

Inducing a new paradigm shift: A different take on synchromodal transport modelling

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Abstract: *To achieve socio-economic and environmental sustainability, utilization of existing capacities and assets has become a key challenge for the transportation sector. New concepts such as the Physical Internet and synchromodality offer an alternative to the current “business as usual” setting of freight transport services. In this paper, we thus start by conceptualizing the Physical Internet (PI) and synchromodal transport where we examine the state-of-the-art models together with their designs and methodologies proposed in the scientific literature. This is to assess and explore possible correlations between these two concepts to understand how they can reinforce each other. The assessment results in a more unified vision of the freight transport research. The focus of our second objective is on synchromodality, where we translate the PI methodological approaches into a new conceptual framework for synchromodal transport modelling. Given the analytical nature of all synchromodal transport models, the authors intend to induce a paradigm shift; a different way of thinking about the modelling philosophy related to synchromodality. The underlying elements of our approach are multi-agent technology and GIS.*

Keywords: *physical internet, synchromodal transport, intermodal transport, agent-based modelling, geographic information systems.*

1 Introduction

With projected growth of international trade and cargo demand, the current infrastructural capacities are put under pressure resulting in congestion problems, safety issues, environmental concerns and decreasing reliability of services. Instruments used in the expanding market (EC, 2011). Therefore, it is necessary to introduce innovative solutions that would support optimal integration of different transportation modes and their cost-effective use. To achieve socio-economic and environmental sustainability, utilization of existing capacities and assets has become a key challenge for the transportation sector. This challenge has been recognized by many scholars, policy makers and practitioners leading to a substantial body of new concepts, models and initiatives. One of these concepts is synchromodal transport which is built on the same chain composition like intermodal transport combining two or more modes in a single run (Reis, 2015) but the main differentiator is the ability to detect and respond to unexpected infrastructural developments (congestion, accidents, low water levels, blockages, maintenance etc.) that lead to delays and time/money losses. Besides these external aspects affecting the smooth flow of freight transport processes, the purpose of synchromodality is also to synchronize containers/orders with other modes so that a more resilient transport system is achieved. Thus, incorporation of real-time information in a dynamic manner should facilitate the most suitable selection of modes, routes and handling

points. These selection decisions are not predefined long in advance, but are taken as late as possible (Verweij, 2011). In this type of dynamic environment, new technologies and modelling approaches are necessary. However, all current modelling approaches that focus on the dynamic context of synchromodal transport are based on mathematical formulations using analytical models. Synchromodality is contingent due to the wide range of external inputs that affect internal resource states, and current practices are not always convenient to simulate the changing world as they are based on static principles and heavily simplified environments. To reflect on real-world developments more accurately, new thinking and modelling approaches are necessary to bridge academic models with physical transport processes. To facilitate the synchromodal complexity, we address another emerging trend; the parallel evolution of the Physical Internet (PI) presents an opportunity to consider its physical, digital and operational interconnectivity with the synchromodal vision. We thus start by exploring the correlations between these two concepts to understand how they can reinforce each other (section 3). Section 4 addresses agent-based modelling (ABM) and Geographic Information Systems (GIS), and section 5 introduces our conceptual approach. Conclusions and future research are described in section 6.

2 Methodology

This scientific literature review applies a computerized search strategy to detect and gather papers from different channels. As an initial step, SSRN (Social science research network) database was searched in order to acquire publications which contain the following words: the Physical Internet/PI, synchromodality, synchromodal transport or dynamic/flexible freight transport. These words of interest had to appear in the title, abstract or keyword section of journal publications. Next, an additional search was performed covering electronic databases such as research gate and google scholar. Only freight related research was considered

out. Papers and conference proceedings related to flexible and real-time modelling of freight transport were included as well to account for the synchromodal nature. Relevant research retrieved from authors we knew about based on informal connections is also included in this review together with studies tracked through previous citations of earlier work (ancestry approach). The body of literature related to the Internet of Things (IoT) is beyond the scope of this review. Figure 1 depicts the division of the reviewed papers discussed in the following sections.

