VIENNA 2018 TRA
A digital era for transport
solutions for society, economy and environment

Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria

Research outlook: A study about inland ports in the Physical Internet

Sandra Stein*

TU Wien, Institute of Management Sciences, Division of Industrial and Systems Engineering, Theresianumgasse 27, 1040 Wien, Austria,

Abstract

Innovative mobility concepts for freight transport require a further digital (and physical) integration as well as a more efficient interconnectivity of all transport modes. Currently, freight transport networks are more or less fragmented and are mainly "managed" by forwarders, shippers or logistics service providers - there is no integrally operating transport network. Synchromodal transport can be regarded as enabler for such an integrally operating transport network and as an important constituent of the "Physical Internet". "PI hubs" and "conventional" (intermodal) logistic nodes need to be regarded as key factors for the success of the synchromodal system: They are the neuralgic nodes where trans-shipment is happening. They form the backbone of an interconnected, synchromodal logistics network and link flows to and from various origins and destinations. So far, basic research regarding the functional design of potential PI hubs was undertaken for unimodal road-based crossdocking hubs, road-rail hubs and road-transit centres, but just a superficial analysis of road-rail-water hubs has been conducted. When undertaking research on hubs and defining their new roles in the PI, it is not sufficient to concentrate on their functional design only: The integration of intermodal hubs at strategic level (*freight TEN-T*), tactical level (*Pan-European service profiles*) and operational level (*city-port relations*) has to be investigated as well.
This paper introduces a proposed research project ("InPoPI") which is about to start during 2018; explaining its objectives, expected results, state of the art and proposed methodology.

Keywords: Inland ports; Physical Internet; synchromodal transport; port development; simulation

* Corresponding author. Tel.: +43-676-88861627.
E-mail address: sandra.stein@tuwien.ac.at

1. Introduction

Innovative mobility concepts for freight transport require a further digital (and physical) integration and a more efficient interconnectivity of all transport modes. A high grade of standardisation of interfaces and modular logistic components will allow various applications such as tailored mobility concepts, efficient design of synchromodal networks, and intelligent transport systems.

Currently, the efficient design (operation, costs, reliability and emission) of inter- or synchromodal freight transport networks is receiving focussed attention in Europe: Shifting freight from road to rail or waterway and an increased competition on hinterland transportation are its most important reasons (cf. van Riessen et al. 2015, p. 386). Freight transport networks are more or less fragmented and are mainly “managed” by forwarders, shippers or logistics service providers; there is no integrally operating transport network. Synchromodal transport[†] can be regarded as enabler for such an integrally operating transport network and as an important constituent of the “Physical Internet” (cf. Pfoser et al. 2016).

> “The Physical Internet (PI) is an open global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols. (…) It has been introduced as a solution to the Global Logistics Sustainability Grand Challenge of improving (…) economic, environmental and social efficiency and sustainability of the way physical objects are moved, stored, realized, supplied and used across the world (…).” (Montreuil et al. 2012)

Comparable to a standardised global freight exchange network, the PI would be able to handle “black box” modular PI-containers[‡] carrying physical goods and information about them, using open and shared transportation networks for worldwide users. The functioning of the PI can be compared to the functioning of the Digital Internet, which does not spread information, but packets with embedded information as in e-Mails. The content within such a packet is encapsulated; the packet’s header comprises all necessary information to be able to identify the packet and lead it correctly to its destination. Though, the PI “borrows” the prevailing Digital Internet concept and would not manipulate physical goods directly, but containers designed for the PI (cf. Montreuil 2011). This would lead to the effect that the capacity of cargo space could be better used and the protection of the products would not be its package, but the PI-container. PI-containers would be digitally interconnected, monitored and routed continuously, leading to a “seamless, easy, fast, reliable and cheap logistics system” (cf. Montreuil 2012).

The following figure illustrates the links and the difference between the Digital Internet (as enabler of the Internet of Things (IoT) and the PI), the Internet of Things that “steers” PI-containers, and the PI as open logistics system:

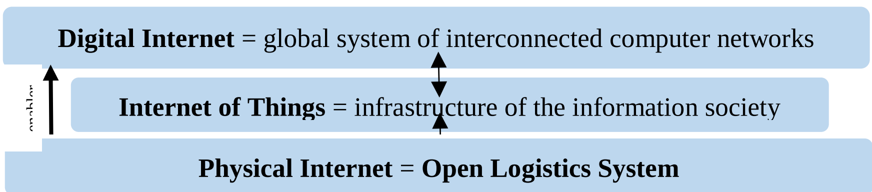

Fig 1 Delineation of contents (adjusted, ibid. p. 23)

