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SIMULATING A PHYSICAL INTERNET ENABLED MOBILITY WEB: THE CASE OF MASS DISTRIBUTION IN FRANCE

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ABSTRACT: *Physical Internet (PI, π) is a novel concept aiming to render more economically, environmentally and socially efficient and sustainable the way physical objects are transported, handled, stored, realized, supplied and used throughout the world. It enables, among other webs, the Mobility Web which deals with moving physical objects within an interconnected set of unimodal and multimodal hubs, transits, ports, roads and ways. We want to develop and use holistic simulations to study and quantify the impact in terms of economical, environmental, and social efficiency and performance of evolving from the current system of freight transportation toward an open logistics web in France. This paper focuses on how the mobility web simulator supporting this study was designed and developed. The simulator produces large-scale simulations of mobility webs consisting of a large number of companies, sites and agents dealing with thousands of daily orders. It supports route and rail transportation modes, pallets and PI-containers for product shipping, different kinds of routing and shipping strategies, and various types of hubs.*

KEYWORDS: *Physical Internet, Logistics Web, Mobility Web, Agent-based Simulation.*

1 INTRODUCTION

Logistics is in the midst of an unprecedented worldwide antagonistic situation between, on one hand, its current attractive performances in terms of rapidity, flexibility, frequency of deliveries and costs, and, on the other hand, the necessity to improve its environmental and societal impact. For example, in France, industry must gear to meet the expected mid and long term objectives of 20% reduction of CO_2 emissions by 2020 and a fourfold reduction by 2050 (Boissieu, 2006). Many potential avenues for reaching this objective are being investigated: (1) improving energy efficiency by using alternative mobility technologies like urban electric trucks; (2) transferring truck-based freight transportation toward less polluting transportation means such as electric trains; (3) exploiting information technologies to develop and more efficiently manage transportation strategies; and (4) adopting political actions to change logistics behavior using incentive or limitative measures such as carbon taxes and regulation of urban accesses and greenhouse gas emissions.

Another important and complementary avenue can be explored. It is the integration of logistics means to increase efficiency, improve multimodal travels and stimulate the innovation around new logistics concepts such as standardized containers, new transportation means, and efficient routing algorithms. This avenue is the focus of the *PREDIT Project: Simulation of the Physical Internet Contribution in Solving Logistics Problems: Application on Retail Industry in France*. This project is conducted within the Physical Internet Initiative (www.physicalinternetinitiative.org). The project is a collaborative research endeavor of Mines ParisTech from France, EPFL from Switzerland and Laval University (CIRRELT) from Canada.

The objective of the PREDIT project is to develop and use holistic simulations to study and quantify the expected impact in terms of economical, environmental, and social efficiency and sustainability of evolving from the current system of freight transportation toward an open logistics web in France to support the distribution of fast-moving consumer goods. This paper focuses on how the mobility web simulator supporting this study was designed and developed, with the aim to enable such studies in a variety of contexts across the world.

The article is structured as follows. Section two provides a literature review presenting the Physical Internet, Logistics Web and Mobility Web concepts and providing supporting evidence for agent-based simulation as used in this research. Section three presents the research objective, expected contribution and adopted methodology. Section four introduces the global architecture used for developing the simulator. Section five presents the simulation model. Section six details the behavior of the simulator's agents. Section seven illustrates the simulator in action and reports on its performance using the case of the mobility web of mass distribution in France. The article ends with a conclusion summarizing the contribution and highlighting future research avenues.

2 LITERATURE REVIEW

This section presents Physical Internet and the notions of open logistics web, open supply web and open mobility web. Then, it discusses the pertinence of the multi-agent approach in simulating complex supply and mobility environments such as those enabled by Physical Internet.

2.1 Physical Internet

Montreuil (2011b) asserts that the way physical objects are currently transported, handled, stored, realized, supplied, and used throughout the world is not economically, environmentally, and socially sustainable. He supported this assertion by highlighting thirteen symptoms of the global unsustainability. Montreuil (2011b) proposed evolving towards a worldwide Physical Internet (PI, π) in order to improve, by an order of magnitude, the efficiency and sustainability of logistics in its broad sense. The Physical Internet exploits the concept of universal interconnectivity of logistics networks and services. It proposes to encapsulate merchandises and products in world-standardized, green, modular, networked, and smart containers that can be flowed and distributed across fast, reliable, and eco-friendly multimodal transportation systems and logistics facilities (Montreuil, 2011b).