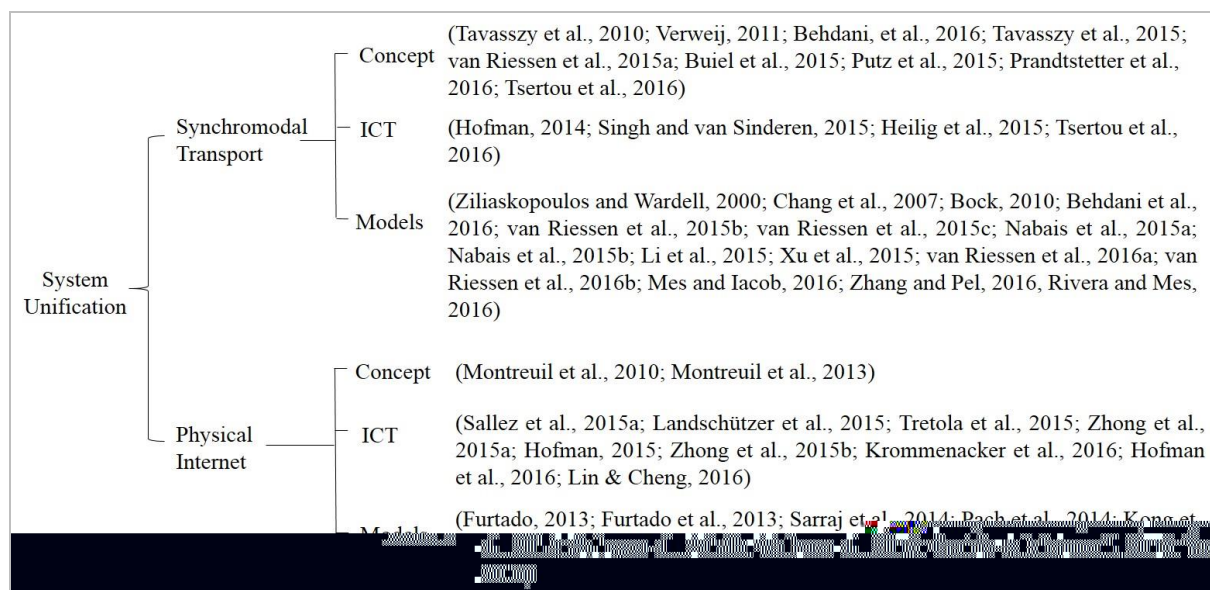


Figure 1: Overview of recent developments in freight transport.

3 Unifying synchronomodality and physical internet

The general observed pattern, observed in the literature review, indicates two integrative flows. The PI research tends to address manufacturers, retailers and distributors whereas synchronomodality aims at LSPs, terminals and network operators. The PI can thus be perceived as a major supply chain project covering the strategic level by designing means and operations to improve and optimize the vertical integration. In this regard, the warehouses and manufacturing sites are to be decentralized and moved closer to the point of consumption. On the other hand, synchronomodality approaches the supply chain from a different angle where the focus is given on horizontal integration, accounting for operations at the tactical and operational levels. In this setting -containers can be pooled in a collaborative way while improving the chain resilience with disturbance management, event handling and dynamic response modelling to support better asset and network utilization. Given these two integrative flows, the unified transport system has the potential to become an intertwined set of flows resulting in a holistic supply chain resilience and efficiency. The commonalities of the studied concepts are very noticeable since both constitute of 3 main entities with similar characteristics. Figure 2 depicts these characteristics by overlaying the integrated views of the synchronomodal service design and PI elements. Despite these similarities, each element addresses problems at different levels with unequal dimensions. Nevertheless, these gaps present opportunities where the concepts can complement each other to create a more resilient and efficient transport system. The following sub-sections elaborate further on these opportunities by assessing the relations between the customer and -containers -movers (LSP Assets), closing with stationary -nodes (Freight Grid).

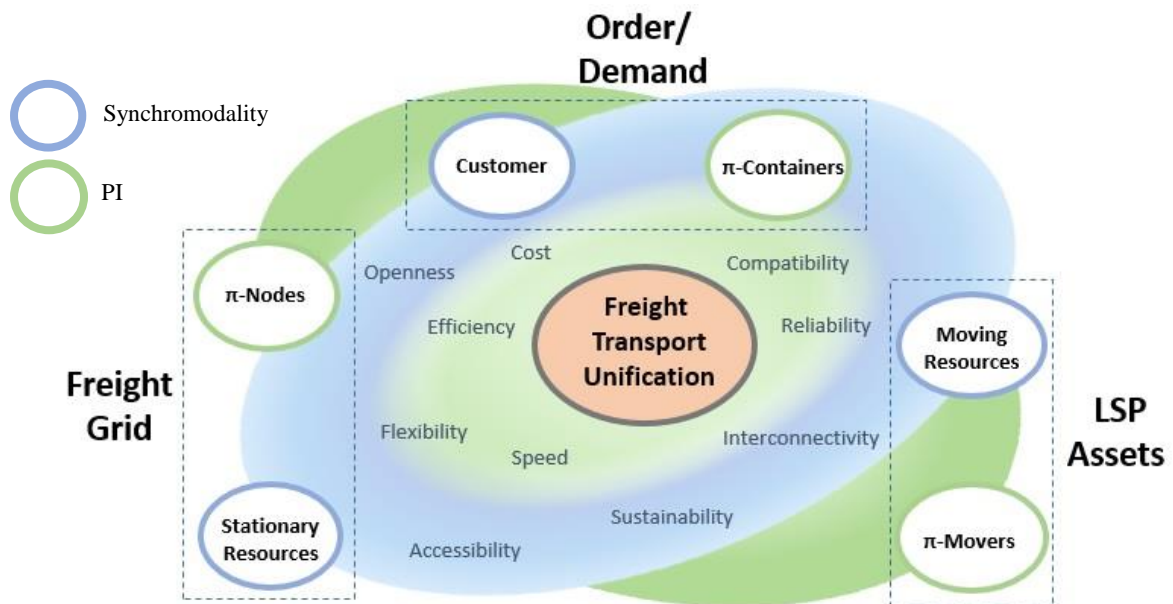


Figure 2: An overlaid unified vision of the synchronomodal and PI concepts (Source: own setup, based on Montreuil et al. (2010) and Behdani et al. (2016))

3.1 Order/Demand

The Order/Demand group consists of the customer, who ships products, and the -containers, which are boxes containing the products in this unified setting. The PI encapsulation is the core differentiator from the contemporary packing and handling of goods. In the current (synchronomodal) freight transport state, the networks are highly proprietary and the opportunities among competitors, who could engage in collaboration, are hindered by trust.

