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DISpATch: Digital TwIn for SynchromodAl Transport

Vision document

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VIL

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FLANDERS INNOVATION & ENTREPRENEURSHIP

Clusters for Growth

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Summary

The DISpATch project will focus on organizational and technical enablers for seamless synchromodal transport services in Flanders and beyond. Given the real-time dynamics and flexible nature of synchromodal transport, different actors and transport modalities need to work together and adapt according to unexpected events as well as contextual information that affect transport processes. These events and contextual information can be positive or negative perturbations that shape freight movement and transport mode selection, such as newly incoming orders, transport delays, cancellations, collaborative bundling opportunities, accidents, water levels, strikes and many more. Crucial elements in this regard are situational awareness of the current system state and projections of how the system will evolve once different actors take different actions.

We will develop a platform represented by a **Digital Twin** component in order to provide a testbed for synchromodal opportunities within a risk-free environment. A Digital Twin is a virtual environment that mirrors the real physical system (a physical twin) and its processes by updating its virtual real-time status from various sources of information regarding weather forecasts, congestion levels, positions of assets (barges, trains, trucks) and their ongoing working conditions. By means of the digital twin, effects of sensor technology and information exchange can be studied in combination with physical flows. Such a risk free environment allows for analysis and evaluation of triggering events (new orders, disruptions, delays…) which induce physical movements. Vice-versa, physical movements may trigger information flows once certain assets arrive at a specific location or enter a geo-fence. The Digital Twin will serve as an interface where different models, their data, granularities as well as processes are integrated. The Digital Twin will contain necessary information and models that have the ability to solve different tasks related to inventory management, freight transport and network planning. It will measure the real-time synchromodal complexity and evaluate various decisions and offer alternatives by making use of mathematical, simulation and machine learning models.

The DISpATch project will address the following objectives:

- Develop key performance indicators in relation to the real-time notion of synchromodality.
- Contribute to new theories by developing and combining modelling paradigms and the Digital Twin concept.
- Prototype, test and validate our methods with consortium partners via case studies.
- Create a scalable and transferable tool, and assess resilience measures and future asset and infrastructural state estimations.
- Devise a mirroring architecture in which the Digital Twin is connected to real-time data fetching tools and existing transport management systems.

The extent to which the project objectives are met will be measured based on the following:

- Knowledge availability that will be disseminated by VIL via its different channels and by research activities of the research groups.
- The speed, efficiency and acquired detail of our model combinations.
- Case study KPIs with regard to modal shift, fill rates, transport costs, lead-times and emissions.
- Scientific impact and the variations of tasks as well as applications covered by the project.
- The level of resilience and adaptation of our methods to freight transport perturbations.
- Ease-of-use of the Digital Twin and acceptance of the connectivity roadmap to existing systems.
- The degree to which the companies intend to adopt or further invest in a dynamic Digital Twin.

1 Introduction

The transport sector faces a huge challenge to become more sustainable and efficient. 20% of the trucks are empty and those that are not empty have a load factor of 56% on average. Despite strenuous efforts to alter the freight modal split, most companies still rely heavily on road transport, and modal shifts to rail and inland waterways have remained modest at best. The DISpATch project intends to support the transition to synchromodal transport in Flanders. It will allow synchromodal processes to be simulated and optimized, bundle fragmented flows of goods on the basis of decentralized algorithms and measure the financial and environmental impact of these.

The DISpATch project fits into the program of the logistics spearhead cluster within the themes of Digitization and Sustainability. The project is also in line with the advice of the Flemish Mobility Council to the Minister of Budget, Finance and Energy to stimulate cooperation models that can bundle fragmented volumes, as well as the exchange of information between companies in the logistics chain. The document "Flanders in Transition", published by the Flemish Council for Science and Innovation, also presents synchromodality and intelligent transport systems as one of the main pillars in the field of science, technology and innovation by 2025. These must lead to higher fill-rates, a reduction in the number of empty runs, a modal shift and a reduction in the environmental impact of freight transport.

DISpATch brings together several innovative methodological approaches. First, it presents the idea of a Digital Twin in the freight sector. The Digital Twin ensures that the real world is mirrored and closely monitored. Simulations can also be performed in this digital environment to analyze the consequences of new solutions. Secondly, geo-fences will be deployed to make the monitoring executable in real-time. This innovative platform is then further strengthened by new inventory management algorithms and integrated network planning.

Companies can use the Digital Twin as a testbed where they can assess their entire supply chain and evaluate their visibility measures (IT/IoT), physical movements, modal shift potential and bundling of shipments; both on a regional and interregional scale.

The methodological approaches will be calibrated and validated in each of our case studies (retail, maritime and continental) where the economic and environmental implications will be assessed. The economic impact is important as it will determine whether the companies will be open to use the algorithms in practice. The environmental impact will be assessed per each scenario setting while considering greenhouse gas emissions, infrastructure costs, noise and other factors such as risks related to accidents. These aspects will illustrate societal benefits for each proposed solution. The application of the smart algorithms in combination with the Digital Twin, will allow to reduce the number of trucks on the road by inducing a modal shift and/or increasing the truck fill rates for regions where a modal shift is not possible. Fewer trucks on our roads mean less CO_2 emissions and fewer traffic jams. This comes at the benefits of the entire society.

The DISpATch project results will also be disseminated within the Flemish logistics sector through various VIL networking events, feedback sessions with the Advisory Board of VIL and other events such as conferences and seminars. The project will result in a number of important outcomes such as a synchromodal platform with a Digital Twin simulation part, various optimization algorithms that can enhance the productivity of the sector and case studies that will allow for demonstrating the potential of synchromodality in practice. Project valorization will be further extended by targeting VLAIO COOK and R&D projects as well as doctoral mandates to further implement the Digital Twin within industry.

1.1 Integration and necessity in the logistics cluster strategy

The DISpATch project fits in the competitive program and roadmap of the Flanders Logistics Cluster. The Logistics Cluster's ambition is to make Flanders the European powerhouse in global supply chain: Digital – Sustainable – Agile. To realize this ambition, the cluster organization elaborated a competitive program in close collaboration with the main triple-helix partners involved in logistics: the industry, the universities, other knowledge centers and the relevant sector federations. In a brainstorm meeting organized in April 2016 by the logistics cluster facilitator VIL (Vlaams Instituut voor Logistiek) with participants from all Flemish universities, iMinds, several representatives of sector associations, government representatives and the industry, a research agenda was jointly determined for the next 3 years. This roadmap is built up around four themes: Digitalization, Flanders gateways, omnichannel and sustainability.

DISpATch fits within the themes of Digitalization and Sustainability. Flanders has a dense transport infrastructure, in terms of roads, railways, waterways and ports. However, the road network faces an increasing threat of becoming totally congested due to the ever-increasing number of passenger and heavy goods vehicles. Belgium appears at the non-enviable first place of the 2015 Europe Inrix Scorecard, which ranks countries in terms of road congestion. Antwerp and Brussels occupy the third and fifth place in the top 10 ranking of most congested cities in Europe. The Federal Planning Bureau predicts a 44% increase of goods transport by 2030.

Synchromodality is about building flexible supply chains based on multimodal transport solutions. The logistics service provider takes care of all transport needs of its customer (shipper or expeditor) by offering a fully integrated solution considering all available transport modes.

DISpATch is in line with the advice provided by the Flemish Mobility Council (Mobiliteitsraad) to stimulate cooperation models that allow fragmented volumes to be bundled, as well as the exchange of information between companies in the logistics chain. Furthermore, the Flanders in transition document, issued by the Vlaamse raad voor wetenschap en innovatie, sets synchromodality and intelligent transport systems as one of the main pillars within the priorities in science, technology and innovation towards 2025. These priorities should lead to increasing fill rates and eliminate empty runs, induce a modal shift and decrease environmental impact of freight transport. The DISpATch project touches upon these aspects as the Digital Twin will have the capacity to simulate synchromodal dynamic processes, capture fragmented flows with decentralized algorithms, and measure financial and environmental impacts.

1.2 Problem statement

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 'business as usual' approach are not sufficient to cope sustainably with the expanding market (EC, 2011) as the freight share of total transport green-house gases is projected to increase from 42% in 2010 to 60% in 2050 which will present a major challenge to decarbonize the freight transport sector (OECD, 2015). The ambition of the European

Commission is to shift 30% of road freight transport by 2030 to environmentally friendlier modes that have lower societal impact, such as rail and inland waterways (iww). This shift should reach 50% by 2050.

If we downscale to the Belgian/Flemish context, Belgium's Federaal Planbureau expects cargo demand to increase by 44% (in tonne-kilometer) by 2030, compared to 2012 ("Vooruitzichten van de transportvraag in België tegen 2030", Federaal Planbureau, December 2015). Compared to an overall mobility demand increase of 22% it is clear that the share of goods transport in daily traffic will increase significantly during the next decades. Despite strenuous efforts to alter the freight modal split, most companies still rely heavily on road transport, and modal shifts to rail and inland waterways have remained modest at best. More specifically, the modal split figures of 2012 illustrate the dominant position of road (74%) and the potential for further development of the alternative modes (iww 16% and rail 10%). Federaal Planbureau also predicts that the share of waterways and rail will show only modest increase of market share by 2030 (iww 16%->18%, rail 10%->12%) in case of "continued policy" (in Dutch "bij ongewijzigd beleid"). The most recent available data issued by Eurostat, depict the modal split of 2016 as road (73.1%), IWW (15.3%) and rail (11.6%) when iww even decreased while rail experienced a modest increase.

