SYNCHRO-NET: a powerful and innovative synchro-modal supply chain eco-NET

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SYNCHRO-NET: a powerful and innovative synchro-modal supply chain eco-NET

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Abstract

SYNCHRO-NET is a Horizon 2020 European research project that aims to overcome the stress due to increasing transportation distances, higher complexity, and vulnerability of supply chains. The core of the SYNCHRO-NET solution is an integrated optimisation and simulation eco-NET system that supports stakeholders' decisions in the transport of goods at strategic and operational levels. In particular, the system enables stakeholders to identify improvement opportunities by quickly analysing and calculating the impacts and benefits of slow/smart steaming and synchro-modality so to enhance sustainability, quality, and reliability. Three case studies considering pan-European and regional trade lanes, as well as commercial activities between Far East and European ports, prove the efficiency and effectiveness of the overall system.

Keywords: Transport Modeling & Simulation; Transfer Hubs (Multimodal)/Synchro-modality; ICT Technology Applications.

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1. Introduction

SYNCHRO-NET is a Horizon2020 European research project that aims to overcome the stress due to increasing transportation distances, complexity, and vulnerability of supply chains. The SYNCHRO-NET project emphasizes end-to-end supply chain management, i.e. coordination across transport modes and supply chain operators. In this approach, high *synchro-modality* and *slow steaming* can both enable and contribute to higher levels of coordination across transport modes and stakeholders. These aspects play a central role in most logistics innovation actions. Synchro-modality refers to inter- and co-modal transportation, in which stakeholders flexibly coordinate logistics operations, and can switch between transport modes in real-time for higher speed and efficiency. Slow steaming is the practice of operating cargo ships at less, and mainly at significantly less, than their design speed. Slow steaming decreases fuel costs and reduces greenhouse gas emissions. The SYNCHRO-NET system enables stakeholders to identify business opportunities by quickly analysing and calculating the impacts and benefits of slow steaming and synchro-modality, enhancing sustainability, quality, and reliability (Perboli et al., 2017).

The core of the SYNCHRO-NET solution is an integrated optimisation and simulation eco-NET system, supporting synchro-modal logistics at different levels. At the strategic level, a *simulator* provides an optimisation engine which, given two geographical points (A and B) and the release and due date of the cargo, returns a list of potential intermodal routes from A to B. For each route, the actual departure and arrival times, a set of KPIs (duration, length, cost, emission), and risk indicators are also given. The simulator interacts with a *supply chain de-stresser*, which aims to encourage stakeholders to use lower risk and lower emission options. At the operational level, *real-time tools* trace the movements of an ongoing shipment. If the trip is stuck or delayed, a different route among those already provided is selected. If no route is feasible, the simulator is run again to generate a new list of potential routes from the last feasible node to the destination node using updated release time and due date. Finally, the *dynamic de-stresser* actuates several real-time optimisation strategies for hauliers.

Many papers in the literature are related to the SYNCHRO-NET research and innovation action. Some are standards which define a common starting point for intermodal and synchro-modal transport in global logistics networks. Others define laws, regulations, and directions for future development of the transport and logistics industry in the EU and elsewhere. Some refer to past and ongoing related projects. These project reviews highlight findings and outcomes that could be beneficial for SYNCHRO-NET work. There are also scientific and industry reports that provide in-depth insights into several important themes underpinning the SYNCHRO-NET work. Standard reviews (GS1 XML and UN/CEFACT, WCO data models for EDI messaging, and ISO/IEC 27000:2016 for data governance) are the most relevant reviews for the overall system architecture and protocols. Regarding the legislative framework, the *Directive 2002/59/EC* [2] establishing a Community vessel traffic monitoring and information system and *Directive 2010/65/EU* [3] reporting formalities for ships arriving in and/or departing from ports of the Member States are good references for the development of SYNCHRO-NET interfaces and cloud-based architecture. Slow steaming is considered by Armstrong (2013), who elaborates novel solutions for redesigning ships to lower cruising speed. Also, the *MUNIN: Maritime Unmanned Navigation through Intelligence in Networks* project (MUNIN, 2015) provides useful insights into slow steaming optimisation. SYNCHRO-NET can also learn many lessons from previous demonstration projects on maritime logistics (see, e.g., eMAR, 2012 and SMART-CM, 2009). Concerning the supply chain risk analysis, the ISO 31000 standard family on generic risk management offers a solid starting point. The 31000 standards provide a common risk vocabulary (73/2009) and provide guidance how to carry out cause-and-effect analyses, root cause assessment, and Monte Carlo simulation for risk identification, evaluation, and management. Concerning data exchange between the different modules of the SYNCHRO-NET platform, a recent survey highlighted that firms feel the need for common communication standards, but few firms use these standards on a regular basis. It is therefore important to provide a single tool in which communication standards between the different modules are embedded, guaranteeing greater scalability, compatibility, and performance. Finally, open data systems will be adopted to support routing and mapping operations within the SYNCHRO-NET platform.