Logistic nodes, transport modes and means, goods, data and infra- and suprastructure would be synchronised and (up to a certain extent) self-organising. Infra- and suprastructure would be decoupled from their owners, which would lead to the fact that any hub, warehouse or logistics facility could be used by any sender or receiver (“open hub” or “PI-hub”). The use of PI-hubs in comparison to the current situation would lead to shorter distances travelled, less fuel consumption and a reduced maximum delivery time, whilst the average delivery time would slightly increase due to more stops, which is illustrated by the following figure:

[†]“Synchromodality is the optimal flexible and sustainable deployment of different modes of transport in a network under the direction of a logistics service provider, so that the customer (shipper or forwarder) is offered an integrated solution for his (inland) transport.” (cf. van Riessen et al., p. 387)

[‡] The FP7-project „MODULUSHCA“ designed a prototype of such a modular container

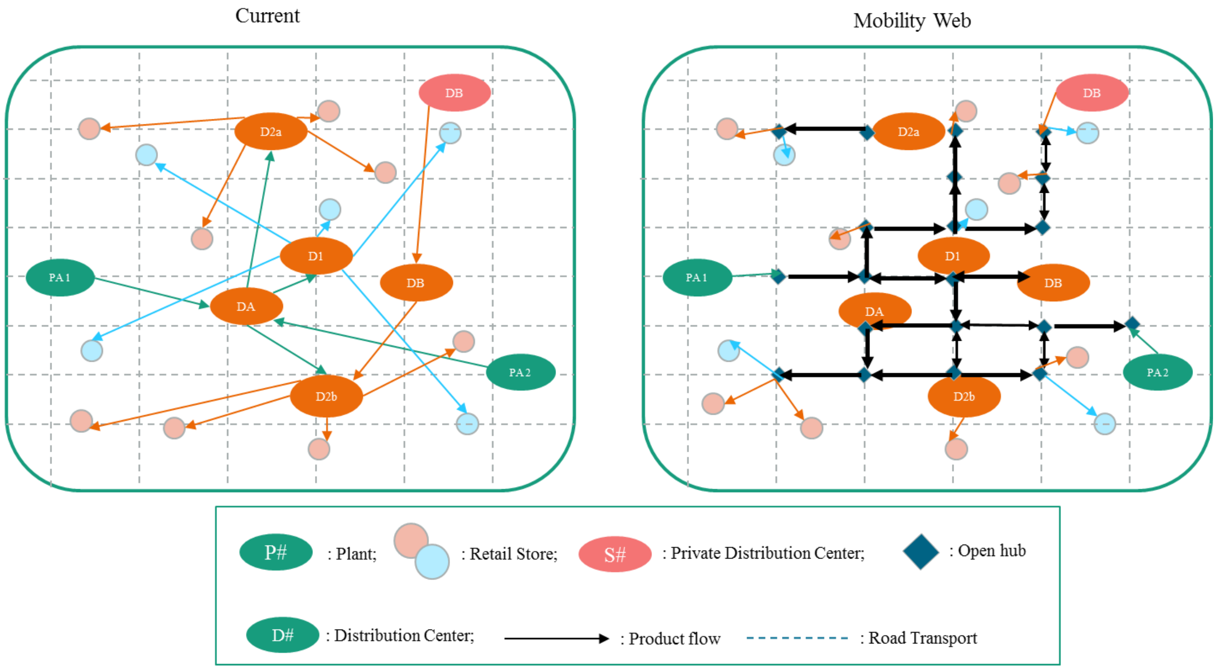

Fig 2 Example of current and potential future distribution network (adjusted, cf. ibid., p.28)

"PI-hubs" and "conventional" (intermodal) logistic nodes need to be regarded as key factors for the success of the system: They are the neuralgic nodes not only for all kind of trans-shipment processes, but for further logistical value-added services and the prolonged supply chain (container repair, final assembly, pick/packing, demand-driven inventory dispositioning, 3D-printing, and more). Hubs form the backbone of an interconnected, synchromodal logistics network and link flows to and from various origins and destinations.

For an efficient synchromodal transport and a possible implementation of the PI, smooth processes in hubs are required, such as loading/unloading with innovative means to make hub operations more efficient, an implementation of automated terminals, and more efficient container assignments, to name just a few approaches. Hence, measures for a reduction of handling time for sorting and consignment by automated consignment systems are mandatory. Moreover, flexible capacity- and storage planning for outgoing and incoming cargo and a seamless last-mile distribution into inner city areas are necessary (cf. Ballot et al. 2012).