The findings of the modal choice literature also yield higher user preferences related to road transport based on the user's needs. Intermodal transport, which is a combination of two or more modes in one unified journey (Reis, 2015), provides more options and opportunities for a positive modal shift. However, the development of intermodal decision support models, where more actors and modes are incorporated (compared to unimodal), are hampered by limited data availability and its static nature (Caris et al., 2013). Furthermore, shippers in Flanders perceive intermodal transport as a slow and inflexible solution with a limited service offer (Meers et al., 2017) which also explains the modal split numbers. The static and inflexible solutions as well as real-time visibility are addressed by the synchromodal transport concept. Given the rather negative freight transport developments, there is a great need for projects such as this one in order to help unlock the potential for inland waterways, rails and better utilization of truck capacities and other assets. With this project, we intend to address the lack of visibility and real-time solutions in the logistics sector which results in sub-optimal use of capacities, empty runs, congestion as well as avoidable pollution and noise.

Most users perceive Synchromodality as already implemented; switching to the best modes is being done when needed. Nevertheless, mere switching does not define synchromodality as this switching is predefined well in advance which makes the system rather inflexible. In fact, it still constitutes intermodal transport. Synchromodal transport employs multiple transport modes in a flexible and dynamic way in order to induce a modal shift towards more environmentally friendly transport modes without compromising on responsiveness and quality of service. It enables optimal integration of different transport modes and infrastructure by the use of real-time (Internet of Things) data to improve capacity usage, flow of transport means and enhance their use cost-effectively. Synchromodality is also another word for real-time/optimized intermodal transport. However, last-minute synchromodal changes are not well understood nor evaluated as these changes require involvement of extra parties in the process and transparency issues as to who has the cargo and where it is located. The planning thus has to be updated and all necessary parties involved (continuous monitoring, emails, messages). The DISpATch project will focus on creating such a transparency in a virtual environment and further address the notion of real-timeliness. We will investigate how such a system can be developed, what the necessary conditions are and what the impact of having such a system would be if real-time information and frequent messages to all relevant parties are sent out.

The synchromodal concept is still rather theoretical as there is not an appropriate platform to provide transparency and evaluate processes in real-time so that shippers and logistics service providers gain insights and better understanding of what real-time is and how real-time can real-time be. The project will also help companies by tackling temporal alignment in order to understand whether 1 hour data updates are enough to switch payloads to rail or inland waterways once a truck is already aligned for a given payload, and what the consequences are in terms of increased/decreased lead times, fill rates, costs and emissions.

With this research project, we combine forces with three universities (VUB, KU Leuven and UHasselt) that have expertise in different aspects of synchromodal transport. The objective is to develop a Digital Twin to further enhance the synchromodal concept and make synchromodal transport a reality in Flanders to boost the competitiveness and sustainability of its logistics sector. The Digital Twin will serve as a testbed for synchromodal opportunities. It is a virtual environment that mirrors the real physical system (a physical twin) and its processes by updating its virtual real-time status from various sources of information regarding weather forecasts, congestion levels, positions of assets (barges, trains, trucks) and their ongoing working conditions. The Digital Twin will have the ability to simulate multiple virtual realities at once which will allow us to test phenomena inexpensively in a risk-free environment as opposed to pilot projects that may be either too expensive, risky, or dangerous to carry out. Furthermore, it will allow us to test new ideas/phenomena which do not simply exist yet. In other words, the main added value of the Digital Twin will be 1) information, 2) tested knowledge that will replace wasted financial resources on pilot projects without having prior sufficient details or analyses, 3) data flow optimization between different actors of the supply chain and 4) simulation of new innovative ideas.

Our Digital Twin will be able to explore, discover, evaluate, inherit and share intelligence among assets. The reason why we carry out this project is the inability of industry to deploy a substantial amount of developers and researchers to create custom Digital Twins for their experiments as they lack time, financial resources and expertise. DISpATch will give a boost to innovation in a sector that is quickly changing and needs necessary platforms to be able to fully grasp the benefits of sharing data and assets. We are well aware this is still a very sensitive subject and companies are hesitating to make these steps. This why we have set-up case studies to show the benefits, both on company and societal levels. As for the extent to which the companies in Flanders will be able to use the project results, our computational and analytical solutions as well as virtual environments will be deployed on Anylogic servers (www.anylogic.com) where the users (LSPs and Shippers listed in this consortium) will be able to interact with their Digital Twins. The interaction will be enabled via PC browsers, tablets or smartphones as the Anylogic simulation solutions are cloud-based. The last stage of the DISpATch project will devise a digital-physical twin integration framework for the companies where the components of the Digital Twin will be linked to existing system applications. The Digital Twin can provide an executable simulation module that will connect to existing transport management systems, control towers etc. Companies can use the Digital Twin as a testbed where they can assess their entire supply chain and evaluate visibility measures (IT/IoT), physical movements, modal shift potential and bundling of shipments; both at regional and inter-regional scales.

1.3 Economic opportunities throughout the value chain

The scientific results of the DISpATch project will provide economic opportunities for multiple types of companies along the value chain. The long-term vision of the DISpATch project is to make the Digital Twin a part of existing system solutions. Our post-project ambition (after DISpATch completion and case study illustrations) is to test the developed architecture and algorithms within pilot use cases for which the consortium will target follow-up financing channels that will support further market penetration. Such an industrial solution testing will depart from the available DISpATch project research results and fuse the Digital Twin's architecture, its logic, granularities and algorithms with existing real-time geofencing tools provided by ESRI or other GIS providers. This fusion will allow data from GPS devices, beacons and sensors to be linked to the Digital Twin for optimization and future state predictions via a mirroring platform. To ensure broader implementation and valorization potential within Flanders, the end-results of the DISpATch project will be used as a basis for COOK and/or R&D grants provided by VLAIO, as the true potential of a large-scale Digital Twin exceeds the confinements of a single project. Nevertheless, the fundamental cSBO DISpATch project will play an imperative role in developing, forming and testing the core components of the Digital Twin. The following opportunities can be identified according to the type of operator in the value chain.

First, for shippers/retailers the opportunities are the following:

- Adapt to growing demand, new concepts and trends to remain competitive by decreasing their environmental footprint; increase fill rates, shift to rail or inland waterways. The Digital Twin will look for modal shift alternatives and link these to their inventory management schemes.
- Technologies are shifting where dynamic and responsive solutions are necessary. The Digital Twin will facilitate human planer's decision by providing order scheduling, mode selection and risk mitigation scenarios in multiple virtual realities in parallel. This will decrease alternative-seeking time of the planner who cannot evaluate 50 possibilities, for instance, and risks related to them all at once.
- Our shippers expressed interest in IoT and real-time dynamic systems but want to see first how it could potentially change their current business processes in a risk-free environment before investing in such technologies. They will have the opportunity to simulate different transparency levels and gain richer insight that will contribute to more informed decisions before investing in IoT applications that are untested for their specific cases. These real-time systems and IoT technologies can be mimicked in the Digital Twin.
- Cost and/or lead-time reduction by introducing more detailed routing strategies for the last-mile and bundling of fragmented flows. Even though bundling can increase fill rates and reduce cost, the cost reduction may be affected by the extra driven kilometers to the bundling/handling points. The opportunity is to reduce cost by well-detailed GIS simulations that will identify whether deviations to bundling/handling points are worth it or not.

Second, logistics service providers (LSPs):

- The LSPs sell their services to shippers which means the above mentioned possibilities need to be executable by the LSPs in the end. The opportunities our project provides for LSPs are optimization of current flows and better transport planning. They will be able to take a holistic approach and account for consecutive processes that depend on each other. Such processes can be assessed in great detail in order to identify how small perturbations can affect their overall delivery processes; for instance, by considering freight movement and warehouse or terminal process.

- A competitive advantage by having tested responsive real-time solutions and gain insight in how real-time updates can improve location intelligence and estimation of arrival times. Knowing where your assets are and where they will be in 1 or 3 hours is central for most businesses when planning return trips.
- The previous will also offer opportunities in terms of better service offers and cost reduction as the Digital Twin will simulate multiple fragmented flows in parallel; this will reveal bundling opportunities by knowing which assets comply with spatial and temporal requirements. In other words, how far the assets are, what distance they need to cover, when they will arrive, how it will impact the lead-time and overall costs if some assets wait for the others to arrive etc.
- Dynamic synchromodal context requires analyzing multiple options and routes at once to meet the shipper's specified time-windows. The Digital Twin will help LSP planners with full or partial automation of route-finding and mode selection while considering contextual risks such as possible blockages and disruptions per mode. The spatial and temporal details of the Digital Twin will also allow for finding the best options for newly incoming orders so that those orders are assigned to the most convenient and available mode, hence increasing response time and improving service level.
- Another opportunity that concerns both, LSPs and shippers, is to be part of the latest scientific progress. The expertise of VUB, UHasselt and KU Leuven embedded in the unique multimethod Digital Twin design, will provide an opportunity to measure the impact of any business-related ideas and expose their limits by stress-testing them in a virtual real-time environment.