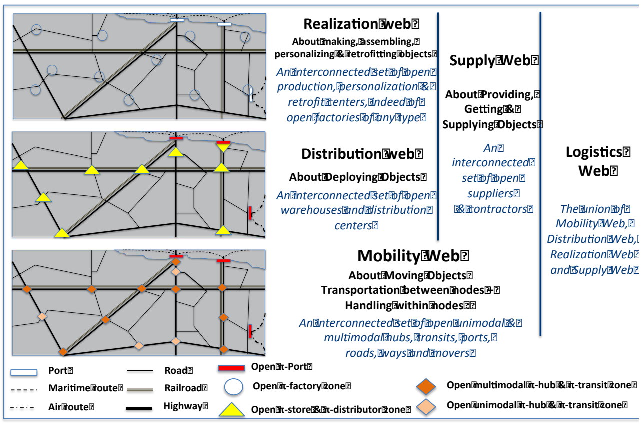

Figure 1: The constituents of a Logistics Web

The Logistic Web is defined as the global set of physical, digital, human, organizational, and social actors and networks serving the worldwide dynamic and evolving logistics needs. In the quest for efficiency and sustainability, the Physical Internet aims to enable the Logistics Web to be concurrently ever more open and global while being reliable, resilient, and adaptive. As depicted in Figure 1, the Logistics Web can be conceived as embedding four interlaced webs: the Mobility Web, the Distribution Web, the Realization Web, and the Supply Web (Montreuil 2011a). The Mobility Web deals with moving physical objects within the global interconnected set of open unimodal and multimodal hubs, transits, ports, roads and ways. The Distribution Web is concerned with objects deployment across the distributed global interconnected set of open warehouses, distributions centers, and storage areas. The Realization Web is about making, assembling, personalizing, and retrofitting objects as best fit within the global interconnected set of open factories of all types. The Supply Web is about providing, getting and supplying objects through the global interconnected set of open suppliers and contractors (Montreuil, 2011a). Each of the Webs exploits the other Webs to enhance its performance. When one of these Webs is written in lower caps, it refers to some subset, such as a logistics web for fast-moving consumer goods distribution within the French territory.

2.2 The Simulation Approach

According to (Choi, et al., 2001) a Complex Adaptive System (CAS) is a system that meets two conditions: adaptivity, meaning that it systematically adapts itself over time, and existence in a complex environment with many relationships and interactions. Several researchers concur that a logistics or supply network should be treated as a complex adaptive system (Surana, et al., 2005; Braha, et al., 2007; Pathak, et al., 2007). Because logistics webs and their constituents such as supply webs and mobility webs involve networks of logistics, supply, and mobility networks, they exist in environments that are even more complex, and will exhibit even more adaptability than that of supply networks. For this reason, logistics webs and their constituents can be considered complex adaptive systems (Hakimi, et al., 2010b; Hakimi, et al., 2011).

Pathak, et al. (2007) argue that the application of CAS perspective to Supply Chain Management research requires agent-based, computational, and process models that are dynamic and generative, and case studies of larger sets of firms. Multi-agent modeling is flexible and appropriate to represent the dynamics, complexity, and distributed aspect of supply chains given the great similarity between industrial systems and multi-agent systems. In both systems, entities are autonomous and have decision-making abilities, while actors are able to collaborate and adapt to their environment (Moyaux, 2004; Labarthe, et al., 2007; Shen, et al., 2006; Lee, et al., 2008).

The multi-agent approach thus seems to be the most appropriate approach for developing logistics web simulations that capture the complexity and dynamics of these webs. This is the reason why we adopted this approach to develop our simulator.

3 OBJECTIVE & METHODOLOGY

This section focuses on the elements that shaped the current research project. It presents the research objective and the paper's main intended contribution, as well as the research methodology.

3.1 Objective

The objective of this paper is to provide a methodology for developing a simulator capable of supporting mobility web impact studies such as the study of the economic, environmental, and social impact of implementing a large scale, France-wide open mobility web for fast consumer goods distribution. Such a simulator is expected to support the dynamic modeling of daily shipments of thousands of orders within a logistics web of hundreds of sites including plants, warehouses, distribution centers, unimodal and multimodal hubs (Ballot, et al., 2010) and transits. It should allow contrasting the way of shipping products through the current logistics system with different variants and levels of implementation of open mobility webs enabled by Physical Internet.

Simulating the current way products are shipped involves manufacturers operating multiple plants and warehouses and shipping products in response to retailer site-specific orders. Products are usually packed on pallets and shipments are affected to trucks that cover the entire travel between the shipping sites of suppliers to the receiving sites of clients. There is generally no sharing of truckloads between different suppliers as a traveling truck only transports products of one supplier.

Simulating open mobility web alternatives involves submitting these to the same demand scenarios transposed into the same set of daily orders as in current system simulation. In addition to the current set of players and sites, the simulation has to include the mobility web and its set of π-hubs and π-routes. Products are not anymore packed in pallets but in π-containers of modular sizes. These π-containers are the only unit loads allowed to be shipped on the simulated open mobility webs. In their way to a final destination, the π-containers can transit through π-hub where they can be transferred between transportation means and/or modes. The simulator should thus support the potential modes (truck-based road travel, train travel, etc.) and various types of unimodal and multimodal π-hubs. Transportation means are not anymore dedicated. They can carry π-containers of different actors. Since direct travels are not the rule in the open mobility webs, routing agents are responsible for determining the set of route segments and transportation means that containers will be affected to in order to reach final destinations. Road-based route segments can be restricted to be less than a few hours to allow most drivers to go back home in the same day. It should be possible to model different shipping and routing strategies in order to study the impact on the target objectives.

The main contribution of the paper is to present how a mobility web simulator can be designed to support these requirements, using the France-based project as a case study. This is achieved by presenting the architecture used for developing the simulator, explaining the simulation model and the adopted modeling approach, and detailing behaviors of typical simulator's agents.