At the same time, hubs need to be included in the supply chain more intensely by altering their traditional nodal service into being an active part of integrated value chains when it comes to real-time capacity/transport planning, or "agile warehousing". "Hubs have to operate as more than isolated collections of resources, equipment, and functions, each independently pursuing its own activities and goals." (Aulicino 2015)

So far, basic research regarding the functional design of potential PI-hubs was undertaken for unimodal road-based crossdocking hubs, road-rail hubs and road-transit centres (cf. Ballot et al. 2015, p.1), but just a superficial analysis of road-rail-water hubs (i.e. inland ports) was made. However, when conducting research on hubs and defining their new roles in the PI, it is not sufficient to concentrate on their functional design only: The integration of intermodal hubs at strategic level (freight TEN-T), tactical level (Pan-European service profiles) and operational level (city-port relations) has to be investigated as well (cf. SteadieSeifi et al. 2014).

Please note, that the author is fully aware of the fact, that the PI is up to now just a concept: there is little evidence if it could work or how it would actually work. However, it is the author's opinion, that this is what basic research is about – thinking the unthinkable. Furthermore, there is enough expert interest and support to justify focused research in order to support such a game change.

2. Objectives

The envisaged project's three main objectives (MO) are:
MO1: To expand the scientific knowledge base of theories in the "Physical Internet", "synchromodal transport", and "port development"
MO2: To define new roles of inland ports in the PI and to support the further development of the PI concept
MO3: To prove that inland ports are able to play an active and shaping role for future logistics, n order to support the development and implementation of the PI.

The main objectives are completed by the following sub objectives (SO):
SO1: To define framework conditions and requirements of PI and PI-hubs, especially inland ports against the background of synchromodal transport; to identify influence factors for inland ports in synchromodal networks, such as pricing, management, or logistics
SO2: To create a real data base for simulation and modelling in inland ports; to assess inland ports against the background of ability for synchromodal integration and PI-development
SO3: To reflect port development aspects in the PI and the synchromodal network to assess the potential impact of the PI and synchromodal transport on inland ports
SO4: To derive the most suitable business model principles for inland ports in the PI and the synchromodal transport network; to provide potential smart specialisation concepts for inland ports
SO5: To support to close research gaps in the "Physical Internet", "synchromodal transport", and "port development", to bridge the gap between theory and practice in mentioned research fields

The following research questions will be answered:
(1) In which way do theoretic models for port development have to be adapted or expanded when considering the role of inland ports in the PI?
(2) How can the theory of the PI be expanded by the definition of new roles for inland ports as an active element in synchromodal transport?
(3) How can different scenarios for the future of logistics influence the development of inland ports?
(4) Do synchromodal transports influence inland port's performance and which are the most suitable strategies for collaborative synchromodal transport?
(5) How does the PI influence port - city interfaces (connectivity index)?

3. Expected results

Within the period of 48 months, the author strives to generate the following results, amongst others:
- Catalogue of target system typologies and influence measures of PI and synchromodal transport
- One map of the influence sphere, stakeholder matrixes, connectivity indexes of each European inland port analysed to create a real data base for simulation and modelling of ports
- Simulation and digital inland port models in a synchromodal transport network to assess the potential impact of the PI on inland ports
- Min. two business models principles to support the development of inland ports in the PI
- One or two smart specialisation concepts for inland ports as PI-hubs
- Improved state of the art in theories of "Physical Internet", "synchromodal transport", and "port development"

4. Short overview of the state of the art

4.1. Synchromodal transport

"Synchromodal transport" as a relatively novel logistics concept aims at increasing the share of rail and inland waterway transport (IWT) by integrating different modes of transport (MOT). Inter- and multimodal transport chains make use of at least two MOT; co-modality is characterised by an optimised and efficient use of MOT to maximise each MOT's benefit. In addition to that, *real-time decisions* on the use of the best suitable MOT, even when the goods are already on track, are typical for synchromodal transport (cf. Putz et al. 2015). This applies for events such as weather conditions, congestion, infrastructure defects, or similar. That aspect easily contradicts the standard arguments why IWT is used unfrequently (unreliable, slow, inflexible, and more). In synchromodal transport, customers allow mode-free booking, which means that the logistics provider or carrier is enabled to decide on the best available transport alternative and all stakeholders do collaborate in optimising the entire transport chain (cf. SteadieSeifi et al. 2014). Therefore, a mind and paradigm shift, especially within the logistics providers' branch, is the necessary base for such interoperability. Again, the role of PI-hubs is important: The synchromodal transport chain as a whole can only be performing as good as the hub and its interoperability with other elements of the chain is performing. Therefore, InPoPI will model synchromodal transport chains in four European, one Asian and one American inland ports and assess their impact on the respective hubs.