Last, technological enablers:
These are companies that have the technological means and expertise to deployed real-time data fetching and geo-spatial tools as well as IoT devices. A sample of companies operating in Belgium are ESRI, HERE, Geo Solutions, IoTBE community etc. We identify the following opportunities for the enablers:

- DISpATch as a showcasing platform for products and services that relate to real-time tracking of assets and process communication. As all the real-time elements in terms of triggering rules, information flows, physical flows, transparency levels, geo-fencing etc. will be assesses in the virtual Digital Twin environment, the technological enablers will gain advantage as DISpATch will present specific case studies where GIS and IoT approaches are used. Most importantly, what type of problems shippers and LSPs want to have solved and how such technologies can help them.
- Creating a larger customer pool. Activities in WP5 will explore Digital Twin – Physical Twin integration architectures so that shippers and LSPs may deploy our developed logic in reality. This step will enable the enablers to attract more potential users. We will apply for follow-up projects to test the integration architectures, after the DISpATch project, with a consortium of technological enablers, Shippers and/or LSPs in order to carry out real-life use cases.

2 Valorisation objectives

In general, planning horizons are divided into strategic, tactical and operational (Caris et al., 2008; Bektas and Crainic, 2007; Hoff et al., 2010; SteadieSeifi et al., 2014): The strategic level concerns long-term planning (5-10 years) related to constructions of new terminals, network capacity, introduction of new equipment etc. The tactical horizon is mid-term, covering days and weeks. At this level, plans such as how to bundle and route goods in a network, and what service to provide (type, quantity, frequency), are carried out. Lastly, the operational planning horizon relates to short-term developments covering hours and minutes. This level concerns vehicle routing, assignment of pending orders, disruption management and last-minute modal choices. Given the dynamic and flexible nature of synchromodal transport, DISpATch focuses on the **tactical and operational planning horizons.**

Based on the aforementioned economic opportunities, challenges and required knowledge leaps, we identify the following valorisation objectives for the DISpATch project. These objectives are defined so as to cover the entire value chain and address the different types of target groups in the advisory committee.

Objectives for shippers/retailers:

- Demonstrate model shift possibilities of fragmented flows by using decentralized route-finding and identification of nearby handling points. More detailed simulations will contribute to identifying how extra service points, deviations to handling points and increased/decreased fill rates will affect time and cost constraints as well as the environmental footprint of such processes.
- Demonstrate risk mitigation and adaptation of deliveries where inventory management goes hand-in-hand with the movement of goods. The risks will be evaluated for potential modal shift flows, but also for current flows that do not have a modal shift potential due to short distances, lack of critical mass or high costs and lead-times. In this regard, real-time synchronization of freight movements and inventory management will contribute to improving established flows and the fill rates of assets, should there be no modal shift potential.
- Demonstrate hypothetical bundling scenarios in a simulated risk-free environment where the costly presence of lawyers is not a prerequisite. The simulated Digital Twin environment will facilitate such bundling opportunities of 2 shippers, for instance, by considering the spatial proximities of their assets that roam in nearby geographic space. These flows will be identified by decentralized local intelligence and spatial characteristics of the environment without exposing any sensitive information. However, different transparency levels of data exposure can be simulated as well, should the shippers on our advisory board agree to expose 10% of their data; these demonstration possibilities will be proposed after our simulations of bundling demonstrations in the Digital Twin.

Objectives for logistics service providers:

- Demonstrate an increased performance of intermodal operations due to a better real-time planning support compared to traditional planning operations. This performance increase can be realized in terms of operational cost reductions, the algorithms’ speed and responsiveness, KPIs related to due times and capacity utilization. The case studies’ success is measured by the degree to which the logistics service providers intend to adopt or further invest in a dynamic synchromodal transport planning. We aim for at least two follow-up projects.

- Demonstrate the potential bundling opportunities of sharing open logistics networks between logistics service providers. This is realized by a continued cooperation in at least one case study.
- Demonstrate the potential advantages of synchromodal planning support to the human planners. This is measured by the degree to which the results of the case studies are accepted by the end-users at the logistics companies in the advisory committee and by the companies attending intermediate workshops organized by VIL.

Objectives for enablers:

- Create a processing simulation module in form of a Digital Twin that will take the current real environment, mapped in real-time and offering present and past asset states, as a departure point. In other words, the Digital Twin will go beyond the present time and leap into the future by taking the current present environment as a point of departure. From this point onward, bundling and optimization processes developed within this project will be initiated.
- Simulate and demonstrate the possibilities of having different companies sharing a community-like TMS with an objective to create one in the follow-up, for instance a geo-spatial data agnostic network.

Objectives for wider logistics sector:

- Demonstrate the Digital Twin possibilities on a broader scale by showcasing the intermediate and final results that can be applicable to the whole Flemish logistics sector. Such an outreach will be facilitated by the network of VIL.
- Demonstrate scalability and transferability scenarios and added value of the Digital Twin if adapted by more companies. This step will illustrate the added value creation once more flows, capacities and assets join the DISpATch environment.
- Communicate project results through professional publications, workshops and a website for logistics professionals.

3 Digital twin platform (Research rationale)

Synchromodal transport involves a shift from static 'predict & prepare' transport decisions to dynamic and flexible 'sense & respond' solutions where the selection of transport modes is based on real-time positions and availabilities of assets (barges, trains, trucks, terminals). However, real-time mode selection requires involvement of extra parties in the process to solve transparency issues as to who has the cargo and where it is located. The planning of the transport modes thus has to be synchronized in a sophisticated manner and with all necessary parties involved. Apart from a limited number of successful pilots, the synchromodal concept remains to date rather theoretical and it is not well measurable in terms of real-time operations due to the lack of an appropriate platform to provide reliable assessments in a highly dynamic and real-time environment. Such a platform would be able to mimic the current real environment, and simulate how it could evolve by taking synchromodal transport decisions. The objective of this project is to develop such a platform. This will allow to test existing and newly developed dynamic planning algorithms and communication technologies which are also the main enablers for stimulating synchromodal transport. The platform will operate like a Digital Twin that mimics the physical reality on a digital platform. It will address questions such as: How much to transport, when and by using which transport mode? How can we integrate replenishment decisions and inventory cost calculation within the transport planning process? How can collaboration between shippers and/or logistics service providers in an open logistics network enhance the sustainability and cost-efficiency of supply chains?

The project will focus on organizational and technical enablers for seamless synchromodal transport services in Flanders and beyond. Given the real-time dynamics and flexible nature of synchromodal transport, different transport modalities and actors need to work together and adapt according to unexpected events and contextual information that affect transport processes. These events and contextual information are related to negative as well as positive perturbations that shape freight movement and transport mode selection, such as newly incoming orders, transport delays, cancellations, collaborative bundling opportunities, accidents, water levels, strikes and many more. Crucial elements in this regard are situational awareness of the current system state and projections of how the system will evolve once different actors take different actions. We will consider individual company objectives at micro level and network objectives at macro level.

A focal point of the Digital Twin is aimed at detecting and measuring emergent behavior of individual business processes (at the point of action) on an aggregated macro level at which more unique individual processes converge and form the overall system pattern. The Digital Twin will offer emergence control methods that will consider local (cost, lead-times) and global (emissions/externalities) objectives at tactical and operational levels. The decisions will be influenced by the Digital Twin's design that will incorporate analytical and computational modelling techniques in order to create a robust virtual environment that may be later on connected to real-time data fetching tools so that LSPs and shippers can query their assets in real-time, run multiple scenarios in a simulated environment, and take decisions in the real physical system; the Digital Twin will then adapt to the newly changed state. The innovative Digital Twin environment will combine features of Geographic Information Systems, agent-based and discrete event models as well as smart algorithms that will ensure freight flows are combined and synchronized efficiently, resulting in higher vehicle fill rates, a shift towards more environmentally transport modes, less trucks on the road and a significant decarbonization of freight transport. Having a great level of detail provided by the Digital Twin, we can capture complex interrelations since individual business processes will not be aggregated or omitted.

Simulation is a commonly used tool for developing systems, new designs and system processes. Simulation-based solutions are also useful for failure prediction and optimization of various processes. The Digital Twin will serve as an interface where different models, their data, granularities as well as processes are integrated. The Digital Twin will contain necessary information and models that have the ability to solve different tasks related to inventory management, freight transport and network planning. The Digital Twin can be perceived as a "box" which will be connected to real-time data fetching tools once the DISpATch project has successfully ended.