3.2 Methodology

The methodology used for mobility web simulator development presented in this paper is adapted from the three-level approach defined in Labarthe et al. (2007). This approach seeks to capture the complexity and dynamicity of logistics contexts by mapping software agents with real world decision-making actors or systems. The framework translates business requirements to system requirements in the following three stages. First, a domain modeling of a selected supply and mobility environment formalizes the overall description and comprehension of the simulated context in an executive non-technical language using combinations of texts, graphs, tables and databases. Second, the conceptual model consists of transposing the domain model into an agent-oriented representation using the appropriate UML diagrams. Third, the operational model is developed based upon the conceptual model. It expresses the design requirements according to the programming language and to the technology to be used for developing the software.

The retained multi-agent framework is combined with the recursive modular protomodel based approach (Montreuil, 2006) which provides a modular technique for the representation of any supply context by using generic components representing the logistics and supply chain entities according to their functional roles.

In addition, as the decision mechanism is distributed over all the agents of the simulated environment, and because each agent encapsulates its own decisional behaviors, the objective is to develop, adapt and change the behaviors of each agent from one simulation to another in order to contrast different ways of doing, multiple mobility web options, and various management strategies and tactics.

4 THE GLOBAL ARCHITECTURE FOR DEVELOPING THE MOBILITY WEB SIMULATOR

Hakimi et al. (2010b) have presented a conceptual framework for designing an agent-based supply web simulation platform. In this, paper we exploit and adapt this framework in order to develop the mobility web simulator. Figure 2 illustrates the proposed architecture resulting from this adaptation.

A logistics web solution consists of a database, a set of business tools, and a gateway. The logistics web database hosts two types of data received from a real world logistics web context: structural data and events. The structural data consists of data, such as the attributes of organizations, sites, products, and product categories, used to configure the logistics web context. Events are rapidly changing data reflecting the evolution of the state of the logistics web. Examples of events include sales, orders, shipments, and order handlings. Since the logistics web database contains data belonging to different organizations, it is necessary to standardize the received data before inserting it into the database. This role is ensured by the gateway application, which makes sure that the elements are uniquely identified and that the pieces of information are stored in the right tables. The logistics web business tools are a set of applications exploiting the content of the logistics web database and the mobility web simulation database to provide a profound understanding and decision support about a selected logistics web (adapted from Hakimi et al., 2009).

Adapting the data to the simulation purposes is of paramount importance. For example, since the data available in the context of the PREDIT project is about the weekly flows of products, it was necessary to generate daily orders by repartitioning the weekly flows over the weekdays. This is done using the data adapter of which the development was inspired by the approach described in (Hakimi, et al., 2010a).

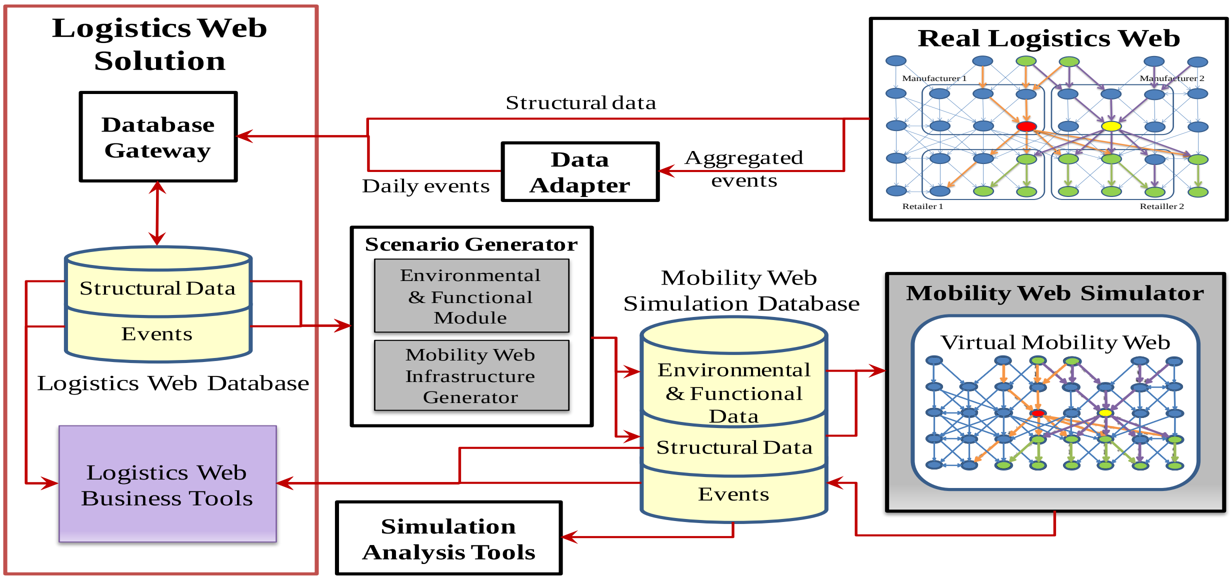

Figure 2: General architecture for developing a Mobility Web simulator

The scenario generator helps users create mobility web alternatives to be experimented using the mobility web simulator. At the core of the generator lies an optimization engine. Specifically, in the France-based project, alternative networks were designed using a metaheuristic optimization engine that generated networks of interconnected unimodal and multimodal π-hubs and π-ways (roads and highways, railways, etc.) according to user defined economical, environmental and societal goals. The scenario generator exploits the content of the logistics web database, including geographic information and the available transportation infrastructure, to generate the environmental, functional and structural data required by the simulator. The functional data determines the behavior of the simulation agents and other components. As the simulation is running, the virtual world generates supply and mobility events that are uploaded to the simulation database.