Synchromodal transport is not a widespread concept in Europe, but known in the Benelux countries, where a synchromodal network was successfully implemented between Rotterdam, Moerdijk and Tilburg. Its impact was assessed at Rotterdam's Maasvlakte terminal: The pilot demonstrated that it is possible to achieve a stable modal split of 19% road, 46% inland waterway and 35% rail, surpassing the port's goals for the year 2033 (cf. Pfoser et al. 2016, p.1464). Especially the free choice for the most efficient MOT and the collaboration between all stakeholders as a kind of "freight exchange" underline that synchromodal transport is one important element of the PI. Recent research ("SynChain") has shown that "cooperation and trust between various companies and stakeholders of the transport chain are crucial" key enablers. At the same time, it could be revealed that focusing on synchromodal transport without launching other elements of the PI does not lead to a successful implementation (cf. Putz et al. 2015, p.14). Therefore, it is necessary to conduct further basic research on other elements of the PI, such as PI-hubs, to contribute to a more detailed knowledge base and support the development of the PI concept. One interesting aspect that will be analysed is the *effect on the reliability and robustness of the synchromodal transport system when shifting freight to inland waterway transport, respectively inland ports as PI-hubs*. Hence, time windows at terminals and destinations, on-trip dynamics regarding infrastructure and service variations and disruptions as well as transport operators' responses in terms of rerouting decisions (cf. Zhang und Pel 2016, p. 8) will be considered and included in the InPoPI simulation for synchromodal transports.

4.2. Port development theories

A stronger focus on hinterland transport and, of course, the approach of synchromodal transport including an intense network orientation lead to the necessity to re-define the role of inland ports in transport (and value) chains. Even in 2005, when inter- and multimodal transport got increasingly important, Notteboom and Rodrigue claimed that current models for the evolution of ports and port systems would only partially fit into (at that time) new freight distribution paradigms.

Within Europe, inland ports differ strongly concerning size, catchment area, integration into the transport network, equipment, and offered range of service resulting from various factors such as the TEU volume handled, expendabilities, and financing possibilities. In the proposed project, four European inland ports (Paris, Liege, Vienna, and Mannheim) and two non-European ports will be analysed to expand the scientific knowledge base in theories of port development and to expand their state of the art and concerning synchromodal transport. They serve as models to prove that inland ports are able to play an active and shaping role for future logistics and especially the PI to support the development of the PI-concept. The following (sea) port development theories will be taken into account and are shortly described (where applicable, further theories will be considered as well):

4.2.1. Anyport model

Bird's *Anyport model* (1963) concentrates on port infrastructure development throughout three different stages: First ports, whose location had geographical background (supply and disposal of agglomerations), close to agglomeration centres, were fishing ports with trading and shipbuilding activities (cf. Rodrigue 2006). Forced by the industrial revolution, ports developed with regard to an expansion of quays, warehouses, shipbuilding activities (docks), the link to rail lines and industrial activities. The phase of expansion was followed by specialisation of ports (container handling, different foci on branches, enlargement or replacement of port areas) and even reconversion of abandoned locations (known as waterfront development). The model includes a viable description of how ports and their port cities interact with each other (port – city interfaces, see paragraph c)). The *Anyport model* was developed to compare the development stages of existing ports and could be proved as useful explanation of port evolvement, for example by Hoyle in 1967 (cf. ibid). The proposed project could expand the *Anyport model* by a phase of "system opening" (or similar), see figure 3.

4.2.2. Port regionalisation concept

The port regionalisation concept expands Bird's Anyport model. Due to the fact, that *Anyport* did neither consider the growth of sea terminals as transhipment nodes in the hub-and-spoke system nor the integration in inland terminals, Notteboom and Rodrigue (2005) proposed two further phases for the port system development: Firstly, the specific element of offshore hubs (such as Freeport, Algeciras, Malta, or Salalah (Oman) on an island location or locations without a significant local hinterland) completes the concept. Their peculiarity is that most of them are sea ports with great depth, recently built for modern containership draughts, resulting in a technical advantage in comparison to established sea ports and offer space for expansion (cf. Notteboom, Rodrigue 2005). Secondly, inland freight distribution centres and terminals as active nodes are considered, which is the "regionalisation" aspect per se. Their functional interdependency and multimodal logistics platforms lead to an implementation of a "regional load centre network" (cf. ibid, p. 5). That stage of development describes the integration of inland terminals into distribution systems and the global production network. In that context, efficient inland distribution is getting increasingly important when it comes to competition between inland ports as hubs (quick processes, low handling fees, easy accessibility, and wide range of services offered, adequate infra- and suprastructure are just some decision factors). However, the development of logistics networks has even moved on and might further develop into the PI (or something similarly open): "International supply chains have become complex and logistics models evolve continuously as a result of influences and factors such as globalisation and expansion into new markets (…)" (cf. ibid, p.6). The following figure shows the six phases of the spatial development of port systems according to Notteboom and Rodrigue, and a potential seventh phase added by InPoPI:

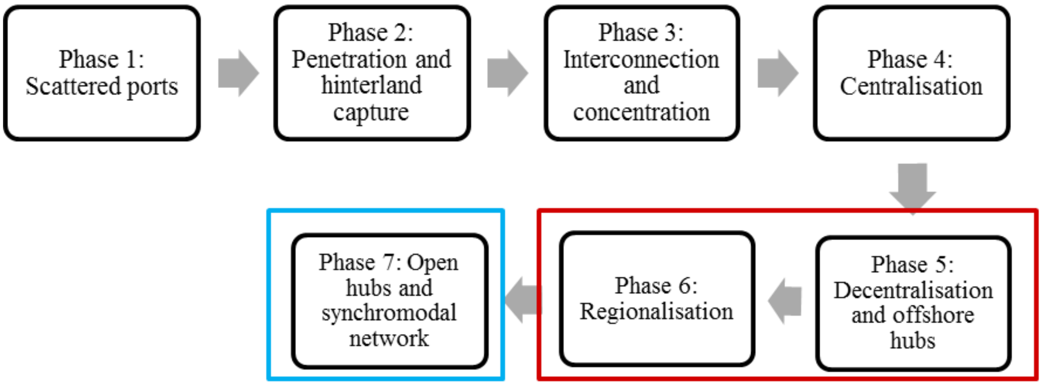

Fig 3 The spatial development phases of a port system and their potential expansion (adjusted)

4.2.3. Port - city interface models

Hayuth was the first to describe a model of the evolvement of cities and ports in 1982: When host port cities and port facilities themselves enlarged, ports were forced to relocate from city centres to outskirts where extension areas were available. As first effects, there was hardly any connection between ports and their cities, underlined by Hoyle in 1982 (cf. Urbanyi-Popiołek, Klopott 2016) and 1989 ("ports and host cities have been growing apart"). A quarter decade later, Hall and Jacobs' (2012) model concluded that there indeed are positive and negative relations between ports and cities when it comes to an increased demand for employment through port activities, tax revenue and economic activity in a certain port catchment area. The other way round, the model shows that increasing importance of cities, development of transport infrastructure or industrial activity do attract cargo flows and therefore lead to higher throughputs in ports. Pollution, congestion and imported commodities are mentioned as negative impact of ports on cities (cf. Hall und Jacobs 2012). Debrie and Raimbault (2016) add the importance of urban governance and port - city development, especially the link between production of the city and the sector-territory dialogue (p. 186). Particularly when it comes to logistics zone or coalitions, an active dialogue between all stakeholders is necessary for a long-term development of port and city. Akhavan (2017) investigated Dubai's port and city symbiosis since the 1900s and proposed a four-phase evolutionary pattern showing that "within less than 100 years, growing from a primitive port of the 1900s to a regional hub port-city by the late 1990s." (p. 349). Janjevic and Ndiaye (2014) explicitly tackle the role of inland waterways and ports for city logistics, assuming that some small-scale solutions for city logistics exist for example in Paris, Brussels, Vienna, Budapest or Pisa.

They stress the necessity of an active involvement of public authorities with regard to implementation (p. 287). In the PI, interfaces between ports and cities have to be examined from another perspective: Influence of the PI on port – city interfaces and their relation, or competition between open hubs. InPoPI will contribute to an improvement of the state of the art of port – city interfaces in such aspects.

5. Methodology

A combination of quantitative (exploratory case studies, modelling and simulation) and qualitative research (expert interviews) will be applied. Accordingly, the author's role as researcher will vary from reactive to non-reactive during the project, depending on the content of the respective tasks. It is not possible to make use of a plain inductive approach due to the non-existing population of PI-hubs; a sheer deductive approach is not considered effective as both PI and port development theories up to now are lacking thematic detail. Hence, structuring the topic will be inductive (with the help of the defined practical problem). Identifying gaps in theories will be deductive; empirical studies and simulation will lead to a verification or falsification of hypotheses/research questions, which will be finally integrated into existing theories.