While there already exist real-time control towers (ESRI geo-event server, MPO, ActiveViam etc.), and data fetching/scrapping tools (Webhouse.io, VisualScrapper, Spinn3r etc) that have the ability to integrate data via JSON at a single reference point, these applications provide past and present positions and trends. With our project, we intend to depart from the past and present assets' states and speed-forward into the future by predicting possible outcomes that may lead to better utilization of potential opportunities. In order to estimate where assets such as barges, trains and trucks will be in for instance 2, 3 or 5 hours based on congestions levels and infrastructural developments, and which terminals, DCs and other moving assets will be in their vicinity, is a challenging task. To acquire such future states of assets, one would need a time-machine to travel into the future, observe how the future looks and then return back to present time to make a decision. This project will not build a time-machine, but our Digital Twin will come close to this metaphor. The aim of the DISpATch project is to fill the "box" with certain logic, as depicted conceptually in figure 1, and test bundling and optimization possibilities in a risk-free environment before it is plugged-in and connected to geofencing tools and real-time data updates. This is to avoid having a mere transparent overview of assets and their processes (which already exists). The Digital Twin will be able to interrogate current asset states and positions, and speed-forward into the future while considering information from external sources (AIS, weather forecasts, traffic jams, accidents, strikes…) by applying Monte Carlo simulations to account for any possible outcomes and uncertainties. The last stage of our project will develop a mirroring platform where real-physical assets will be converted into object instances so that users will be able to tap into the Digital Twin "box" and connect it to their new or current transport management systems.

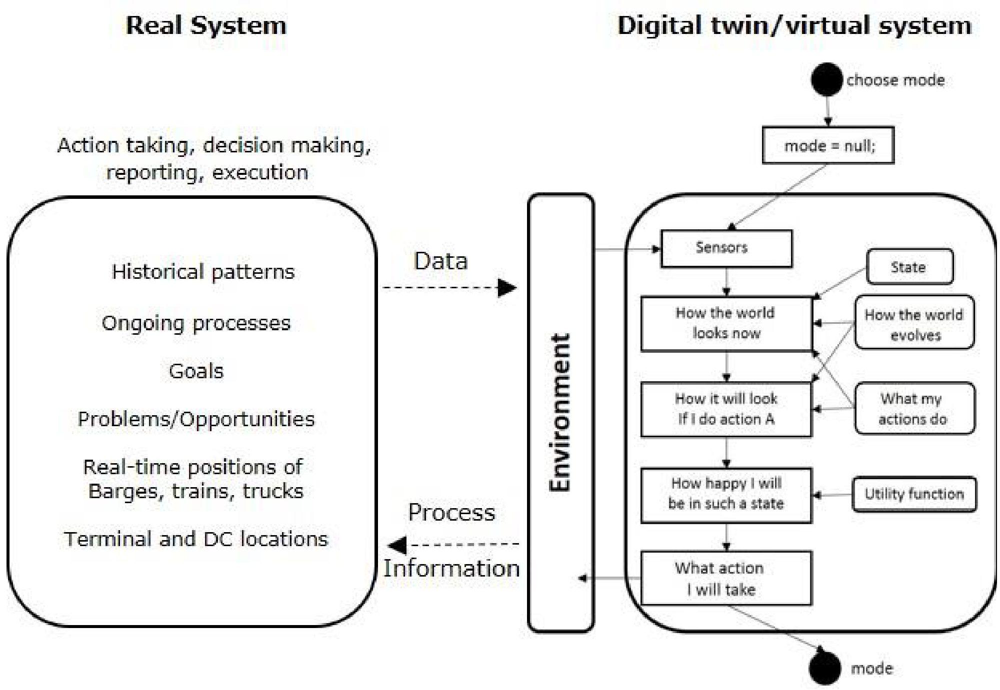

Figure 1: Conceptual illustration of the digital and physical Twin interaction. Right-hand side of the figure adapted from Russell et al. (2003).

As indicated in figure 1, the real physical system will provide data to the virtual space and in return the virtual space will provide information flow and process specifications to the real system. Virtual sub-spaces (multiple virtual realities) will work in parallel where Monte Carlo simulations will be executed to account for various replications to capture all possible outcomes of the future. Besides the Digital Twin's ability to simulate and evaluate multiple virtual realities, effects of sensor technology and information exchange can be studied in combination with physical flows. Such a risk-free environment will allow for analysis and evaluation of triggering events (new orders, disruptions, delays…) which induce physical movements, and vice-versa, physical movements may trigger information flows once certain assets arrive at a specific location or enter a geo-fence. The moving (barges, trains, trucks, vans etc.) and stationary (terminals, DCs etc.) assets can be perceived as physical objects that can communicate their location to a centralized platform. As the Internet of Things (IoT) deals with the Internet as the network or virtual space and things as physical objects (Atzori et al., 2010), the DISpATch project will go beyond getting mere data out of sensors, and rather focus on the data processing mechanics, machine learning and business automation within the Digital Twin to answer questions of businesses that are considering IoT applications such as: what if objects can talk to each other? Which objects can talk to each other? How will the object transparency affect physical flows and vice-versa? The core focus of DISpATch will be to develop the Digital Twin box since trying to answer and evaluate the above-mentioned situations and questions would be expensive and time consuming when deploying dozens of pilot projects.

3.1 Research gaps

Decision support models in literature, both for long-haul and drayage, typically take the perspective of a single decision maker. Yet, the use of high-capacity modes in intermodal and synchromodal transport involves the bundling of freight flows to achieve economies of scale. This provides a setting in which cooperation among different parties (i.e., LSPs) may offer huge benefits. Unfortunately, little is known about the magnitude of and conditions for achieving these benefits which our project will explore.

By means of simulation, business rules and objectives will determine the evolving system when projecting into the future, as these rules will mimic how businesses act over time. Pure analytical solutions are goal seeking and lack decentralized biases that exist in reality which is why they may not capture counterintuitive elements as good as simulation does; things one would never think about. We will use the Digital Twin concept to mimic the physical system through virtual reality where we will deploy the earlier mentioned GIS for better spatial intelligence, agent-based models for decentralized local behaviors of entities such as transport means, and discrete event models for process-centric logic in terminals and other 4-wall environments. The process centric logic of stationary entities will be connected to transport means which will allow for a holistic approach that relies on consecutive steps; terminal and DC processes depend on asset arrivals while freight transport depends on terminal and/or DC rules and efficiency.

Furthermore, smart replenishment algorithms will need to be developed that can cope with the complex nature of synchromodality; if the transport operations need to be altered, the inventory replenishment needs to be aligned as well, taking inventory and service levels into account. The availability of a Digital Twin will allow companies to dynamically adapt the transport mode planning and as such facilitate a shift from road transport to more sustainable transport modes, such as inland waterways or rail transport without sacrificing logistical efficiency or service quality. Similar to the way reinforcement learning has beaten the world champion of the board game Go, we will demonstrate the power of smart algorithms to stimulate synchromodality.

The DISpATch project will make use of the above described background knowledge and extend the current body of literature by introducing a novel virtual environment that contains a crucial real-time-based component (level of time still flowing) which is lacking in current synchromodal model applications. Another aspects our project will address are a combination of centralized methods with decentralized processes of assets, more accurate route-finding where local roads, main roads, inland waterways and railways are presented in great detail via GIS and built-in stochastic elements where uncertainties can be assigned to any process via probability distribution functions. In fact, a digital map with dynamic multi-agent-based interactions within it, will allow for integration of routing approaches and mode/service-selection updates over time as object-oriented programming enables execution of multiple processes in parallel. Furthermore, we will offer visualization features which will be more comprehensive for users in order to create trust around the model, compared to abstract mathematical formulations. Such an ambitious vision will be achieved by breaking silos and combining expertise where UHasselt will focus on integrated network planning, KU Leuven on smart replenishment and VUB on freight transport execution, uncertainty and predictability. The concrete objectives and research steps are presented in the following section.

3.2 Scientific objectives

Synchromodality is contingent due to the wide range of external inputs that affect internal resource states, and only dynamic models can effectively capture state fluctuations over time. Given the dynamic nature of synchromodality, 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 modeling approaches are necessary to bridge academic models with physical transport processes. The most challenging aspect when making decisions in a complex adaptive dynamic system is the ever-changing environment as we introduce more flexibility which may lead to more unpredictable outcomes. The main objective of DISpATch is to develop a model that will measure the real-time synchromodal complexity and evaluate various decisions and offer alternatives. More specific objectives and research questions are presented below:

Objective 1: Develop key performance indicators in relation to the real-time notion of synchromodality

Current scientific publications take "real-time" for granted and ignore the flow of time in their models. This is to say that once models are executed and observables move mathematically from node A to node B, triggering events or an extra information insertion can no longer enter the model while the observables are being moved between the two nodes. Asset coordinates that determine its location between these two points, the remaining distance to the next location(s) as well as the time at which the information is received or sent, is impossible to model mathematically. Current models thus assume to have real-time data inputs before the model-runs. It is however unclear what happens during the model executions, as changing parameters and variables would require a complete model restart. Our objective will challenge the notion of the temporal alignment where we will create a modelling framework that will concern time-constraints and various information exchange architectures in order to assess information exchange and reactive behaviors of physical process flows during model executions; the rules and processes that occur on the inside of the model. Achieving this objective will help us understand the "when" dimension of synchromodality so that more knowledge is gained with regard to last-calls of mode switching given customs/DC/Terminal procedures.

