrastructure" means those basic facilities and services which facilitates different economic activities and thereby help in economic development of the country, education, health, transport and communication, banking and insurance, irrigation and power and science and technology etc. are the examples of infrastructure. These are also called social overhead capital. These do not directly produce goods and services but induce production in agriculture, industry and trade by generating external economies (w.A., 2020). As society moves deeper into the twenty-first century, the societal demand on infrastructure assets is growing rapidly, with high expectations in terms of productivity and service delivery (Anaswamy, 2016). Table 1 first explains the term infrastructure.

Table 1. Term Infrastructure (Jochimsen, 1966) (Benedict et al., 2002)

Technical Infrastructure	Social Infrastructure	Green/blue Infrastructure
Transport infrastructure: roads, railway lines, shipping routes, air traffic	Education system	Interconnected network of waterways, wetlands, woodlands, wildlife habitats and other natural areas; greenways, parks and other conservation lands; ranches and forests; and wilderness and other open spaces that support native species, maintain natural ecological processes, sustain air and water resources and contribute to the health and quality of life
Energy and water supply	Healthcare system	
Disposal facilities for waste water, waste disposal, recycling	Justice and prisons	
Digital Infrastructure & communication	Nursing homes for the sick and elderly	
	Public administrations	

This quest for more efficient infrastructure associated with the rise of information technology (IT) has led to the concept of „smart infrastructure”, wherein enabling technologies such as connected sen-

sors and big data analytics are integrated with physical infrastructure in order to achieve real-time monitoring, efficient decision-making and enhanced service delivery (Weiss, 2009).

The potential benefits of smart infrastructure include decreased maintenance costs, reduced damage and disruption costs (i.e. traffic congestion or power blackout), increased quality and value of service (i.e. on-demand use and flexible tariffs), as well as protecting human life (i.e. better response to disasters) (Morimoto, 2010).

The intelligence of the infrastructure can be described by the following properties (Compare Müller et al., 2017):

- Integrated functions for identification, localisation and diagnosis of internal parameters,
- Ability to recognise physical conditions and measure outcomes (e.g. performance),
- Ability to process data to identify relevant information,
- Ability to interact with other smart objects and central information systems,
- Standardisation with uniform protocols.

Figure 1 shows how the smart infrastructure fits into the model of the Smart Logistics Zone. A smart logistics solution can always be characterised on the basis of the eight aspects mentioned: Initially, it does not matter in which areas the intelligence lies. The goal is to create logistics solutions whose intelligence corresponds to the requirements of the overall solution. Thus intelligence is not an end in itself, but is derived from the concrete customer requirements. The logistics infrastructure forms the basis for smart logistics objects, systems and processes. Only their interaction enables the implementation of the logistics service.

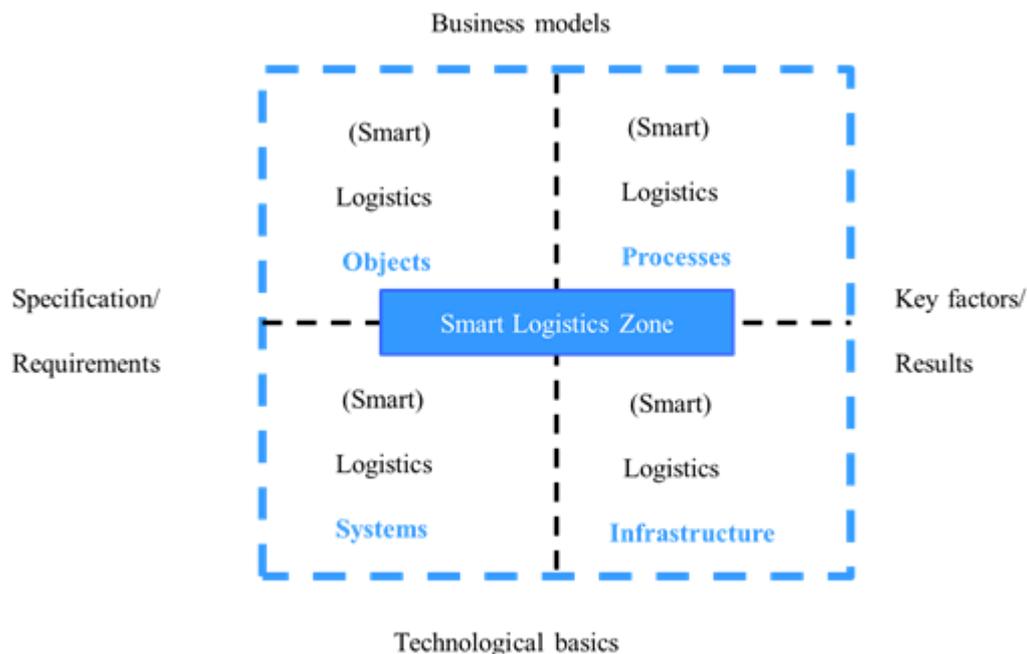


Figure 1. Smart infrastructure in the Smart Logistics Zone model (Glistau,2020)

First, the classic infrastructure objects (cf. Table 2) will be named as examples before the smart logistics infrastructure is characterised.