Simulation analysis tools are mainly spreadsheets used to reduce the manual processing of the simulations' result. They exploit the content of the simulation database and the result of different scenarios to study the behavior of multiple Key Performance Indicators (KPIs) in order to determine the performance of scenarios based on the user input parameters.

5 THE SIMULATION MODEL

The Mobility Web simulator is a multi-agent application that reproduces an alternative reality to mimic a current or potential way of moving products within a supply web by exploiting a mobility web. It is developed using a simulation software tool such as AnyLogic (www.xjtek.com) that was used in the France-focused project. The class diagram of Figure 3 highlights the main classes related to the behavior of the functioning of the virtual supply web and the mobility web within the model and the relationships between them. Classes supporting the other functionalities of the simulation such as the computation of the KPIs and algorithms are not shown for the sake of simplifications.

The "Company" class represents the organizations that can be simulated in the model. There are a variety of company types, such as a "Manufacturer", a "Retailer", a "Transporter", a "Transiting Company" or a "Routing Company". The "Site" class represents physical centers that deal with physical objects or provide services. Conceptually, as shown on the class diagram of Figure 3, any company can own any types of sites. However, in the context of the presented project, manufacturers have plants and warehouses, retailers own distributions centers and stores, transporters and routing companies have departments, and transit companies own unimodal road-based π-hubs and bimodal road-rail π-hubs.

All types of sites are directly involved in the manipulation of physical objects except for departments which provide services such as determining routes and transportation means for π-container travel. Current plants, warehouses, distribution centers and stores can be components of both current and π-enabled logistics webs. They can be found in all scenarios. In π-enabled scenarios, they are assumed to be π-facilities (Montreuil et al. 2010) or at least have π-gateways enabling them to ship and receive π-containers. In π-scenarios, π-hubs have to be modeled, as they are distributed focal nodes where π-containers are transshipped to their next step in their route towards final destinations.

In the context of this paper, the simulation focus is on the mobility web, limiting the nodes of the realization and distribution webs to be sources and destinations for encapsulated shipped objects. Open distribution and realization webs are out of scope. For example, in the France-based project, the focus is on the first phase of the project in which the suppliers have their proprietary dedicated plants and warehouses, and the retailers have their proprietary dedicated distributed centers and stores.

Each node of the distribution web can carry inventory of products classified under a hierarchy of product categories. A supplying site receives orders from its client sites. The orders consist of order lines specifying the ordered quantities of desired products to be delivered within a specified lead time.