- containers are to serve
- t cannot be open by the transporting party but
- containers are handled by service providers
- container, resulting in a more secured and trustworthy

order combinations w

containers would be treated as black boxes. Smart tags and sensors described in the reviewed papers, also contribute to better visibility of orders based on tracking and location intelligence

-containers. The visibility is a crucial factor for establishing a unified system which can then identify dedicated overlapping flows. The unified system should therefore be a system that assesses these inefficient flows and translates them into a transparent web where orders and freight volumes can be

-container research, such as the MODOLUSHKA project in Landschützer et al. (2015), prototypes mostly packing containers (p-containers) and pallet-level containers (h-containers) at a single enterprise level whereas limited research is done on transport containers (t-containers) being carried by trucks, trains and barges. This gap can be filled by synchromodality by addressing the flexible revenue management and order resilience in terms of cancellation and delay handling of t-containers which are the biggest transportation unit carrying the p- and h-containers. The combination offers a more holistic approach where the PI deals with fill rates and space utilization at pallet levels and synchromodality with external container management that occurs outside warehouses and manufacturing facilities.

3.2 LSP Assets

-containers. Since the logistics web enabler consists of inter-connected physical, digital, human, organizational and social agents, the PI allows any goods to be handled by any kind of LSP as long as they are PI certified (Montreuil et al., 2013). In this setting, the shipper determines pick-up location, drop-off location, arrival time windows, assigned transport budget and the LSP decides on the mode combination, the routes they will follow and which containers will travel together. Hence, the uniformity of the PI designs can help solve interoperability and proprietary issues since the PI is based on the principle of totally open and connected networks. The reactivity and automation of

-handlers should also be applied in the synchromodal context in which the response of planning operators to delays and unexpected events is done manually. Not only does this slow the procedures but also allows for inaccuracies due to the lack of insights concerning other affected services that could be potentially bundled or handled more efficiently. On the other hand, synchromodal related research addresses the problem of uncoordinated and separately planned services by integrating service schedules of different transport means such as barge, rail and truck. Furthermore, the dynamic response modelling, event handling (vehicle breakdowns, accidents) and general disturbance management fortifies the role of synchromodal transport in creating a more resilient chain in which a better utilization of assets is achieved. However, shared and cooperative consumption of assets is of high importance and certain standard coordination protocols should be first established to facilitate bundling or transition between constituents without imposing special closed collaboration contracts inaccessible by other service providers.

3.3 Freight Grid

The freight grid represents a network connecting different elements. In general, networks form a basis of various structures such as the internet, which is made of a network of servers.

waterways, roads, rails) forms the PI. However, the metaphor of the digital internet should be

considered with caution since digital internet movements incur negligible costs (Sarraj et al., 2014) whereas the PI constitutes of fixed, transshipment, handling and variable costs. The synchronomodal but also intermodal research can improve the PI performance with studies related to the cost-impact of intermediate transfers in combination with break-even distances and routing over the network to reach a more realistic flow within the PI network, compared to the digital network. The freight grid herein embodies the network of stationary resources - addressed in the synchronomodality studies and -nodes - denoted by the PI concept. As for the latter, the reviewed literature suggests

-loading process studies are of high importance. Hubs, and more specifically terminals, infer an integrative role where the feeds from LSPs, terminal operations and road-rail-iww (inland waterway) networks are combined. In this setting,

reshape the supply chain as to bring the deployment and manufacturing of products closer to the end-users by redesigning the distribution and realization web. In this regard, synchronomodality has the potential to improve the chain resilience with disturbance management, event handling (traffic congestion and accidents) and dynamic response modelling to achieve better network flow. In the academic sphere, synchronomodality offers model predictive control approaches to account for cargo evolution at critical points so that delays and unexpected developments are handled more efficiently and preferably in real-time to avoid bottlenecks. These external perturbations, occurring outside of the hub, should complement the internal operations within it. In this respect, predictive analytics that estimate turnaround times within terminals can be linked to the external developments so that smart objects can react in an active manner and group accordingly to reduce loading and delivery times. In terms of methodology, all synchronomodality-related models are based only on analytical approaches whereas physical internet models make mostly use of agent-based models. In the following sections, we conceptually apply the ABM notion to the synchronomodal paradigm. GIS features are further applied to account for a more realistic modelling environment.