Table 2. Examples of "hard" infrastructure objects of the technical infrastructure

Infrastructure objects of the		Examples of "hard" infrastructure objects
IT and communication networks e.g. satellites, cables, data centres, fibre optic	Road traffic	Roads including motorways, bridges, tunnels, intersections, traffic lights, street lamps, traffic signs, traffic guidance systems, level crossings, roundabouts, car parks, rest areas, bus stops, ferries, toll stations, loading and unloading ramps, petrol stations and electric charging points, freight transport centres
	Rail transport	Tracks, signal boxes, stations, bridges, tunnels, railway parks, locomotive sheds, turntables, marshalling yards, repair workshops, railway depots, points, control and safety technology and crane systems
	Water traffic	Waterways, ship lifts, locks, lighthouses, marinas, ports, natural harbours, canal bridges, sea bridges, ship tunnels, quays and wharves
	Air traffic	Runways, towers, hangars, airport terminals, air cargo terminals, passenger transport systems and baggage handling systems
	Energy supply	Electricity grid, gas grid and compressor stations
	Disposal	Infrastructure of disposal technology including preparation for reuse, recycling, other (material and energy) recovery, disposal
	Water supply	Wells, pumps, water pipes and *waste water pipes (see also disposal), infrastructure of water supply companies and water treatment companies

In addition to the "hard" infrastructure components, there are also "soft" infrastructure components such as road traffic regulations, infrastructure management and infrastructure administration. (Cf. Infrastructure, 2019) The term institutional infrastructure includes the legal order, the social order and the economic order. In the context of logistical spaces and the impact of Industry 4.0 / Logistics 4.0, digital and smart as well as transport, energy and communication infrastructures are of particularly high relevance (compare Krampe et al., 2012).

The digital, also called information technology infrastructure (cf. Table 2) has a cross-sectional function and includes the technical information and communication systems for handling digital data. These include, for example, data centres and data transmission paths such as cables, satellites or radio frequencies. They are the basis of the technical communication infrastructure. They include mobile radio and fibre optic networks, routers for public WLAN as well as servers and IP addresses. Communication protocols define in which form, speed and quality data is transmitted and repair mechanisms are carried out (compare Geisberger & Broy, 2012) (Obermann & Weiß, 2016).

The term transport infrastructure refers to transport routes (e.g. road and rail networks), -stations (e.g. freight transport centres) and facilities (e.g. traffic lights) (cf. Table 2), (compare Malina, 2018). It enables the logistical flow of people and goods by means of the various means of transport (e.g. buses, trucks, conveyors) and thus represents the basis of logistics services. The same applies to the other modes of transport.

There is little general clarification of the term "smart infrastructure" in the scientific literature. Schenk characterises the infrastructure within Smart Logistics Spaces as "logistical infrastructure with an IT-technical ambient intelligence". (Schenk, 2015) Geisberger and Broy define smart infrastructures as a further developed digital infrastructure equipped with smart sensor and actuator technology for monitoring and controlling networked logistics processes. (Compare Geisberger & Broy 2012)

The literature distinguishes between four development stages of smart infrastructures: descriptive, prescriptive, predictive and plan-full (Compare Mynatt et al. 2017). This means with descriptive: the infrastructure detects traffic congestion, with prescriptive: the infrastructure offers an alternative route, with predictive: the infrastructure plans a route based on weather- and time-of-day-dependent patterns and with plan-full: the infrastructure takes over traffic control based on real-time information. (Compare Mynatt et al., 2017)

In order to describe the smart infrastructure on the basis of its characteristics in a morphological box, the following characteristics were used: Functionality, identification, localisation, sensors, data and information processing, data transmission technology, networking, command and control, actuators, cooperation technology and the type of software interface.

This newly developed morphology of smart infrastructure serves to characterise existing smart infrastructure and opens up options for the further development of infrastructures and their properties. Table 3 shows a small excerpt from the developed morphology.

Table 3. Excerpt of a morphology for the definition of smart infrastructures (Compare Lange, 2020)

Feature		Characteristic property								
Functionality		Identification	Localisation	Data collection	Data-processing	Data storage	Communication skills	Making decisions	...	
...									...	
Sensors	Function	none		Identification	Integrated smart sensor		Wireless sensor network			
	Measured variable	Physical						Chemical		
		Temperature	Power	Humidity	Surroundings	Object identification	Other	Concentration	...	
...									...	