5.1. Exploratory case studies in six inland ports

Four European inland ports have been chosen for the case studies at different TEN-T corridors, namely the ports and cities of Paris (at the Seine and the Le Havre-Range), Liege in the Rhine-Schelde-Meuse basin (important as hinterland hub for Rotterdam, Antwerp, Zeebruges, Dunkirk), Vienna at the Danube (TEN-T 17, 18, 22 important for Hamburg, Venice, Koper, Constanta) and Mannheim at the Rhine (important for the Rhein-Neckar metropolitan region). The ports have already confirmed their collaboration. Moreover, one Asian port and one American port will be analysed (which ones will be decided at a later stage). Exploratory case studies are expected to produce real data providing a base for the simulation of ports and their digital models. Case studies will result in a map of the influence sphere of each European inland port analysed. A quantitative questionnaire for the ports will create a valid data base and a stakeholder analysis (primary, secondary and key) by stakeholder mapping (influence-interest grid) will enable the drawing of a complete picture of the port and its influence factors, serving as base for the business models principles and specialisation concepts. For each port, its city-port relation is analysed, illustrated by connectivity indexes. Together with the port authorities, a minimum of two transport chains will be selected and synchromodal transport options simulated.

5.2. Expert interviews

In each case study, expert interviews with stakeholders (approx. 10 per case with port authorities, logistics providers, public authorities, PI-experts, researchers) are conducted as their results are used to produce real data (framework information) input for the simulation. *Explorative* (applied in little investigated field for explorative purposes) and *theory-generating* methods (reconstruction of implicit knowledge of action and interpretation) will be employed. A standardised questionnaire will be generated; the analysis will contain the following six steps: Transcription, Paraphrasing, Headlining, Thematic Comparison, Scientific Conceptualisation and Theoretical Generalisation.

5.3. Discrete Event simulation and Agent-based modelling and simulation

The exemplary ports will be transferred into simulation models, which are essential to get a scientific reliable output and digital models of the ports. Simulation approaches for logistics and transport can be differentiated by their various purposes such as strategic planning, operative planning or network control. The simulation method describes the type of time-lapse control that can be time-discrete, event-discrete or respectively continuous processes. Various methods such as *hybrid simulation-analytical modelling, system dynamics, Monte Carlo simulation, discrete event simulation or agent-based simulation* are common. Two simulation approaches will be applied in WP 3 and their state of the art is therefore described here: *Discrete event simulation* (DES) as a modelling approach widely used as decision support tool in logistics and supply chain management (cf. Tako und Robinson 2012) and *agent-based modelling and simulation* (ABMS).

In the proposed project, DES will be used for modelling different scenarios (see above) in inland ports as PI-hubs. A state of the art summary of container terminals is provided by Stahlbock und Voß (2007) and Steenken, D., Voß, S., Stahlbock, R. (2004) concentrating on operation and methods for optimisation in the single subsystems. Acciaro and McKinnon (2013) present a state of the art summary regarding hinterland transport management: The approaches include optimisations regarding yard planning, berth allocation problems, crane scheduling and transport planning. Boer and Saanen (2008) introduce the seaport container terminals simulation and emulation "CONTROLS". With regards to application of *DES* in inland ports (or, in most cases, terminals) and their functional design, a first discrete simulation model of stacking methods and strategies of cranes at their specific working area in sea port container terminals was introduced by Duinkerken et al. (2001). The coordination of terminal equipment was improved in 2007 by Chen et al. with a mixed-integer programming model. A decision support system for the berth handling in container terminals was presented by Murty et al. (2005): Algorithms and models to minimize the berthing time and reduce the resource-input as well as the storage utilisation were developed. A container sequencing for quay cranes with internal reshuffles was developed by Meisel and Wichmann (2010). Gambardella et al. described a scheduling for loading and unloading operations in intermodal terminals in 2001, Jung and Kim presented a load scheduling algorithm for multiple quay cranes in sea port container terminals in 2006. According to Jürgen 2001, the planning of a terminal involves the steps described in the following figure:

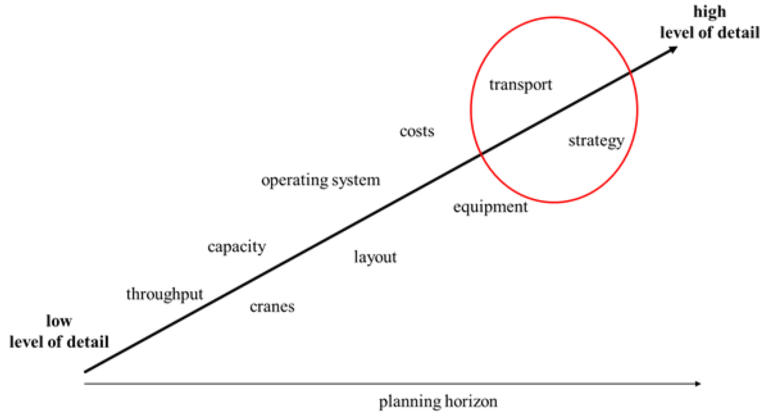

Fig 4 Planning tasks depending on the level of detail, focus for InPoPI (adjusted, cf. ibid.)