RQ1: How accurate should real-time information be to make synchromodal decisions?

Objective 2: Contribution to new theories by developing and combining modelling paradigms and the Digital Twin concept

Mathematical and data-centric models (machine learning) are able to learn from past outcomes, predictions and errors. However, relying purely on mathematical and data-centric models for decision making in complex systems is risky as they are limited to forecasting and assessing effects of events in the aftermath; meaning that a similar event must have occurred historically and this effect is known at present. The challenge thus comes when the system is exposed to previously unexperienced or unseen events. In this regard, computational/simulation models can reinforce mathematical models by offering process-centric approaches. If data is lacking, simulation can generate a vast amount of data and execute model runs outside of historical bounds. Simulation works best when business processes are well understood, the preferences clearly stated and the fidelity of physics well mimicked. On the other hand, mathematical and data-centric models will help simulations by using data driven approximations to reflect on processes more accurately and better inform simulation models where behavioral processes are hard to identify.

The essence of the scientific innovation is to represent space via Geographic Information Systems (GIS) that have the ability to mimic real-world entities as opposed to generative mathematical models with abstract environments. GIS will form the Digital Twin Environment (DTE); the cornerstone of our Digital Twin. A fine-grained Digital Twin will also contribute to more detailed external cost calculations as the real cost of transport goes beyond the immediate internal costs related to transport and logistics operations. A wide variety of externalities and the impact of up- and downstream processes create additional burdens for society. We will use an External Cost Calculator (ECC) that translates these externalities of transport to society into monetary terms, the so-called external costs of transport. The ECC will play a role in defining global system objectives (emissions/externalities) against local individual ones (cost, lead-times).

RQ2: How can the combination of simulation and mathematical modelling support synchromodal decisions in case there is no or limited data?

RQ3: How can emergence of individual micro processes lead to better decision making and where do we find the equilibrium between centralized and decentralized decision making?

Objective 3: Prototype, test and validate methods with consortium partners

This objective aims at matching academic theories against real-life problems faced by industry. We will virtually showcase potential benefits of synchromodal transport by addressing the tactical and operational planning horizons. Through close dialog with the consortium partners, our models will be (re)calibrated and validated by means of three case studies that concern maritime, continental and retail supply chains. We will tackle the following set of research questions:

RQ(s)4: How is the transport mode choice affected by taking real-time information into account in a synchromodal planning context? How can we integrate replenishment decisions and inventory cost calculation within the transport planning process? How can collaboration between shippers and/or logistics service providers in an open logistics network enhance the sustainability and cost-efficiency of supply chains?

Besides demonstrating and testing our methods, we will also touch upon new technologies and measure the effect of these technologies via the Digital Twin. The Digital Twin's unique design will allow for testing and measuring real-time data sensor information exchange through simulation.

RQ5: What opportunities and case applications would emerge if assets could start talking to each other and/or sense their surroundings?

Objective 4: Create a scalable and transferable tool, and assess resilience measures and future state estimations

We will focus on the scalability of the solutions and integration of maritime, continental and retail supply chains into one holistic application to capture system responsiveness once all parts are connected. By doing so, we will contribute to a more holistic understanding of supply chains. The maritime, continental and retail cases will be simulated together to account for door-to-door freight deliveries that involve 1) replenishment, 2) interregional flows via waterways, rails or roads and 3) last-mile urban deliveries. Most, if not all, applications cover either interregional flows or urban flows but never the combination of both; this objective will aim at closing the gap.

RQ(s)6: Do the performances at different scales vary over time? How much do they depend on each other and what measures do we have to take to optimize the freight delivery system as a whole?

After evaluating our case studies and their specific characteristics, we will test the resilience of the devised solutions by making use of Monte Carlo simulations that will take into account different disruption profiles. Simulations will help mathematical models by generating data and training models in situations that have never happened before; when reality kicks in alongside the simulation scenario trajectories, we will already have solutions as we will have tested those in the virtual world. In the occurrence of an unexpected event outside historical bounds, the Digital Twin and its mirroring platform would query available assets, contextual information, and evaluate multiple scenarios in parallel as illustrated in figure 1. We pose the following:

RQ7: How do disturbances and other perturbations affect the performance of currently established supply chains and how can we mitigate them? The main KPIs that will be taken into consideration are costs, lead-times, load factors and externalities.

Objective 5: Devise a mirroring architecture in which the Digital Twin is connected to real-time data fetching tools and existing transport management systems

Once we have developed the virtual Digital Twin that integrates replenishment models, freight transport models and network planning models, and tested various scenarios and solution resilience, we will delineate a digital and physical twin integration scheme where physical objects will be converted into digital assets (object instances). These digital instances will manifest as physical asset replicas which will be subject to all developed rules and logic of the Digital Twin and its DTE. The java object instances, that are represented as agents with decentralized intelligence, can simulate information exchange among other agents that can be queried as “things” in the IoT notion. Geo-servers that enable geo-fence and IoT integration are rather expensive which is why our modeling approach will be useful to mimic similar transparency systems and assess various what-if scenarios in a risk-free environment to gain more insight before empirical tests or industrial implementations. Our experiments will mimic geo-spatial servers that are capable of imposing conditional filtering rules and geo-fences for asset detection and message/notification exchange among entities such as moving and stationary assets. This objective will thus assess transparency systems and use VIL WIN4TRACK project findings as its starting base. We will devise a roadmap for implementing real-time data fetching tools and sensor connectors to the DTE, where the DTE will represent a living simulation environment that will continuously adapt its state according to real-world data and run potential scenarios and optimizations along event updates.

RQ8: How can companies plug-in the Digital Twin and what are the necessary technical and organizational requirements for doing so?

4 Research approach and work packages

The project is organized into six Work Packages (WPs). Each work package provides an answer to the corresponding objective stated in the previous section. In the sixth work package separate attention is given to reporting and dissemination of project results. The WP relationships are depicted in Figure 2.

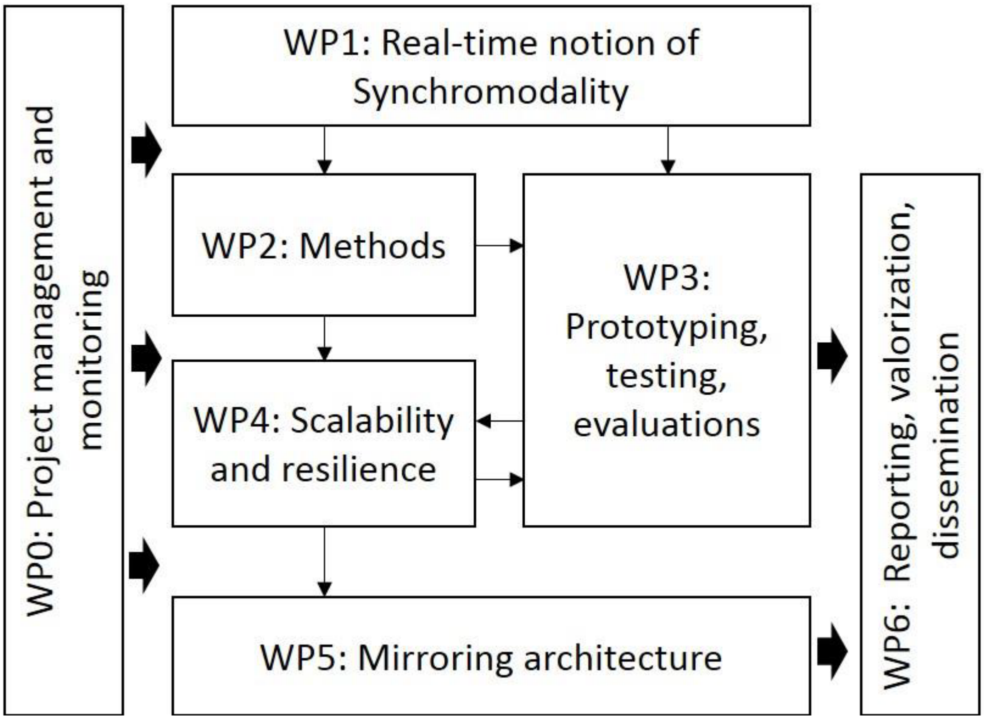

Figure 2: Global overview of the Work Packages and their relations

WP0: Project management and monitoring:

All project partners have extensive experience with basic research projects and cooperation with industry partners. Moreover, MOBI has a broad experience in managing national and international projects. This provides a solid base for successfully managing the DISpATch project, achieving its research goals, and pursuing our valorization objectives.