4 Combining ABM with GIS

Having defined the unified vision, the focus is shifted to synchronomodality where the PI methodological approaches are translated into a new conceptual framework for modelling synchronomodal transport. The framework presents an incipient step to a proof-of-concept model for assessing synchronomodal benefits by a means of simulation, rather than focusing on analytic solutions of operational planning alone. By doing this, the authors intend to induce a paradigm shift; a different way of thinking about the modelling philosophy related to synchronomodality. The underlying elements of our approach are multi-agent technology and GIS. The former represents physical objects of the transport chain (transport means,

intelligence so that the objects can be queried in space and time.

4.1 GIS as a modelling environment

Geographic Information Systems model the real world in real sense by capturing, storing, coding,

surface (Burrough, 1992; Murphy, 1995). The evolution of GIS has undergone substantial technological developments since 1995 when the GIS was not considered as a sufficient decision support tool (Murphy, 1995)

such as multiple regression, location allocation and spatial interaction models (Batty, 2012) with a focus on strategic planning horizons. However, technological developments have -standard

programming and scripting languages like Java, C++, visual basic, Jscript and Python which have the ability to incorporate GIS software libraries such as ArcGIS, OpenStreetMap, Landsat, GeoTools etc. (Crooks & Castle, 2012). It is not just the technological developments that allow us to compose more realistic models, but also the interdisciplinary nature embodied in geography, incorporating economics, mathematics, physics and computer science. Interdisciplinarity as such has a tremendous potential to model freight transport processes, compared to stand-alone operations research (OR) applications. In this sense, GIS serves as a medium for communicating results and assessing patterns which are generated by simulation runs. As will be discussed in the next sections, agents can roam a certain artificial environment and there is no other environment representing reality better than GIS. This particular ABM-GIS link has been also addressed by Patel and Hudson-Smith (2012) who highlight the importance of ABM visualization via GIS. Most obvious elements reinforcing agents in geographical space are navigation, route finding (Batty et al., 2012) and most importantly, situational and environmental awareness of surroundings represented by spatial, temporal and topological relationships. GIS is thus an essential milestone allowing for a shift from generative models, where designed agents represent simplified conditions, to fitted models, where agents mimic real-world entities based on values that are realistic substitutes of observed processes (Coclelis, 2001). In general, GIS present a modelling canvas full of geocoded information and location intelligence which facilitate the movement of agents and contribute to better and more informed decisions.

4.2 Agents as synchronodal entities

Planning in synchronodality is done as late as possible, bringing the planning and execution horizons closer together. Responding to system changes will not be carried out with deterministic algorithms since reaching an optimum could take too long and by the time it is reached, the system state can change again in the meantime. In this sense, near optimum scheduling algorithms offer a solutions (Bongaerts, 1998) accounting for the stochasticity in the synchronodal system. In case schedules become altered or invalid because of internal or external perturbations, alternatives must be determined as soon as possible. In this regard, ABM exploit the power of parallel computing where the problems are decomposed into sub-problems and solved by agents in order to avoid stand still (Karageorgos et al., 2003). Agents possess various properties capable of mimicking the dynamic behavioral aspects that should be represented in the synchronodal system. Actions of agents are prescribed by the modeler at individual level in a series of rules that are activated under different conditions (Batty et al., 2012; Borshchev & Filippov, 2004). Agents can process and exchange information with other agents as well as perceive other entities, obstacles or sense their surroundings (Crooks & Heppenstall, 2012). These features are highly relevant as synchronodality is to create a more resilient system that reacts to unexpected data changes such as disruptions, incidents, breakdowns, newly incoming orders but also infrastructural developments like congestion, lower water levels etc. The awareness of these events but also awareness of asset locations can be simulated in a transparent manner allowing for more bundling opportunities once the agents know about each other. These simulation capabilities enable modelers to truly assess the synchronodal rigors.

The synchronodal paradigm involves many entities that have timing, directions, objectives, event order, various behaviors and many other aspects affecting the transport system once exposed to perturbations. In our synchronodal setting, there are three agent classes; 1) decision making/coordinating agents (LSP, Terminal Operator, Network Operator), 2) stationary agents (terminals) and 3) moving agents (barge, train, truck). Agents are able to perceive their environment through sensors and act upon the input via actuators (Russell et al., 2003). Table 1 points out the varying goals and characteristics of agents which may affect the

synchronomodal chain as the agents rely on each other and subsequently affect one another, resulting in emerging behavioral patterns. In other words, the movement of LSP agents is restricted or facilitated by their environment which is managed by network operators through control centers. This relationship also works vice versa as the developments within the network control center environment ((big) data feeds), is determined by the movement of LSP agents. Lastly, terminal operations also influence the timeliness of barges, trucks and trains that are in return affecting the overall network flow.