During the planning steps, planning information is available at a different Level of Detail (LoD), starting with a low LoD during pre-planning and ending with a high LoD during the operation of the terminal. For the proposed project, it is necessary to model potential scenarios with new logistic concepts for future demands that includes *strategies and transport* (network), for which the LoD is high and what makes it more complex than functional design. To verify DES results, the simulation library "TerminalSim" might be used. "TerminalSim" is based on the Logistics Suite of the simulation software Enterprise Dynamics8.

For modelling the respective synchromodal transport chains, the *agent-based modelling and simulation* (ABMS) will be used. According to Hakimi (2012), agent-based simulation is appropriate to simulate complex logistics webs and thus to depict synchromodal transport networks. It is based on multi-agent systems (MAS). An agent responds to its environment and can detect changes and take appropriate measurements to respond, which is necessary for the case of synchromodal transport. The autonomy of an agent entails that it defines its own conduct. An agent is socially cooperative by interacting with other agents. The premise for this is that a min. of two or more agents exist in a model, which is then referred to as a *multi-agent system (MAS).* Besides the fact that it is a system with multiple agents, the following additional characteristics are typical of MAS: Incompletely available information, limited problem-solving abilities of each agent, decentralised data storage (each agent stores its data locally), calculations are made locally and asynchronously, and there is no central supervisory authority. A simulation that uses multi-agent systems is called an agent-based modelling and simulation (ABMS). There are various application types of agent-based systems, such as business process management, entertainment; e-commerce, knowledge management and simulation of complex systems (cf. Weiss, Jakob 2005). Julka et al. (2012) provide a general approach to *model a supply chain through software-agents* and present different types of agents and their attributes. Each existing agent takes over different tasks and functions in the model. Furthermore, there are two additional object types (messages and goods) which are exchanged between different agents in order to *simulate the material and information flow.* Using these components, company- or hub-specific transport chains can be modelled (ibid).

As part of the research and development project CoagenS, an agent-based software system for supply chain management has been developed. The supply chain is divided into suppliers, carriers and customers, which is very similar to the approach in InPoPI: For each of the stakeholders of the synchromodal transport chain, an agent system within the MAS will implemented. The usage of cooperating software agents is expected to bring competitive advantages (Dangelmaier et al., 2004).

Zhang and Pel (2016) developed a "Synchromodal Modelling Operator" which joins road, rail, and navigable inland waterway networks (p. 3ff). Fleet size, frequency, departure times, route, speed, and travel time are modelled. The model consists of a "demand generator, a super-network processor, a schedule-based flow assignment module, and a system performance evaluator" and is "implemented in the TransCAD® GIS-based transportation planning software". (ibid). If suitable for InPoPI, the author will contact Delft University of Technology to further collaborate on the development of the model.

To sum it up, DES will be used for modelling scenarios in inland ports as PI-hubs and ABMS for modelling the respective synchromodal transport chains. As a software, preferably AnyLogic will be used, as it enables agent-based simulation and the depiction of processes at company and network level and supports discrete event and system dynamics simulations.

6. References

Acciaro, M.; McKinnon, A. (2013): Efficient Hinterland Transport Infrastructure and Services for Large Container Ports. International Transport Forum 2013, Discussion Papers No 2013–19, 1-31., 2013.

Akhavan, M. (2017): Development dynamics of port-cities interface in the Arab Middle Eastern world - The case of Dubai global hub port-city. In: Cities 60, 343–352.

Aulicino, A. (2015): Corridors, Hubs and Synchromodality. Research & Innovation Roadmap. Hg. v. ETP ALICE. Alliance for Logistics Innovation through Collaboration in Europe. Online available at http://www.etp-logistics.eu/?page_id=79, 04.11.2016.

Ballot, E. et al. (2012): Functional design of Physical Internet Facilities: A road-rail hub. In: Progress in Material Handling Research 2012 (MHIA, Charlotte, NC (2012)), 1–34.

Boer, C. A.; Saanen, Y. (2008): Amulation to improve the Performance of Container Terminals. In: Proceedings of the 2008 Winter Simulation Conference, 1094–1102.

Crainic, T.; Montreuil, B. (2016): Physical Internet Enabled Hyperconnected City Logistics. In: Transportation Research Procedia 12, 383–398.

Debrie, J.; Raimbault, N. (2016): The port–city relationships in two European inland ports. A geographical perspective on urban governance. In: Cities 50, 180–187.