The management team is the highest management and decision-making body in this project. This board is chaired by Tomas Ambra and Cathy Macharis (VUB) as well as representatives from each other partner: Robert Boute (KU Leuven), An Caris (UHasselt) and Kris Neyens (VIL). The management team's primary duties include (a) steering the overall project and making strategic decisions; (b) monitoring progress; (c) anticipating problems which may affect the project's success; (d) analyzing the followed IPR and dissemination strategy; and ensuring good cooperation and communication between the partners. Daily project management is performed by Tomas Ambra (VUB), including communication with VLAIO and VIL, organizing and coordinating project meetings, and setting up and maintaining the project dissemination platform.

4.1 Real-time notion of synchromodality

The activities conducted in the following tasks will address objective 1.

- Task 1.1 Case study characteristics

The initial step will be to engage researchers in deeper dialog with the companies that are included in our advisory board. The researchers will observe the companies' business-as-usual processes, current problems, and identify specific operational synchromodal opportunities. Based on this, the researchers will identify a case study and develop specific scenarios and characteristics to be modelled. This will ensure that the development of algorithms and methodological combinations will have a practical industrial relevance. The output of this task will lead to the creation of established business rules, objectives, preferences and constraints that will be taken into account in the modelling phase. The Digital Twin will be developed around these rules and constraints.

- Task 1.2 Initial data collection

The initial data collection relates to available company data but also available external data that will be translated into contextual information. The former entails acquiring historical data, which will determine key model parameters and variables. The latter, external data collection, will be used to determine infrastructural developments that affect freight movement within inland waterways, rails and roads. This type of external information will be crucial when developing simulations for business cases for which companies do not possess any data; for instance, a single company uses truck-only transport for which it has historical data, but has no idea how their business would be affected when switching to barge or rail transport, or bundle goods with different trucks at certain points. Therefore, the combination of historical company data, external information regarding infrastructural conditions but also business rules, objectives and preferences from task 1.1, will provide researchers with a solid set of inputs for their models.

- Task 1.3 Current/potential real-time aspects

The researchers will explore current IoT technologies and real-time data fetching tools and identify how and where they are used in different industries. They will further explore the current situation of the companies involved in the consortium with regard to their transport managements systems, how and if they work with real-time information, what is the desired frequency of data updates, which new technologies could improve their processes etc. This task will set the first tone for the Digital Twin's communication links between entities

4.2 Developing and combining modelling paradigms

The tasks described in this work package will contribute to meeting objective 2. The developments regarding the different modelling techniques (mathematical, machine learning, simulation) will explicitly account for and explore methodological combinations. To this end, frequent meetings will bring VUB, KU Leuven and UHasselt researchers together in order to integrate their approaches. The output of this WP will yield a methodological framework which will form the base of our Digital twin's modelling architecture. The framework will specify levels of abstraction, granularities, geo-scales, input-output relations and the hierarchy of entities in order to facilitate efficient planning and multifactor settings.

- Task 2.1 Mathematical modelling (UHasselt)

Planning algorithms will be developed to tackle synchromodal network planning in a dynamic context. A modular approach will be followed, in which long-haul and local drayage optimization problems are combined in an integrated model. However, current approaches do not support such kind of integrated decision making in a real-time context, and may not be suitable for realistic problem sizes. In a dynamic context, new information needs to be considered, such as customer information and changes in travel times. Due to this dynamic nature and the size of a realistic network, a heuristic solution approach is needed to generate near-optimal solutions in a very short time frame. Therefore, we will base our approach on the work of Heggen et al. (2018b), and extend it by 1) considering the dynamic, real-time context of synchromodal transport and by 2) proposing a heuristic solution approach to solve instances of realistic size.

- Task 2.2 Machine learning for Smart replenishment (KU Leuven)

To develop the smart replenishment algorithms, we will rely on state-of-the-art deep reinforcement learning techniques. Reinforcement learning is focused on developing (near)-optimal policies for sequential decision-making problems under stochasticity (such as periodic inventory review models). The underlying modelling structure a reinforcement learning problem allows to adapt decisions to the real-time state of the system, enabling synchromodal decision-making.

Traditional methods to find optimal policies for sequential decision-making under uncertainty suffer from two curses. First, an exact representation of the environment is sometimes unavailable (such as for instance the distribution of demand in a replenishment problem), a problem which is also referred to as the curse of modelling. Second, traditional solution methodologies such as dynamic programming suffer from the curse of dimensionality, making large (often more realistic) problems intractable in practice. By sampling data effectively while using function approximators, reinforcement learning is capable to solve both of these curses and can consequently tackle larger and more realistic problems. Accordingly, we can develop a model that is applicable in practice.

- Task 2.3 Computational/simulation modeling (VUB)

Since simulation technology forms the backbone of the Digital Twin, this task will create the Digital Twin Environment (DTE) where all case studies and methods will be integrated. The DTE will be represented as a digital map with a great level of detail that will facilitate accurate navigation, route finding, and spatial awareness.

The Digital Twin Environment: Real-world locations will be based on the WGS84 geographic coordinate system, having Greenwich (0, 0) as its prime meridian. The reason behind choosing the WGS84 coordinate system is twofold. Firstly, it is used as a reference system by GPS, Google Maps as well as by Microsoft in its Bing Maps. Secondly, Anylogic, which is the main software where the DTE will be constructed, uses the WGS84 datum2 for GIS projection conversion. The conversion is crucial as the shapefiles in ESRI-ArcMap (a GIS provider) are based on a spherical coordinate system (due to shapefile properties), whereas Anylogic uses a Mercator projection which projects the earth's spherical surface onto a two-dimensional plane. Hence, a spherical coordinate system has different lengths and shapes, compared to a projected coordinate system. As far as shapefiles are concerned, we will use the European Transport policy Information System (ETIS-plus) and Eurogeographics (www.eurogeographics.org) to acquire geospatial data for roads, rails and all navigable inland waterways.

The Digital Twin of the physical system will be embedded in this DTE. The physical assets will be mimicked by digital instances/objects that are called agents. Agents possess various properties capable of mimicking behavioral dynamics of freight transport systems. They can process and exchange information with other agents as well as perceive other entities, obstacles or sense their surroundings (Crooks & Heppenstall, 2012). Thus, decisions of agents are influenced by the available information and data in their network which means some decision outcomes may vary due to the existence or absence of a specific piece of information. In this regard, we will use ABM computer simulations which offer substantial benefits as they allow for execution of multiple parallel processes. The starting-point of such a DTE with agent-based characteristics will be the SYMBIT model

- Task 2.4 Emergence control (centralized vs. decentralized)

Standard planning algorithms are embedded in deterministic and fully observable environments that assume all information is accurate and known in advance. However, real-life transport processes violate these assumptions as information and behaviors of entities are uncertain and governed by individual biases. In this regard, agents in multi-agent systems can engage in cooperative or competitive tasks. Agents cooperate when they comply with global laws and goals, or they compete, in which case the individual goals govern the agents behavior (Davidsson et al., 2005). In this task, we will explore and test conventions for joint activities (constraint rules) and uni- or bi-directional communication links among agents that would lead to feasible joint plans. This task will be aimed at detecting and measuring emergent behavior of individual business processes (at the point of action) on an aggregated macro level at which more unique individual processes converge and form the overall system pattern. The Digital Twin will offer emergence control methods that will take into account local (cost, lead-times) and global (emissions/externalities) objectives at tactical and operational levels in nondeterministic environments where action outcomes will be uncertain. In other words, agents can be designed to have self-organizing rules to follow their own goals, just like businesses do in reality.

To elaborate further on this, a local solution may be the best for a single agent, but not necessarily for the environment or a group of other users. In this setting, agents lack a global view of the system state (Becker et al., 2006) that may lead to greedy local solutions while creating bottlenecks in a different part of the system. For instance, a terminal system can experience a bottleneck at a gate if container cranes spend too much time loading one specific batch of containers on a train without applying the round-robin policy. Locally, it is optimal for the train, but sub-optimal for the terminal as a whole. Another example may concern a network operator; if a barge agent does not have a more general knowledge of the overall network developments provided by the network agent, the route selection and sailing strategy may not be optimal. Also, an LSP may choose a different mode once the water level is not sufficient to transport containers by barge. However, if all entities are advised to switch from inland waterways to train, this development can cause a negative butter-fly effect in another part of the system. The global network view will thus be incorporated into local decision making, and vice versa, local information will be included in more general network processes to reduce bottlenecks and increase efficiency at both levels. We will devise consensus-seeking as well as coordination algorithms in this type of multi-agent system by considering sequential decision problems, Markov decision processes, game theory and times series analysis.

4.3 Prototyping, testing and validation

The activities in this work package will contribute to fulfilling objective 3. The calibration and validation of the developed algorithms and theories will be tested iteratively by following the structure proposed by Oberkampf and Barone (2006). While movement calibration of agents will by correlated against vessel data from AIS such as marinetraffic.com, road from traffic map providers etc., the case studies will help us to validate the business processes and logic of the industry. The following tasks describe 3 case studies.