The rest of the paper is organized as follows. In Section 2 the overall logical and software architecture of the eco-NET system is presented. Sections 3 describes the SYNCHRO-NET toolset to support synchro-modal logistics optimisation at a strategic (Section 3.1) and real-time (Section 3.3) level, and the risk calculator (Section 3.2). In

[2] Directive 2002/59/EC - European Parliament and Council. Establishing a Community vessel traffic monitoring and information system.

[3] Directive 2010/65/EU - European Parliament and Council of 20 October 2010. On reporting formalities for ships arriving in and/or departing from ports of the Member States and repealing Directive 2002/6/EC.

Section 4, three case studies considering *East-West*, *Pan-European* and *Regional* trade lanes will prove the efficiency and effectiveness of the overall system. Conclusions are given in Section 5.

2. The SYNCHRO-NET eco-NET system

2.1. Overall architecture

The SYNCHRO-NET platform is designed as a collaborative cloud-based eco-system. It guarantees cost-effective robust solutions that de-stress the supply chain. Emissions and costs for logistics operations are reduced by incorporating strategic and real-time synchro-modal logistics optimisations, smart streaming ship simulation and control, risk/benefits analysis, stakeholder impact assessment, and synchro-operability communications.

The architecture provides the connectivity and protocols for SYNCHRO-NET modules to communicate internally and with related external supply chain systems. It serves as the blueprint for the implementation by providing all functional and non-functional aspects in a unified way. This is achieved by relying on a service-oriented approach using workflow technology to implement an integral platform. This platform allows logistics networks to communicate with the platform as needed in a highly granular fashion and to easily interact with other logistics stakeholders. A combination of SYNCHRO-NET specific logistic modules acts as the platform's core which allow integration with external services using standardized and open APIs. Flexibility of the architecture is obtained using a service-based paradigm (SOA) including message handling capabilities to facilitate information transport. Furthermore, cloud concepts are included to achieve a maximum degree of flexibility for platform deployments.

From a layered perspective of the architecture (see Fig. 1), the platform's *Analytics and Decision Layer* encompasses the portal including means of visualization, a *user interface*, access for *mobile devices*, *dashboard*, and a *cloud controller* to adjust the deployment of the eco-system. Via the implemented APIs, some services will be externally accessible to allow integration into existing infrastructures. The *SYNCHRO-NET Service Layer*, representing the core of the eco-NET, hosts all services that support the SYNCHRO-NET scenarios like *simulator*, *driver scheduling*, *booking*, and *real-time monitoring*. The modules highlighted in grey (related to strategic and real-time synchro-modal logistics optimisation) are discussed in detail in the upcoming sections. The *Messaging & Integration* layer provides message passing and integration with other services and databases. Finally, the *Data Layer* provides data persistence and external data linking.

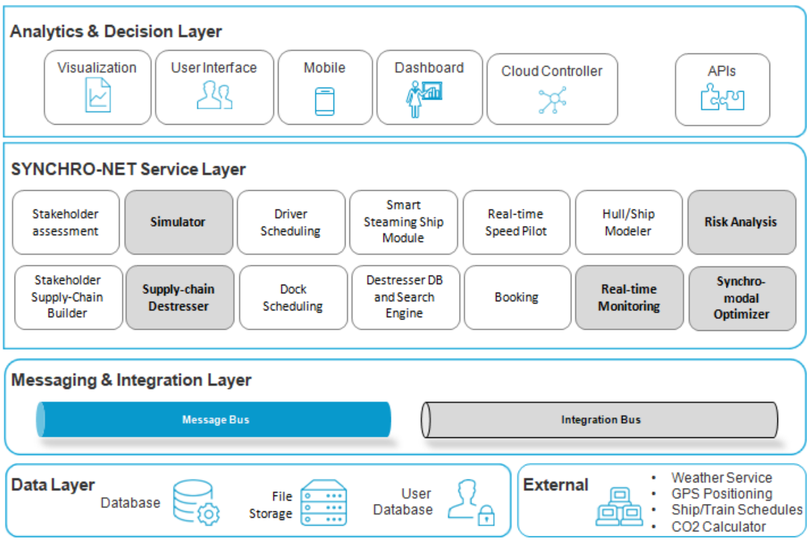

Fig. 1 Overview of the SYNCHRO-NET architecture including major components

2.2. Users, stakeholders and configurations

SYNCHRO-NET enables stakeholders in the supply chain to identify improvement opportunities by quickly analysing and calculating the impacts and benefits of slow/smart steaming and synchro-modality. The most prominent actors within the platform are *General Stakeholder*, the role of a *Retailer*, *Freight Forwarder*, *Ship Operator*, and *Real-Time Ship Manager*, each appointed with special rights to support their duties.