Duinkerken, M. B et al. (2001): A simulation model integrating quay transport and stacking policies on automated container terminals. In: Proceedings of the 15th European Simulation Multiconference, 909–916.

Gambardella, L. et al.M. (2001): An optimization methodology for intermodal terminals management. In: Journal of Intelligent Manufacturing 12, 521–534.

Hakimi, D. et al. (2012): Simulating a physical internet enabled mobility web: The case of mass distribution in France. In: Proceedings of the 9th International Conference of Modeling, Optimization and Simulation, 1–10.

Hall, P.; Jacobs, W. (2012): Why are maritime ports (still) urban, and why should policy-makers care? In: MARITIME POLICY AND MANAGEMENT (39), 189–206.

Hayuth, Y. (1982): The port-urban interface: an area in transition. In: Area 14 (3), 219–224.

Janjevic, M.; Ndiaye, A. B. (2014): Inland waterways transport for city logistics: a review of experiences and the role of local public authorities. In: urban Transport 20, 279–290.

Jung, S. H.; Kim, K. H. (2006): Load scheduling for multiple quay cranes in port container terminals. In: Journal of Intelligent Manufacturing, 479–492.

Jürgen, W. B. (2001): Handbook of Terminal Planning. Berlin.

Meisel, F.; Wichmann, M. (2010): Container sequencing for quay cranes with internal reshuffles. In: OR Spectrum, 569–591.

Montreuil, B. (2011): Towards a Physical Internet. Meeting the Global Logistics, Sustainability Grand Challenge. Québec/Canada. Online available at http://www.physicalinternetinitiative.org/Towards%20a%20Physical%20Internet%20-%20Document%20-%20Benoit%20Montreuil.pdf.

Montreuil, B. (2012a): Physical Internet Manifesto. CIRRELT, FSA, Université Laval. Seville/Spain, 28.11.2012. Online available at http://www.physicalinternetinitiative.org/Physical%20Internet%20Manifesto_ENG_Version%201.11.1%202012-11-28.pdf.

Montreuil, B. et al. (2012b): Physical Internet Foundations. In: IFAC Proceedings Volumes 45 (6), 26–30.

Murty, K. G. et al. (2005): A decision support system for operations in a container terminal. In: Decision Support Systems 39 (3), 309–322.

Notteboom, T., Rodrigue, J. (2005): Port regionalization: Towards a new phase in port development. In: MARITIME POLICY AND MANAGEMENT (Vol. 32, No. 3), 297–313.

Pawlewski, P. (2015): Asynchronous Multimodal Process Approach to Cross-Docking Hub Optimization. In: IFAC-PapersOnLine 48 (3), 2127–2132.

Pfoser, S.; Treiblmaier, H.; Schauer, O. (2016): Critical Success Factors of Synchromodality. Results from a Case Study and Literature Review. In: Transportation Research Procedia 14, 1463–1471.

Putz et al. (2015): Identifying key enablers for synchromodal transport chains in Central Europe. University of Applied Sciences Upper Austria. Online available at http://research.fh-ooe.at/de/publication/4548.

Rodrigue, J. et al. (2006): The geography of transport systems. New York.

Stahlbock, R.; Voß, S. (2007): Operations research at container terminals – A literature update. In: OR Spectrum. Online available at http://www.springerlink.com/content/018j57r4364148m0.

SteadieSeifi, M.; Dellaert, N. P.; Nuijten, W.; van Woensel, T.; Raoufi, R. (2014): Multimodal freight transportation planning. A literature review. In: European Journal of Operational Research 233 (1), 1–15.

Steenken, D., Voß, S., Stahlbock, R. (2004): Container terminal operation and operations research – a classification and literature review. In: OR Spectrum, 3–49.

Tako, A.; Robinson, S. (2012): The application of discrete event simulation and system dynamics in the logistics and supply chain context. In: Decision Support Systems 52 (4), 802–815.

Urbanyi-Popiołek, I.; Klopott, M. (2016): Container Terminals and Port City Interface – A Study of Gdynia and Gdańsk Ports. In: Transportation Research Procedia 16, 517–526.

van Riessen, B.; Negenborn, R.; Dekker, R.: Synchromodal Container Transportation: An Overview of Current Topics and Research Opportunities 9335, 386–397.

Yang, Y.; Pan, S.; Ballot, E. (2015): A model to take advantage of Physical Internet for vendor inventory management. In: IFAC-PapersOnLine 48 (3), 1990–1995.

Zhang, M.; Pel, A. J. (2016): Synchromodal hinterland freight transport. Model study for the port of Rotterdam. In: Journal of Transport Geography 52, 1–10.