- Task 3.1 Maritime synchromodal transport

The first case study will cover maritime-based intermodal transport where the flows of Lineas will be assessed and evaluated at tactical and operational planning levels. Historical data of transport means will be used for agent movement calibration within the Digital Twin Environment (DTE) to reflect more accurately on real-life movements. This will contribute to better Estimated-Time-of-Arrival (ETA) calculations where we will probe agent (truck, barge, train) speed parameters based on contextual information such as congestion levels, current state of inland waterways etc. Lineas data will also be used to replicate their current flows and practices, and simulate real-time switching in a virtual environment by connecting asset movements and their ETAs with process-centric operations in terminals and/or DCs. This case study will be mainly used to evaluate the synchromodal real-timeliness of decision making, switching and bundling of containers. Various what-if scenarios will be developed to test transparency levels and spatial awareness of assets and their working conditions. Figure 4 schematically depicts how current geolocations of moving assets will be sent to stationary agents (terminals, DCs or headquarters) once they cross a certain geo-fence. The current latitude and longitude (x, y) and ETA of the assets will be determined based on the methods developed in task 2.3 and the information will be sent to terminals and/or DCs to allow for more proactive queuing, switching and bundling strategies. By means of the Digital Twin, we will be able to integrate processes of 4-wall environments and connected them to external processes, such as freight transport outside of the 4-walls. We hypothesize that this connection will increase overall efficiency as freight movement depends on terminal and DC rules and operations, and these same operations are governed by the order in which assets arrive.

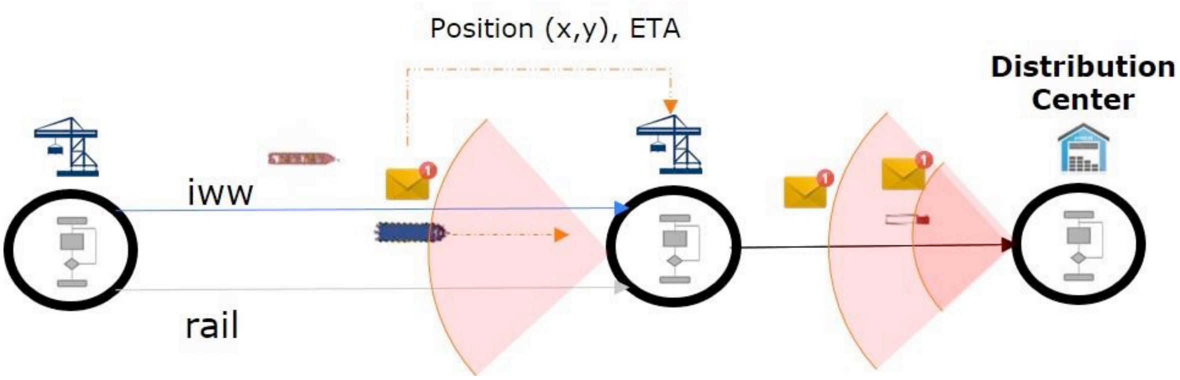

Figure 4: Schematic overview of ETA reporting

Through close dialogue with Lineas, we will mimic their business-as-usual and optimize their routing and mode switching strategies with regard to which mode to use, where to switch, what terminals are located enroute, how far the handling points are and if the assets will make it before closing hours given the assets' current geo-locations etc. These options will be simulated and output measured in terms of emissions, fill rates and lead-times. Furthermore, we will consider terminal sizes, utilization rates and terminal capacity which determine handling cost per unit as indicated in Wiegmans and Konings (2015).

- Task 3.2 Continental synchromodal transport

The second case study concentrates on continental synchromodal transport chains. To this end, the company H. Essers is included in the advisory board. H.Essers is one of the largest logistic service providers in Europe, offering a broad range of transport, warehousing and other services. Although tactical and operational transport decisions at H.Essers are supported by their own Transport Management System (TMS), human intervention in the planning process is still major. Even when supporting software is applied, transport planners still have to take ad-hoc decisions based on the available information for their business unit. Each business unit runs its own planning process of freight flows, considering its own trucking capacity and empty return flows. This case will demonstrate and validate the modeling of real-time transport planning decisions. The company believes that more opportunities for synchromodal transport exist depending on the agreed transport lead time. Also bundling opportunities between the different business units inside the company offers a challenge. Currently, the business unit of high security goods makes the most use of synchromodal transport. By sharing capacity information and bundling freight flows of multiple business units, more consolidation can take place, thereby stimulating the use of synchromodal transport. This case study thus validates the modelling approaches developed in WP2, taking into account the operational network planning at the detailed level of a logistics service provider. Next, it provides an insight in how logistics service providers can collaborate in an open logistics network to encourage the use of synchromodal transport.

- Task 3.3 Retail-based synchromodal transport

Thirdly, we will assess the usability of the Digital Twin in the retail environment. Colruyt has a significant number of truck shipments and they are looking for solutions to reduce pressure on mobility and contribute to a sustainable future. Based on the flows of the retailers, we will simulate replenishments to their Distribution Centers, as well as to their retail shops; in both cases, it can be analyzed whether shipments could be altered from road transport to lower-carbon modes, such as rail or waterborne transport. Our smart algorithms will be implemented to determine which (part of the) shipments can be shipped using rail or waterborne transport, and which (part of the) shipments should remain to be transported using road transport. In each of the cases, the economic and environmental implications will be assessed. The economic impact is important as it will determine whether retail companies will be open to use the algorithms in practice. The environmental impact will be assessed for each simulated setting while considering greenhouse gas emissions, infrastructure costs, and other external factors. These aspects will illustrate societal benefits for each proposed solution. The application of the smart algorithms in combination with the Digital Twin will allow to reduce the number of trucks on the road. As fewer trucks on our roads mean less CO_2 emissions and fewer traffic jams, this comes at the benefits of the entire society.

4.4 Scalability and resilience

The activities in this work package will contribute to fulfilling objective 4.

- Task 4.1 Framework integration

Once a first validation has taken place per case study in WP3, this task will further build on the integration initiated in WP2. The VUB will fuse model structures of the 2 universities so that the Digital Twin can operate under one umbrella. This is to avoid restarting models each time as well as using different models for replenishment, freight transport and network planning separately. Such an integration will create a holistic model, with the right level of abstraction, where interdependencies will be studied in detail, rather than averaging or omitting some parts of the supply chain. The model scales, granularities and levels of complexity will be discussed with the partners in order retain a reasonable computational time and preserve a certain level of validity.

- Task 4.2 Scalability testing

The fragmentation of various freight transport applications presents challenges in terms of knowledge transferability and solution scalability. This is due to the ad-hoc nature of current models which focus on specific scales and geographical regions. Scalability testing will be conducted in parallel with task 4.1, and will entail changes in variables, input parameters and geo-locations in order to determine how the developed routing, replenishment and coordination algorithms react when up-scaled to a European level, or when they are simply transferred to other companies with different origin-destination settings. This task will mainly help us understand how fast another company will be able to use the Digital Twin and what coverage and speed it will be able to handle. We will not involve other companies at this stage, but mainly change geolocations and quantities of input related to demand and transport capacities.

- Task 4.3 Door-to-door analysis

With this task we will revisit our separate case studies and test the scalable Digital Twin by combining inputs and logic from all 3 cases. Last-mile deliveries with smaller geographical areas will be linked to inter-regional flows presented in the 2 other case studies. Synergies will be sought by using the existing data and combined algorithms. In case of no synergies that would allow a synchromodal door-to-door analysis, the Digital Twin will simulate hypothetical cases with the partner's/company's current logistics service providers and established contacts. The ultimate goal of this task is to test the first synchromodal-door-to-door service and showcase the integrated and scalable Digital Twin which will have been devised in tasks 4.1 and 4.2. Such an analysis will demonstrate the twin's scalability and transferability by combining dense urban road networks with national/international roads, inland waterways and rails.

- Task 4.4 System resilience/disruption testing

This task will evaluate system responsiveness to disruptions by making use of decentralized reconfiguration protocols at tactical and operational levels, and assess potential risk severity and its consequent impact via Monte Carlo experiments. When exposed to perturbations, the Digital Twin will calculate other modal alternatives in terms of ETAs, cost, fill rates, emissions and lead-times by considering all modes, infrastructures, terminals and costs related to handling and movement of payloads.

The predictive elements will start from the current state of the assets where the digital instances will be queried with regard to their ongoing working conditions, current geolocations via latitude and longitude (x, y coordinates), their history states and performances. The future projections will rely on the fidelity of physics that govern asset movements. Multiple digital instances/agents such as barges, trains, trucks, terminals and DC's will feed data into the DTE where the Monte Carlo simulations will take over and execute future possible states and patterns that may emerge once individual agents with their own biases and objectives start taking actions and affect each other. The Monte Carlo simulations will draw input values from probability distribution functions from historical and hypothetical disruption profiles, and impose delays, blockages and other events upon agents during model executions. These events will trigger a transition from agents' current ongoing process states to new "disrupted" composite states where agents will seek for alternatives from a decentralized perspective and their individual context (geo-location, distances, infrastructure etc.). We will thus approach this problem by making use of state charts, developed by the Anylogic company, which are the most advanced constructs capable of describing time- and event-driven behaviors.