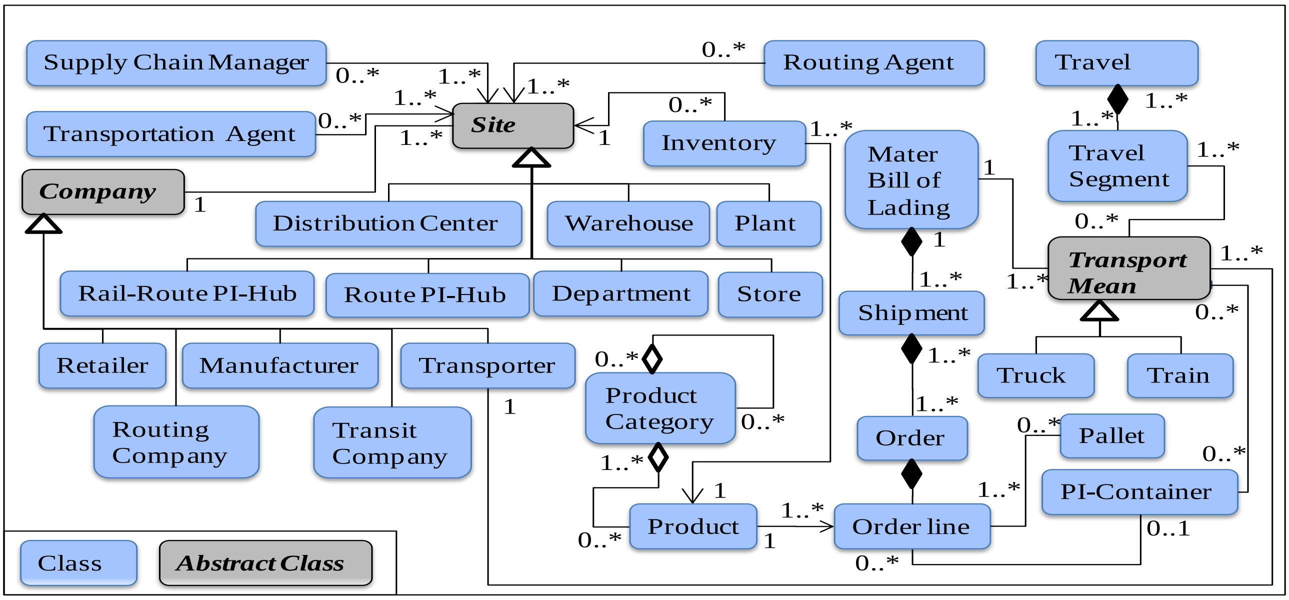

Figure 3: A Simplified class diagram of the Mobility Web simulator

In current context not π-enabled, the ordered products are typically prepared in cases piled on pallets. The pallets to ship to the same destination are combined into a shipment. In road based settings, a truckload is built from a set of shipments respecting the weight and volume constraints and then associated with a Master Bill Of Lading (MBOL) assigned to a truck ensuring direct delivery to destination. In a π-context, products of various orders are packed in π-containers which are assigned to one or many transportation means that will transport them to intermediary nodes of the mobility web toward the final destination.

The model contains three main agent classes that are directly linked to the "Site" class to provide flexible modeling. The behavior of these agents is detailed in the next section. Different agents can be associated with any type of site and companies. This way, it is possible to generate specialized companies like routing companies owning departments that host routing agents, manufacturers or retailers with their own routing departments, and even sites like plants or distributions centers with their own agents.

6 AGENT BEHAVIOURS

The proposed model contains three main agents responsible for decision-making within the virtually simulated logistics web: supply chain managers, transportation agents and routing agents. For each task performed by an agent, many behavioral variants can be developed to allow the simulation of multiple and rich alternatives, support different levels of mobility web openness, and achieve diverse objectives. For example, it is possible to adapt the agent behaviors to target economical, environmental, or social objectives or any level of tradeoff between these three dimensions. Different ways of building, routing and transporting shipments and π-containers can be modeled to assess their impact on the transportation cost, greenhouse gas emission, number of used transportation means, travel distances and durations, etc.

In the following subsections, typical agents and behaviors are presented in both a representative current context and a π-enabled context.

6.1 Supply Chain Manager

In the mobility web focused simulation, the main function of the supply chain manager (SCM) agent is to deal with order shipment decisions.

In a current not-π-enabled context, the SCM agent organizes daily orders by destination and builds shipments from orders to be delivered to the same destinations while respecting the maximum allowed volume and weight of the targeted transportation means. In road based transportation, shipments that are less than a truckload can be consolidated together into MBOLs in order to maximize truck loadings. When either the volume or weight of an order exceeds truck capacity, the agent fractionates the order or its lines to fit in multiple MBOLs that respect weight and volume constraints. Once a MBOL is ready to be released, the SCM agent sends a notice to the transportation agent who assigns a truck to the MBOL.

In a π-context, instead of consolidating the orders into shipments and MBOLs, the SCM agent affects the order lines to π-containers while observing, in this case, the weight and volume conditions of the corresponding π-containers. In this case, lines of a given order can be dispatched over many π-containers. Nevertheless the SCM agent must be able to decide to group the lines of orders having the same destination in common containers whenever possible. When a container is ready for shipment, the agent transfers a notification to the routing agent, rather than to the transportation agent since direct deliveries and vehicle dedication are not the rules in the π-scenarios.

For π-containers that are only transiting through the facility of a SCM agent, the agent ensures the transshipment of these π-containers according to the specifications of the routing agents.

Upon receiving delivery of products they ordered, the SCM agents acknowledge these arrivals and update their inventory records.

From the above, it should be clear that when the focus is put on mobility web simulation, the role and behavior of the SCM agents focalizes on the injection and retrieval of deliveries into and out of the simulated mobility web. In more comprehensive logistics web simulations, SCM agents will have to manage more complex supply chain operations.

6.2 Transportation Agent

Transportation agents are responsible for managing travel of transportation means belonging to their company.

In a typical not-π-enabled context, once the transportation agent receives the notification about the availability of a MBOL from the supply chain agent, it schedules a truck for the specified shipping time. When the time is due, the agent decides on pallet loading associated to the MBOL into the vehicle, then sends the vehicle toward the destination. The agent monitors all vehicles on the road, and when a truck arrives at destination, the agent initiates unloading operations and sends a notification to the SCM agent of the receiving site so that the latter acknowledges the receiving and updates its inventory.

In a π-context, the loads of π-vehicles and π-carriers are determined by routing agents instead of SCM agents. Therefore, the notification about the availability of π-containers to transport is coming from routing agents. In distributed road-based transport, trucks travel on segments of a few hours in order to allow most truck drivers to return home every day. When a full trailer load of π-containers has to travel over many segments before reaching its final destination, it will be pulled by a distinct truck along each segment. Changes of trucks are done at π-hubs and π-transits across the mobility web.

The transportation agent ensures the loading of π-containers in transportation means and the unloading at the π-hubs across the mobility web. Upon vehicle departure from a site, the transportation agent has to notify the appropriate routing agents if there was a schedule change. Upon vehicle arrival at a site, it has to notify the SCM agent about the delivery.