3. Synchro-modal logistics optimisation

The myriad of transport services available and the extended nature of many supply chains imply that a human planner tasked with finding the best way for moving their freight will only be able to consider a small subset of the possible options. In an ever-changing environment where new transport services become available every day, this means that many opportunities for cost saving and environmental impact reduction are missed. Existing optimisation systems tend to only consider a single mode, for example a limited geographical area, or a specific issue (empty container repositioning, berth scheduling in ports, rail capacity). Furthermore, these systems are generally driven by an over-simplified cost model.

The SYNCHRO-NET toolset represents a major step forwards in logistics optimisation capability, since it models the integrated supply chain, including all modes and related activities, and pursues a more sophisticated de-stressing approach which considers several cost voices, environmental impact, risks, and other factors. The system allows the user to find, at a strategic level, the best multimodal route and schedule to move their freight (Section 3.1), analyses the relative risk indicators (Section 3.2), and enables the dynamic switching of that solution in response to real-time events (Section 3.3). Through this integrated vision, SYNCHRO-NET can address the potential concerns of shippers/transport to de-stressing a supply chain using slow steaming and greener transport modes: *complexity* (multimodal transport is inherently more complex to plan/manage), *costs* (does “greener” always means “more expensive”?), and *flexibility* (multimodal transport is sometimes viewed as inflexible and not appropriate for dynamic business models).

3.1. Strategic de-stressing, optimisation, and simulation

Within the eco-NET, the *simulator* tool is responsible for providing strategic-level decision support regarding routes and schedules for synchro-modal freight transportation. More precisely, by using optimisation techniques and algorithms over a well-defined database of geospatial and commercial information, the simulator finds the best possible solutions according to users’ differing objectives and constraints. The route optimisation core (detailed in Section 3.1.1) can be used by other software modules in the eco-NET to elaborate solutions (mainly, risk analysis and real-time tools). However, as advanced searching options and parameterization are provided (Section 3.1.2), the simulator can also be used as a stand-alone application (primarily by advanced users) to simulate, test, and compare the outcomes of different transportation scenarios.

The simulator is built upon an open-source collection of libraries called *OpenTripPlanner* (OTP, *http://www.opentripplanner.org/*). This Java package uses client-server architecture and provides a map-based web interface and REST APIs for use by third-party applications. Originally, OTP was conceived as a platform for multi-modal and multi-agency journey planning, primarily for the urban level movement of people. It relies on open data standards including *Open Street Map* (OSM) for street networks and *General Transit Feed Specification* (GTFS) for schedules and transits (see Appendix A.1). For this project, the OTP has been extensively customized for use as a freight transportation planner. Specific optimisation procedures, new searching features and the calculation of additional outputs have been implemented, together with tools to make use of them in the graphical interface.

3.1.1. Route optimisation

The core optimisation engine allows the user to select an origin and destination for the shipment, some constraints on departure and arrival dates and times, and returns a list of feasible synchro-modal itineraries. More precisely, the searching process is as follows. The locations can be selected from a list of cities, harbours, and inter-modal ports already included in the system, or picked interactively on a map. The system then applies optimisation routines based on algorithms for routing problems (see, e.g., Manerba et al., 2017) and for the well-known Shortest Path Problem (SPP), such as the *Dijkstra* and *A** algorithms (Festa, 2006), but adapted to:

- consider the synchronization of the schedules among the different itinerary legs, considering the alighting, boarding, and transit times at each vehicle change;
- simultaneously minimize the distance travelled, time elapsed, CO2 emissions (the three main KPIs), and their relative costs. Note that in general these objectives may be conflicting.

The solutions are displayed graphically on a map, together with summarized and detailed information for each itinerary (Fig. 2a). The summary panel is particularly useful for comparing and sorting the solutions by different quantitative values including the three main KPIs, the total cost of the trip, the types of vehicles involved, the number of stops, and the associate risk indicators (see Section 3.3).