Table 1: Examples of synchronomodal agent characteristics. Italics present decision making agents and underlined text presents physical agents (Source: adapted from Russell et al. (2003))

Agent type	Percepts / Sensor	Action	Goal	Environment
<i>LSP</i> <u>(Barge/Train/Truck)</u>	Orders, asset location, containers / GPS,	find/take route, shift, bundle, assign orders	destination, arrival time, fill rate, max. profit	IWW/Rail/Road networks, locks, terminals, containers, other modes
<i>Terminal Operator</i> <u>Terminals</u>	Incoming LSP agents / camera, scanner,	scan, report, assign/organize flow	detect bottlenecks, optimize flow, high queue performance and cargo items per day	Gate, terminal personnel, cranes, tugs, yards
<i>Network Operator</i> <u>Network</u> <u>(Waterways/Rail/Road)</u>	Infrastructural developments / GPS, cameras, land stations infrared or sonar sensors	Open/close lock, assign flow, navigate, variable message signs	Safety, lock throughput, smooth network flow	Big data feeds

The LSP acts as a broker who receives orders from shippers and assigns transport means to them. Table 1 provides a simplified conceptual example of the main agents. In reality, shippers may book services via forwarders (4PL non-asset based), or 3PL (asset-based) companies to deliver their goods. On the demand side, forwarders and 3PLs serve the

served by intermodal and terminal companies who provide actual locomotives, barges, trucks, terminal equipment etc. For simplification purposes, we define the LSP as an intermediary who stands between the shipper and intermodal/terminal companies.

5 Our approach - Synchronomodality in the light of ABM and GIS

In synchronomodality, communication among the 3 agent types in table 1 is a key factor to create a more resilient and responsive system. Given the existing network monitoring platforms, there is enough evidence that real-time infrastructural data is available and should be further improved by integration of IWW, road and rail data. Historical data from these links offers added value for models that can capture real physical flows by deploying dynamic agents and simulate various logical combinations of orders, routes and response handling based on perturbations. Since pilot projects are very costly to carry out, computer simulation offers a more affordable alternative for introduction of new concepts. Main advantage of ABM, compared to current synchronomodal models, is the ability to simulate and assess communication structures based on a certain level of transparency determined by the modeler. This is possible due to the ability of agents to send messages that are assumed to be transmitted via sensors. The sensors in table 1 are mere examples of currently used technologies and may change over time, but the agent communication structure remains the same as conditional statements determine when and how agents detect and respond to

different phenomena in the program. The sensors thus serve as an information input feature for the agents.

5.1 Process overview

The orders are a-modal, a precondition for synchromodality, giving the LSP freedom to choose a mode based on the availability and network developments. The barges, trains and trucks are then queried by the LSP to learn their location via various sensors. The LSP then takes actions to meet its goals. The terminal agents also use sensors to detect barges, trains and trucks at their gates to proactively optimize flows and utilize their assets. In case of network operators, the infrastructural developments are monitored from a more centralized perspective using land-based sensors deployed alongside roads, inland waterways (IWW) and rails or satellite-based receivers. Information from different sensors can be combined in Automated Identification System (AIS) used for vessel tracking, road traffic control centers and rail managements systems. All three network segments are becoming more digitalized resulting in new data platforms. Road and IWW segments offer real-time GIS based traffic flows, whereas the railway network seems to be lacking behind.