In addition, the transportation agent is responsible for managing the travel schedules of the transportation means and for publishing these schedules so that the routing agents can exploit them when establishing travel paths of π-containers. The transportation agent can adopt a variety of strategies to attract π-containers and maximize the loading of the transportation means. It may determine the travel schedules through various ways, for example exploiting information about the density of segment flows, weighing the importance of the served hubs, or estimating the potential business opportunities. Alternatively, there can be scheduled trips along π-routes at fixed frequencies within each day. Depending on the size of the set of π-containers ready to ship, the agent can decide to let the transporter depart, delay its departure until more π-containers accumulate, or cancel the trip and transfer the set of π-containers to another transporter-time combination. When regular services are not available, the transportation agent can also create customized trips upon request from the routing agent.

6.3 Routing Agent

Routing agents need to be activated in the π-enabled scenarios. Such agents are responsible for determining the path segments, π-hubs, and, depending on scenarios, transportation means, that containers will contract to iteratively reach the final destinations.

A routing agent continuously handles requests for routing π-containers that are sent by SCM agents. For each request, the agent determines, segment-by-segment, the entire travel of a π-container. Various π-container routing methods can be experimented. There are essentially static vs. dynamic methods, and a myriad of hybrids.

Illustrating the static group, a simple two-step method first assigns a fixed cost to each segment between nodes of the mobility web. The cost associated to each segment can be the distance, the expected average travel time, a monetary estimation, the expected greenhouse gas emission, or any other cost function. The second step executes a shortest path algorithm from a source to a destination over the graph whose vertices are the nodes of the mobility web and the edges are the inter-node segments.

Illustrating the dynamic group, a method searches to assign the π-container to a set of transportation means associated to a set of route segments that will ensure the entire travel between the source and the final destination. The method solves a time-phased shortest path problem from source to destination across the graph whose vertices correspond to a mobility web node at a given time (e.g. π-hub A at 9h00) and whose edges correspond (1) to time-phased inter-node segments (e.g. departing from π-hub A at 9:00 and arriving at π-hub X at 11:00) and (2) to sojourn times at node (e.g. flowing through π-hub A from 8:30 to 9:00). The costs associated to each inter-node edge and each intra-node edge can be set so that the shortest path algorithm minimizes for example the total cost incurred, the total greenhouse gas emission or time to final destination. The routing agent generates the set of potential inter-node edges by exploiting the travel schedules published by the transportation agents. It generates the set of potential intra-node edges by estimating the handling capacity of the hubs within the sojourn time window. If the algorithm is incapable of finding a feasible time-phased path from source to destination, the routing agent can request a customized travel from the transportation agent, re-try to route the container later, or route it to the an alternate intermediary destination. Then, the routing agent monitors the arrival of new travel availabilities that will iteratively lead the π-container to its final destination. As long as a complete source-to-destination path is not found, the agent dynamically keeps trying based on new published travels.

Various ways of combining the static and dynamic methods result in hybrid routing methods that can be applied by the agent to route π-containers. Moreover, in order to minimize the handling operations and costs, the agent can decide to group containers according to their final destinations, creating composite containers (Montreuil, 2011b) that will then have to be routed to destination. Using such consolidation, the routing agent can prioritize the shipment of full-carrier-loads to be transported between π-hubs all the way from source to destination across the mobility web.

7 A MOBILITY WEB SIMULATOR

This section illustrates the application of the methodology to the case of developing a simulator enabling the assessment of the potential impact of implementing a π-enabled open mobility web within the French territory to support fast moving goods distribution.

The developed simulator is capable of simulating mobility webs consisting of hundreds of sites exchanging millions of orders during years of the simulation time. The simulated virtual environment is a complex adaptive system that reproduces complex interactions between a large number of manufacturers, retailers, transporters and routers. Each of these companies or departments acts as an autonomous entity managed by independent decisional agents that adapt their decisions according to the evolution of the global environment.

This section starts by explaining, in the first subsection, the steps for running the simulator. The second subsection contrasts the simulation of current non-π-scenarios vs. π-enabled mobility web scenarios. The last subsection shows how external applications can interact with the simulator for analysis and decision support purposes.

7.1 Running the Simulator

In order to run a simulation, the user starts by selecting the scenario, the scenario parameters and the input and output databases. When he launches the simulator, the following steps are performed:

1. The simulator creates the simulated environment by:
    a. Setting the simulation starting time;
    b. Loading the geographic information and maps;
    c. Loading companies and their sites, and localizing the sites on the maps. In π-scenarios, the π-hubs and their companies are included in the loaded data.
    d. Setting the mobility web by defining the possible links between sites. In the non-π-scenarios, supplier sites ship directly to their client sites. The mobility web consists of all the links resulting from the simulated flows. In π-scenarios, the mobility web is now considered open at various degrees and is fortified by a network of π-roadways and π-railways. The result is an open π-enabled mobility web.
2. Each day
    a. The simulator loads the orders to ship and transmits them to the shipping sites;

b. The SCM agents, the routing agents, and the transportation agents perform their task according to their prescribed behavior.
c. KPIs are updated while the simulation is running;
d. At the end of the day, the selected daily KIPs are inserted into the database;