3. Success stories of smart infrastructure

In the following, some examples of smart infrastructure will be named and characterised. Smart infrastructure solutions reduce energy consumption and energy costs. They help to reduce traffic-related emissions and enable the careful use of resources. Examples include streetlights that only light up when vehicles or people approach, or charging stations for company cars that optimise themselves automatically. On the other hand, they contribute to increasing road safety, traffic efficiency, enabling autonomous driving or supporting maintenance. Table 4 lists some success stories of smart infrastructure. This explicitly includes BIM (Building Information Modelling) as a digital data basis for infrastructure construction.

Table 4. Some success stories of smart infrastructure

Success story	Content	Application
Telematics solutions by using vehicle-to-everything (V2X) [19] [20]	Include vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-pedestrian (V2P) communication, Early warning of disruptions on the route	Collision warning, Construction site warning, Emergency vehicle detector, Column formation, Intersection assistant
Smart motorway [21]	Sensors record position, speed, direction of movement, Digital image of reality	Looking ahead to route, increasing traffic density
Smart crossing [22]	Sensor network enables transmission of a 360-degree model to road users	Increase road safety at blind intersections
Smart street lamp [23] [24]	Regulation of lighting according to the number of users in the area, natural lighting and special weather conditions	Reduce energy costs
Smart bridge [25] [26]	Detection of strain, vibration, inclination, humidity, pH value, temperature	Provide information on potential material weaknesses for targeted, preventive maintenance.
SAFARI digital test field [27] [28] and projects for the use of automated vehicles	Self-updating HD maps as a basis for automated driving, sensory environmental understanding and localisation of automated vehicles, Communicating road infrastructure, Identification of temporary events (e.g. road works), Use of automated vehicles as local public transport	Test fields and projects for urban transport
Smart airlock [29]	Information on water level, use high water level to fill sluice with as little energy as possible	Reduction of energy expenditure
New Silk Road [30]	Differentiated into land route "Silk Road Economic Belt" and sea route "Maritime Silk Road".	Planned to connect more than 60 countries and thus two thirds of the world's population
Smart Grid [31] [32]	Refers to an smart power grid, within which information is exchanged for the dynamic control of power generation, consumption and storage.	Realisation of temporally and spatially homogeneous power consumption through better integration of inhomogeneous power generators.

4. Tasks for the logistician to plan a smart infrastructure

Policymakers (BMVI in Germany) are drawing up their own packages of measures in relation to digitalisation and AI in mobility, for example, and defining fields of action that include the following:

- Expansion of an efficient, digital infrastructure,
- Equipping the transport structure with the necessary digital technology,
- Creation of a comprehensive and reliable data basis,
- Promotion of innovative technologies and their regulation for the automation and networking of vehicles, processes and services for all transport modes and
- Networking of measures and actors across transport modes in the overall system. (BMVI, 2021)

For the logistician, the following tasks arise for planning a smart infrastructure:

- Plan logistical requirements for the infrastructure,
- Planning the concrete infrastructure,
- Further development of infrastructure solutions,
- Research and evaluate relevant new infrastructure solutions,
- Transferring infrastructure solutions into implementation,
- Securing critical infrastructure,
- Connecting infrastructure, logistics object and logistics system into a smart overall solution (Smart Logistics Zone).

5. Research tasks/questions for the future in the thematic field of logistical smart infrastructure

The literature review revealed some gaps in the research, which will be illustrated with research tasks and questions. They provide starting points for a scientific discourse. As examples, some of them will be mentioned that are already being discussed or are in progress (cf. BVL, 2021), (Sucky & Haas, 2021):

- (1) Which scenarios are conceivable in order to be able to install a nationwide, smart infrastructure in Germany/Europe/the world?
- (2) How should the charging infrastructure in cities/regions/nationally be planned for individual means of transport (e.g. for e-cars or for cargo bikes)?
- (3) What does a nationwide infrastructure for hydrogen look like? What are the specific requirements?
- (4) What intelligence should be transferred to the infrastructure for autonomous driving?
- (5) How do climate change and other influences affect critical infrastructure?
- (6) What is the role of sustainability in smart infrastructure?
- (7) What are the drivers for implementing smart infrastructure? How are the responsibilities divided?
- (8) What are the benefits of deploying 5G for smart infrastructure?
- (9) How are the target variables of logistics changing? What impact does this have on the infrastructure?
- (10) What new technologies are needed to realise an smart logistics infrastructure? Can existing systems be upgraded to meet new requirements?

6. Summary

The logistics infrastructure is part of the logistics solution. In the scientific world of logistics, it has so far led a shadowy existence. In the article, the terms infrastructure and smart infrastructure are defined under a logistics focus.

The (smart) logistics infrastructure is placed in the model of the Smart Logistics Zone to describe Logistics 4.0 solutions. To show possible solutions, examples of new infrastructure solutions are named and briefly explained. The tasks of the logistician for planning the infrastructure are derived from the solutions. The article names exemplary research tasks and questions for the future in the subject area of logistics infrastructure.

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