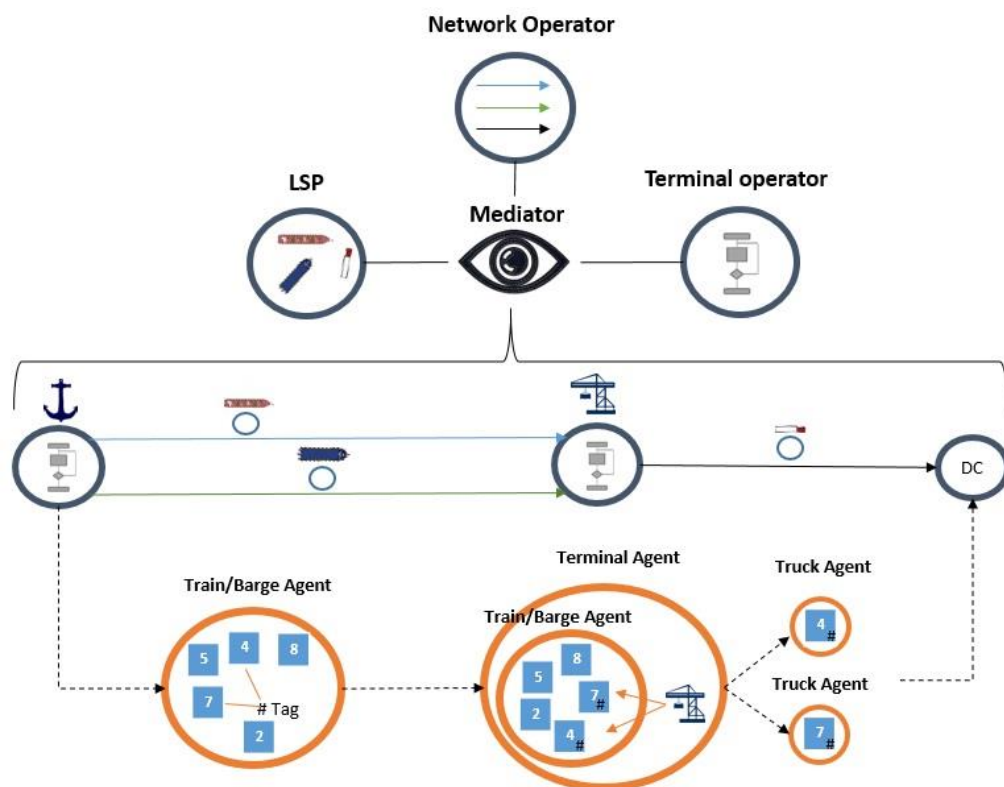


Figure 3: A conceptual perspective of the agent-based synchromodal hinterland chain. (Source: own setup)

Figure 3 illustrates a synchromodal journey that originates at the port and ends at a distribution center (DC) with an inland terminal as a handling/switching point. Moving agents coordinated by the LSP (barge, train, truck) roam the environment between these stationary agents by following one of the three infrastructural links. The links are managed by the network operators and handling points by terminal operators. Note, that moving agents may enter a terminal agent that becomes the head agent of the agent society. The role of the head agent is then to communicate with the rest of the agent society that it contains, and manage terminal resources accordingly. This type of structure is known as a holarchy (Cossentino et al., 2008; Koestler, 1967) where acceptable solutions are reached through negotiation about resources and elaborate cooperative solutions (Becker et al., 2006; Gambardella et al., 2002).

In this respect, the LSP agent is also perceived as a head agent that contains sub-agents, being the means of transport. The decision power thus lies on the level of synchromodal agents who search for local optimal solutions via negotiation with higher structures; transport means talk to LSPs and terminals, and LSPs/terminals talk to network operators to make better informed decisions and adapt proactively.

The action of agents is determined by commands in statecharts (figure 4). Each agent has a specified action code with an objective to fulfill its goals (table 1). The action code may contain transitions that are induced by network messages in case of disruptions. In this setting, the LSP has the possibility to react to network developments and chose an appropriate agent which fits his needs based on conditional statements. This consequently leads to mode assignments and switching at handling points, such as the port or inland terminal, before transport execution takes place. The LSP thus runs a simulation facilitated by the mediator, taking into account the network developments, terminal locations and their handling processes as well as nearby available agents. Agent transitions are triggered by external or internal events captured by conditional statements and/or timeouts.