4.5 Mirroring architecture

Activities in this work packages will contribute to objective 5.

- Task 5.1 IoT applications and adapter requirements

The Internet of Things (IoT) sphere contains many applications and technologies that can be incorporated in one coherent network. As our research focus goes beyond a single company application and concerns multiple companies with various geographical scales that require different reach, network coverage and hence different technologies to be used for sensing objects, this task will explore how such a real-time dynamic network could look like. We will aim at connecting application silos and explore sensor/beacon technology and its attributes together with their performances. This task will create knowledge regarding IoT platforms that put information together in order to understand how devices can be queried from the real-world and how the sensor monitoring processes can be integrated and exposed to rules and logic developed in the Digital Twin. We will build on the VIL-WIN4TRACK project findings and update them with new emerging IoT applications that will have manifested by the time this task takes place. The goal will be to draft a holistic framework that integrates parcel/pallet object location updates with emerging Bluetooth application at terminals, beacon and WIFI applications within warehouses, and asset movement monitoring via inland waterways, rails and roads.

The same way a person arrives home and a thermostat learns about his/her location via a bracelet which consequently communicates with the thermostat that turns on the heating, other stationary entities can sense vehicles via various network structures and trigger necessary actions at terminals or DCs. These networks differ in terms of spectrum, range and subscription costs such as Low-Powered Wide Area Networks (LPWAN) provided by LoRaWAN, ETSI LTN etc.. Other technologies include RFID, Bluetooth, and cellular networks such as 3G-4G-5G. Since these diverse networks work with different spectra and ranges, there will not be a holy grail-like application that will fit all the scales and geographic coverages. We will thus further identify potential gray zones and depict how the Digital Twin can fill these zones by computing probabilistic positions and ETA's of assets.

- Task 5.2 GIS platforms and adapter requirements

The "things" in the IoT notion need to have an environment that will be similar to the DTE and its coordinate system for accurate location intelligence and geo-fencing. This task will explore GIS providers and their real-time geo-servers that may integrate external sources of information at one reference point. Such servers allow for process integration via real-time data analytics once real-time data inputs are gathered. It is unknown how many transport management systems and IoT devices can be combined and integrated at one point and at which cost. This task will explore possible implementation plans for companies. Our analysis will go beyond regular GPS satellite overview of a single company's assets by studying the possibilities to integrate 1) many moving "things" and "sub-things" of more than one company, 2) geo-fences and the rules as well as processes they may execute, and 3) JSON contextual information feeds from AIS, road mapping platforms, and potentially social networks to facilitate decision making. With this task we will explore how to exploit data streaming, how to achieve continuous processing and analytics (not merely on a point-to-point basis), and how and by whom alerts and messages should be sent. This roadmap will be discussed with GIS providers such as ESRI etc., who possess such geo-event processing tools.

- Task 5.3 Digital and Physical twin integration framework

At the last stage, we will produce a blueprint for merging the virtual world instances/agents with real world assets which will create a genuine live and adaptable simulated environment. As agents are able to perceive their environment through sensors and act upon the input via actuators (Russell et al., 2003), the Digital Twin can mimic real physical processes since sensor inputs may be connected to agents' actuators via receiving-channels determined by their communication links, and consequently process and exchange information among other agents as well as perceive other entities and obstacles within their environment. This task will specify how the Digital Twin's architecture will be able to a) receive data updates via input connectors, b) mirror the real physical assets by converting them into digital object instances, c) execute optimization logic, future state projections and risk assessments described in previous tasks, and finally d) feed the information/processes back to the real system through output connectors which will disseminate notifications such as updates and alerts (see also Figure 1 in the rationale for conceptual overview). While the main purpose of our DISpATch project will be to develop the mechanics within the Digital Twin, this final task will shed light on how the Digital Twin can be plugged-in for industrial use.

4.6 Reporting, valorization and dissemination

With respect to reporting, dissemination and valorization, an online project dissemination platform has been set up (www.dispatch-project.be) where all events, conferences, workshops, publications and deliverables will be uploaded or referred to.

Task 6.1 Demonstrations and advisory board workshops

Meetings will be held at least once every six months between the research partners, advisory board and sub-contractors to convey the progress and findings (preliminary and final), discuss issues and project directions, and further validate the research output with the companies. These meetings will be facilitated by VIL.

- Task 6.2 Deliverables and journal publication

In order to address the broader professional or interested public, deliverables will be issued for each work package reporting on the progress and intermediate project steps. Besides using our dissemination platform, we will further communicate and provide these deliverables via our individual professional network via LinkedIn, Research Gate, and research group websites such as www.mobi.vub.ac.be. National journal magazines we have experience with will be used for further dissemination such a valuechain.be3. More detailed scientific output will be communicated through well-ranked journals such as Transportation Science, Transport research part C: Emerging technologies, Computers & Operations Research, European Journal of Operational Research, Transportation Research Part E: Logistics and Transportation Review, Journal of Business Logistics, the Journal of Transport Geography, …

- Task 6.3 External workshops and conferences

VIL will organize annual workshops accessible by broader public and other companies from VIL's network. These workshops will also serve as an opportunity to exchange ideas and reflections between the broader public as well as other universities and external partners we have worked with; MOBI-VUB has organized several MOBI seminars that were attended by over 100 participants. These participants will be targeted together with VIL's network in order to create critical mass and substantial industrial outreach. The project results will be also communicated internationally such as Transport Research Arena (TRA), International Physical Internet Conference (IPIC), Winter Simulation conference, EURO conference, Verolog…

- Task 6.4 Knowledge transfer to industry

In close cooperation with VIL, the DISpATch project results will be transformed into new ideas and initiatives through R&D and COOKS funding channels provided by VLAIO. Besides transferring the project knowledge to our industrial partners and advisory committee, we will aim at involving more companies from VIL's network in order to ensure broader use case applications in the future. The results and architectures developed in the DISpATch project will have cross-thematic relevance within VIL's themes that consists of 1) Sustainability, 2) Omni-channel, 3) Digitalization and 4) Flanders Gateways. As our project touches upon the synchromodality concept under the Sustainability theme, the Digital Twin environment will be also highly relevant in terms of Digitalization and Flanders Gateways since DISpATch will have developed algorithms and roadmaps that fit into artificial intelligence, Internet of Things, and digital collaborative business models that may be intertwined with the ports of the future that concern inter-operability and inter-connectivity. Therefore, the knowledge transfer to industry will not be limited to a small sample of companies as our project's content has a great potential to address more themes and reach out to more users.

Table 1 provides an overview of our timing, work pages, milestones and division of tasks.

Table 1: Overview of the timing with regard to Work Packages, their corresponding tasks and milestones.

		Year 1				Year 2				Year 3				Year 4			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
WP 1 Real-time notion of synchromodality	Task 1.1: Case study characteristics	■	■														
	Task 1.2: Initial data collection		■														
	Task 1.3: Current/potential real-time aspects		■														
WP 2 Developing and combining modelling paradigms	Task 2.1: Mathematical modelling			■	■	■	■										
	Task 2.2: Machine learning			■	■	■	■										
	Task 2.3: Simulation modeling and external cost calculations			■	■	■	■										
	Task 2.4: Emergance control (centralized vs. decentralized)						■	■	■								
WP 3 Prototyping, testing and validation	Task 3.1: Maritime synchromodal transport				■	■	■	■	■	■	■	■	■	■	■	■	■
	Task 3.2: Continental synchromodal transport				■	■	■	■	■	■	■	■	■	■	■	■	■
	Task 3.3: Retail-based synchromodal transport				■	■	■	■	■	■	■	■	■	■	■	■	■
WP 4 Scalability and resilience	Task 4.1: Framework integration									■	■	■	■	■			
	Task 4.2: Scalability testing												■				
	Task 4.3: Door-to-door analysis													■	■		
	Task 4.4: System resilience/disruption testing						■	■	■				■	■	■		
WP 5 Mirroring architecture	Task 5.1: IoT applications and adapter requiremetns			■										■	■		
	Task 5.2: GIS platforms and adapter requirements			■										■	■		
	Task 5.3: Digital and Pysical twin integration framework													■	■	■	■
WP 6 Reporting, valorization and dissamination	Task 6.1: Demonstrations and user group workshops	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Task 6.2: Deliverables and journal publications	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Task 6.3: External workshops and conferences	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Task 6.4: Knowledge tranfer to industry	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
				M1		M2			M3		M4				M5		M6

Milestone	**Definition**	
M1	Literature review, use cases and parameters ready	
M2	Combined methodological approach defined	
M3	Emergence control algorithms ready and tested	
M4	First case evaluations and Digital Twin calibrations	
M5	Calibrated, validated and scalable Digital Twin	
M6	Digital and physical twin integration framework for companies. Final workshop and demonstration of future applications/research	

5 Project Outputs

The execution of this vision document can be tracked via our project's website where deliverables, models, presentations, etc., will be uploaded based on the above timeline and objectives. These outputs will be available at: http://dispatch-project.be/output/.