3. At the end of the simulation, the selected global KIPs are inserted into the database.

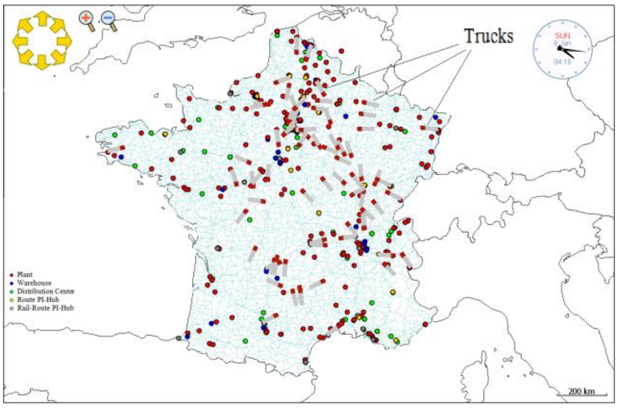

Figure 4: A screenshot of the main simulation view

As shown in Figure 4, while the simulator is running, it displays the geographical map of the investigated mobility web, the current time of the simulation and the transportation means that are traveling between sites along roadways and railways. The user can also consult the current values of many variables and all monitored KPIs.

7.2 Simulating Alternative Mobility Webs

The development of the mobility web simulator is conducted under the project PREDIT: *Simulation of the Physical Internet Contribution in Solving Logistics Problems: Application on Retail Industry in France*. The project exploits real world data about the logistics web flows provided by a French association called *Club Déméter* (www.clubdemeter.fr). The data mainly consists of the weekly flow of fast-moving consumer goods within the supply webs of two major French retailers and their most important 106 suppliers. The database explicitly concerns grocery products excluding fresh food. It covers the first 12 weeks of 2006.

Disaggregating the weekly flows into daily orders, using the data adapter, demand scenarios were generated. An illustrative scenario includes 282 381 order lines associated with 211 167 orders for 702 different products belonging to 53 categories. These orders are moved across a logistics web encompassing, on one hand, 303 plants, and 57 warehouses belonging to 106 manufacturers and, on the other hand, 58 distribution centers belonging to 2 retailers. To these, π-scenarios require adding open π-hubs strategically distributed across France.

	Route and Rail-Route PI-Hubs	Orders	Order lines	PI-Containers of 2.4*2.4*1.2 (m^3)	Transport Mean Travels	Total Travel distance (Km)
Number of Instances In a non Physical Ineternet Scenario	---	211 167	282 381	---	124 618	54 725 706
Number of Instances In a Physical Ineternet Scenario	38	211 167	868 093	677 551	270 623	43 735 190

Table 1: Contrasting mobility web scenarios

Table 1 provides a simple report contrasting two mobility web simulation scenarios that exemplifies the type of investigation enabled by the simulator. Firstly, the non-PI scenario represents the quo status described above, precisely matching real historical performance results. To distribute all the orders in the historical demand scenario, a total of 54 725 706 km were traveled by 124 618 transportation mean trips. The second scenario represents a π-enabled open mobility web where only small π-containers of 2,4m*2,4m*1,2m were considered. In order to be able to fulfill the orders, the SCM agents divided the original order lines into 868 093 smaller order lines that filled 677 551 π-containers. Each of these was routed, handled and carried as an independent object. A total of 270 623 trips were required for a total travel distance of 43 735 190 km.

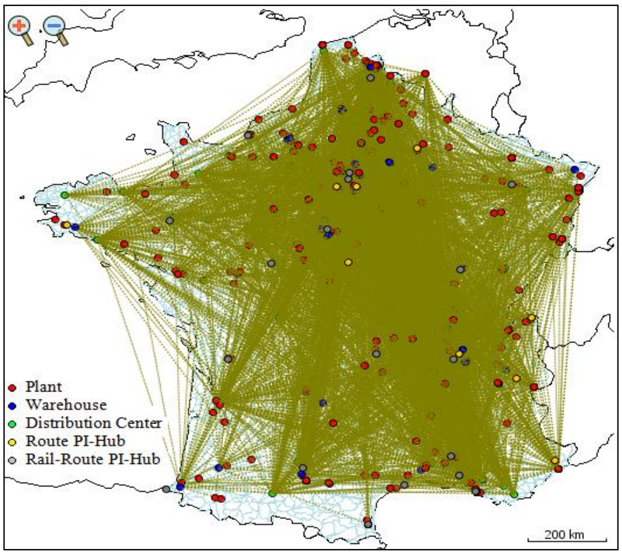

Figure 5 : Flow of goods in the existing mobility web

Even though the purpose of the paper is not to report and analyze exhaustively the simulation based experiences performed in the case project, it is interesting to highlight some significant differences between the above scenarios. First, the number of trips in the π-scenario is much higher than in the baseline scenario: the distributed travel from π-hub to π-hub in the open mobility web of the π-scenario indeed creates more yet smaller hopping trips. Second, the overall travelled distance is significantly lower in the π-scenario: the dynamic distributed consolidation of π-containers indeed increased the transportation means efficiency. The graphical display of inter-node flows in both scenarios provides visual evidence of the transformative impact of the switch from the current scenario to the π-enabled scenario. In Figure 5, the flow diagram of the current scenario is a dense spaghetti mess. In contrast, the flow diagram depicted in Figure 6 for the π –scenario reveals the structuring impact of consolidating travel through π –hubs in the open mobility web.