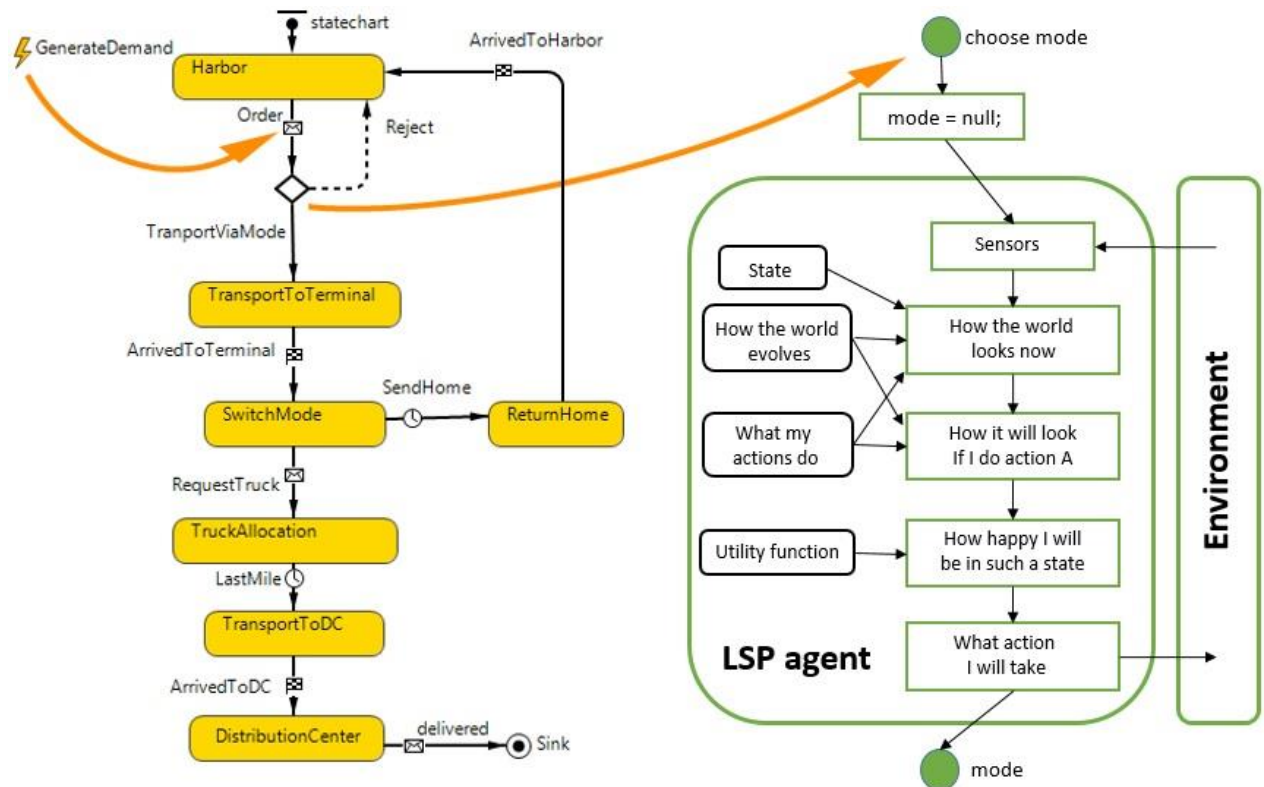


Figure 4: Mediator perspective using statechart assessment of LSP's action chain. (Source: own setup based on Russell et al. (2003))

As indicated in figure 4, the decision process linked to mode selection takes place when the LSP receives an order to transport a certain quantity of goods. The first step is to assess the current system state of the agents' environment through the sensors (figure 4, right). Next step

modal choice, will affect the transport system a restrictions. The restrictions are usually imposed by shippers who specify the

The action taken is then recorded and sent back

return trip is known and contained in the environment. This may be very useful for identification of transport means that are returning home empty so that another LSP can again

confined only to decisions at ports; it can run in parallel with the execution of transport, and once the agent is approaching a terminal, the LSP may query near-future options and

5.2 The Environment

The artificial environment from figure 4 is represented in a GIS form (see figure 5). The most upper layer (a) contains agents in continuous space. To mimic their movement and location

routing in geographic space. The GIS network provides paths (b) for agents (trucks, barges, trains) to execute movements from an origin to a destination determined by the LSP. The network links lead to terminals which are geocoded as points in the map (c), and at each point a terminal agent is created. This third layer contains 3 types of terminals, namely rail-road, IWW-road and trimodal terminals. Finally, an Open-Street-Map tile layer (d) is used to assess the visual fit of the IWW/rail/road paths taken by the moving agents. Since synchromodality is a real-time system, Anylogic environment proves to be suitable as it provides real-time tracking of movements and events which are consequently recorded in logfiles.

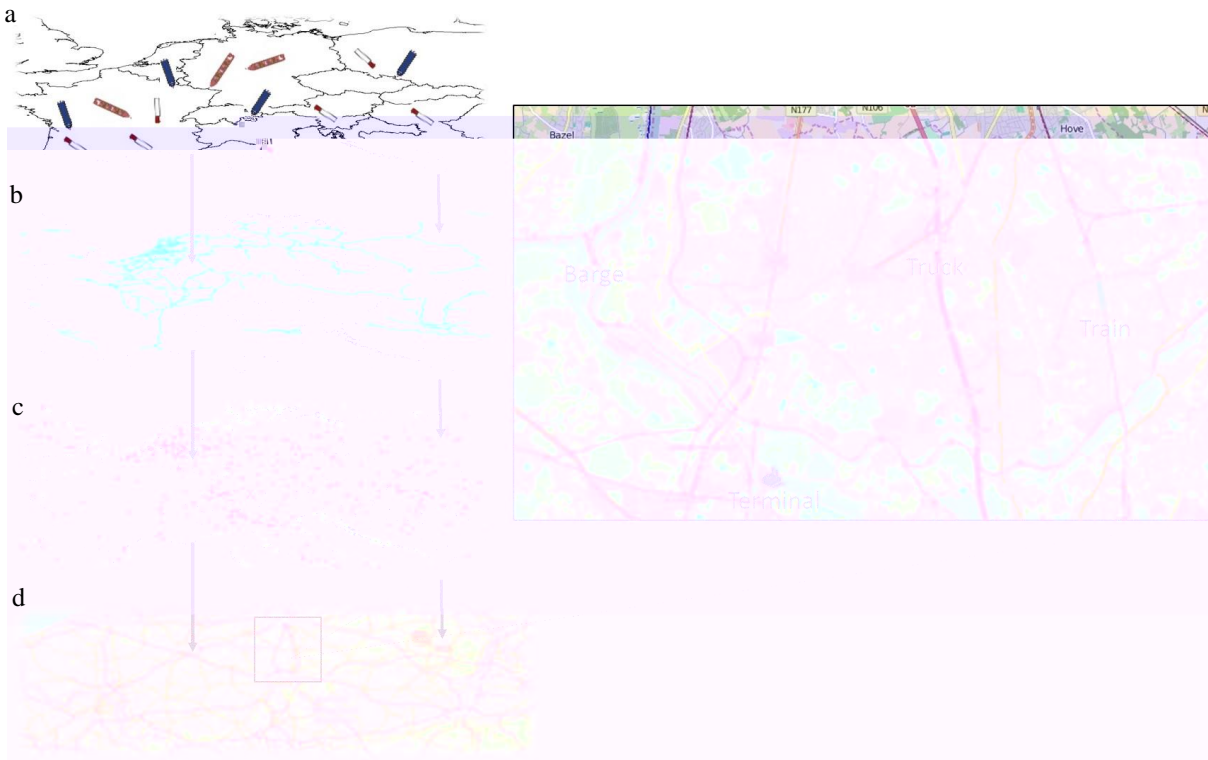


Figure 5: Illustration of an agent-based GIS environment. (Source: own setup)

The real-time switching and resource/asset allocation is carried out at terminals via discrete events. The terminals thus serve as central points containing bundling logic based on the availability and occupancy of other nearby agents. Therefore, the distinction between the above 3 terminal types is crucial since they determine the switching possibility as a result of mode accessibility. In other words, the possibility to switch to train which follows the rail network can be done only at road-rail and trimodal terminals, but not at road-IWW terminals.

5.3 PI elements in our approach

(the # in figure 3 on each container and moving agents) that serves as an extended hand of the mediating agent. The tag enables asset visibility so that the mediator has an overview of the current system state. In case of perturbations, the LSP decision making agent may query the mediator for solutions. Since not all assets are monitored and shared in reality, the tagging solution is to account for what-if scenarios that might occur in a certified group or community of users. In such sense, the tag may present equipment and transport means that are PI certified and comply with uniform handling and communication standards. The main element of our approach is the ability to assess communication structures and information exchange by passing messages between agents. These messages represent signals sent and intercepted by sensors from different sources (section 4.2) to account for the reactive behavior of agents in case of perturbations. Unlike analytical models that focus mainly on schedule synchronizations, the proposed framework enables simulating communication structures and potential cooperation concepts to gain more confidence in future investments towards more transparent (PI) networks. Given these capabilities provided by ABM, various cases may be assessed in terms of comparative analysis (PI vs status quo) of freight flows while having and not having communication capabilities and visibility within the system. For this reason, simulation is chosen to test transparent flows of goods and network developments in real-time to evaluate responsiveness of the system prior to its implementation and practical use.

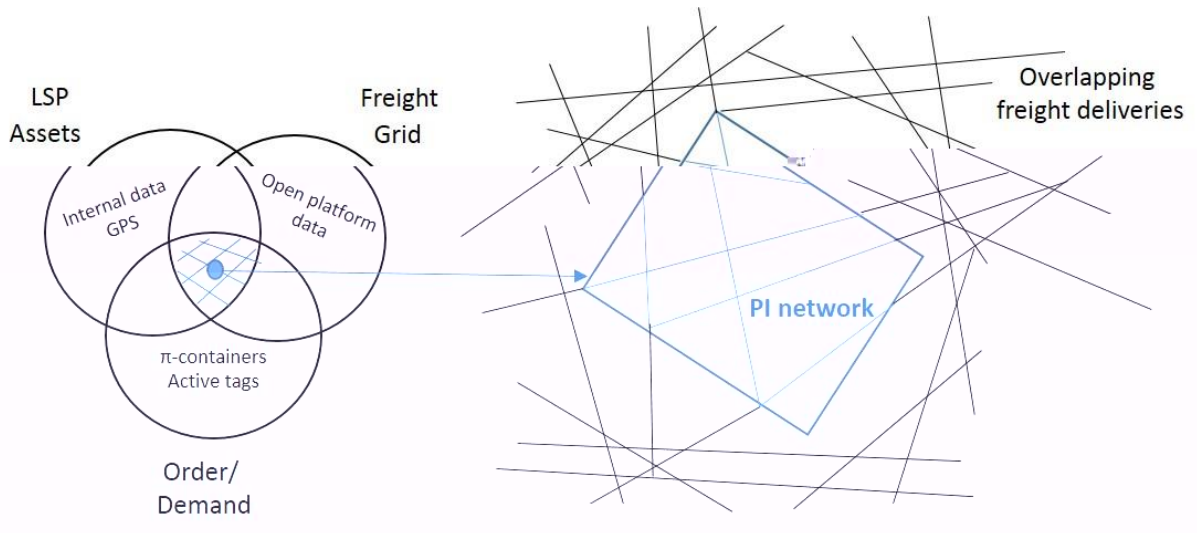


Figure 6: Conceptual illustration of a transparent and resilient freight network

The unified transport system (figure 6) has the potential to become an intertwined set of flows resulting in a holistic supply chain resilience and efficiency. The transparency and identification of flows acquired via contextual awareness and communication, has a potential to fill backward empty flows as they can detect cargo and its attributes such as O/D, expected delivery time, weight, fill rate, cargo type etc. This may be achieved by creating a cooperative community of providers who are PI-certified so that containers (Orders) and available transport means (LSP assets) can be queried in space and time, facilitated by open infrastructural data (Freight grid) for better ETAs for timely bundling opportunities.

6 Conclusion

The underlying elements of our vision on synchronomodal modelling are multi-agent technology and GIS. The former represents physical objects of the transport chain (transport

location intelligence so that the objects can be queried in space and time. The proposed conceptual framework has a potential to contribute to more empirical assessments, once

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