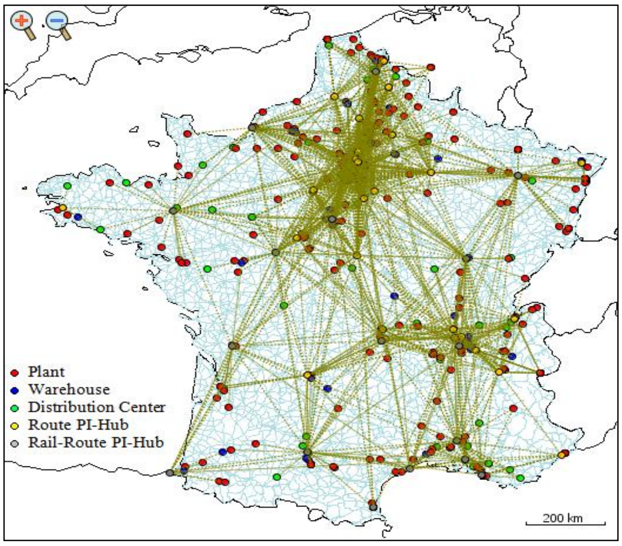

Figure 6 : Flow of goods in a π-enabled mobility web

7.3 Connecting the Simulator to external applications

While the simulator is running, it continuously generates and inserts event data into the mobility web simulation database (see Figure 2). These events along with other data are exploited by external applications for experimentation and decision support purposes. The simulation analysis tools are used for analyzing and studying the output of the scenarios of identified experiment plans. The supply web business tools provide dynamic and static, visualization, monitoring, assessment, mining, and decision support for the simulated supply and mobility environment (Hakimi, et al., 2010b).

There are three supply web business tools: the supply web mapper, the supply web playback, and the supply web monitor. The supply web mapper is designed to help statically visualize, mine, and assess a supply web and its performance (Montreuil, et al., 2009). It provides more or less aggregated snapshots of the supply web history. Figure 7 provides an illustrative example depicting an aggregate view of a supply network within a supply web and a more detailed view of the same supply network, depicting with more precision the various product flows exploiting color and width of inter-node links. The supply web playback is conceived to dynamically visualize, mine, and assess the past of a supply web and its performance. It provides multi-screen multi-perspective videos of a supply web over a prescribed past time horizon. The supply web monitor aims at monitoring, mining, and assessing in real time a supply web and its performance. It provides multi-faceted live windows on the supply web and its constituents helping to signal anomalies and gaps as they unfold in the field.

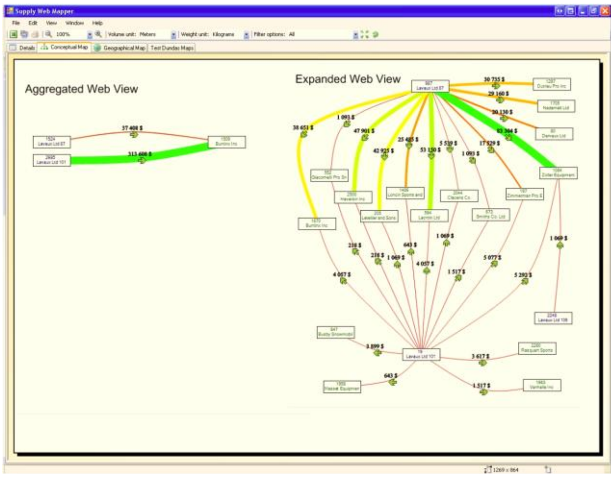

Figure 7: Conceptual map of a supply network within a supply web, provided by the supply web mapper (data and names altered for confidentiality purposes)

8 CONCLUSION

Physical Internet is a novel concept aiming to render the way physical objects are transported, handled, stored, realized, supplied and used throughout the world more economically, environmentally and socially efficient and sustainable. Physical Internet enables a Logistics Web consisting of Mobility, Supply, Realisation, and Distribution Webs.

This paper introduces a mobility web simulator that is used to support the investigation and the study of the impact of evolving from the current system of fret transportation toward an open logistics web in France. The simulator is a multi-agent application capable of reproducing large-scale virtual mobility webs consisting of thousands of actors and agents interacting together to mobilize shipments and π-containers over a connected network of sites, and unimodal and multimodal hubs. The simulator will be exploited to study and compare simulations of various alternatives of existing mobility webs as well as open π-enabled mobility webs. The results of these studies will be reported in future works.

In the current stage of the research, the focus was on the mobility within existing and potentially open logistics webs. In the next stage, we will expand our perspectives to include the simulation of other components of the Logistics Web. We will work on upgrading the behavior of the supply chain agents to manager supply chain operations over an open distribution web exploited by these agents to strategically deploy products.

This paper presented the first simulator of π-enabled environments. Many research avenues can be followed. The Physical Internet will have an important impact on transportation and supply chain management. New algorithms for managing supply operations, and transporting and routing PI-containers should be developed, simulated and tested. Simulation of all the other components of the Logistics Web in even larger scales of what was considered in this project should be targeted to capture the potential impacts of Physical Internet on the economical, environmental and social levels.

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