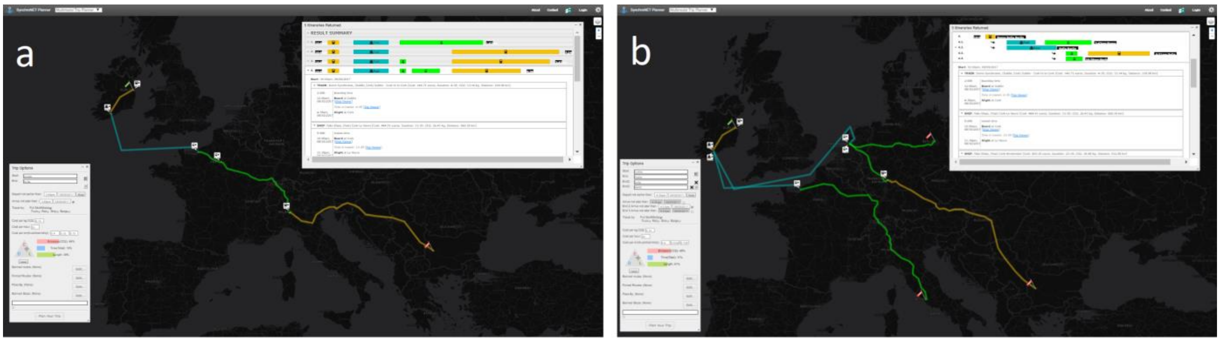

Fig. 2 Graphical outputs of synchro-modal route optimisation. Truck routes are in green color, train routes in yellow, and ship routes in blue. (a) A shipment itinerary from Dublin to Sofia; (b) A multi-destination plan from Dublin to Sofia, Rome, and Berlin.

A *multi-destination* search has also been implemented which allows more complex plans, of freight transportation from a single origin to many different destinations, to be created. Each destination may have its own arrival date and time specified. This simulation modality, particularly important to the assessment of freight consolidation processes, can be also customized using the options presented in Section 3.2. From an optimisation point of view, the system applies a plain search for each destination, stores a certain number of possible alternatives for each, and then combines them by merging common parts. Hence, the output of a multi-destination search is not a list of alternative itineraries but a list of complete plans to reach all the destinations within the same shipment (each plan is thus represented by a tree of paths, see Fig. 2b).

3.1.2. Advanced search options and parameterization

To simulate more complex transportation scenarios, the simulator allows advanced users (agencies, carriers, shippers) to specify an additional set of preferences and to fully customize the simulation parameters. Whilst in general the preferences tend to restrict the solutions provided and affect the feasibility of the outputs, the parameterization allows evaluation of solutions under different conditions, thus affecting optimality.

The list of the advanced search options implemented are described below:

- **transportation modes**: through a simple check box the user can specify their desired combination of allowed transport modes. The default selection is full synchro-modality;
- **banned locations or routes**: the user can specify a set of locations and/or routes which must not be part of a provided solution. This can be used, for example, by a shipper to avoid passing a particularly congested port or high-risk corridor. By default, no locations or routes are banned;
- **forced locations or routes**: the user can specify a set of locations and/or of routes that must be part of a provided solution. This can be used, for example, when there is a need to visit a specific location with certain facilities or to use routes managed by an agency with which the shipper has a long-term contract. By default, no locations or routes are forced.

The global parameters used to evaluate the KPIs of the solutions can be set to specific values. These include proportional costs per km, per hour, or per kg of CO2 for each type of vehicle, as well as its average speed. This is useful to simulate very realistic scenarios and to keep the system updated with respect to market and technology changes. Of particular interest is the ability to control the extent to which the three main KPIs, i.e. the length, the duration, and the emissions of a solution, affect the optimisation. The combination of percentage weights used reflects the needs of a specific user or scenario.

3.2. Risk analysis

Data uncertainty and unforeseen events are fundamental aspects to consider even in strategic routing optimisation models and systems (Beraldi et al., 2017). To improve the reliability of the complex supply chain logistics plans and operations returned by the simulator, additional *Key Risk Indicators* (KRI) are provided together with the already presented KPIs. To assess the risks of a specific route, existing knowledge and experience of nodes and links corresponding to this route should be included in the analysis. Therefore, within the eco-NET, real-time information is not only used to react and adapt the route if a problem occurs (see Section 3.3), but also to create a database so that different kinds of risks can be analysed in future planning. This so-called *historical storage* is filled with comparative data from the planned and executed routes. With this learning structure, the system will get better and better over time.

A Monte Carlo simulation is used to determine the following KRIs to make the user aware of the risks of each potential intermodal route provided by the simulator:

- expected cost deviation;
- expected time deviation;
- safety considering user information about loss/damage along the route;
- flexibility with respect to change modes.

As shown in Fig. 3, the risk analysis tool interacts with the simulator and is connected to the historical storage. On the one hand, the simulator calls the risk analysis tool to get KRIs for different route alternatives. On the other hand, the risk analysis tool calls the OTP API provided by the simulator during Monte Carlo simulations. Within these simulations, the feasibility of a planned route is tested and evaluated against different scenarios to predict possible risks and the results are summarized using the above KRIs. The different generated scenarios consider different possible disturbances. The simulation of the disturbances is based on the stochastic information extracted from the historical storage using suitable clustering and machine learning methods (more details are given in Simroth et al., 2016). The behaviour of a planned route is estimated by a large number of such simulations.

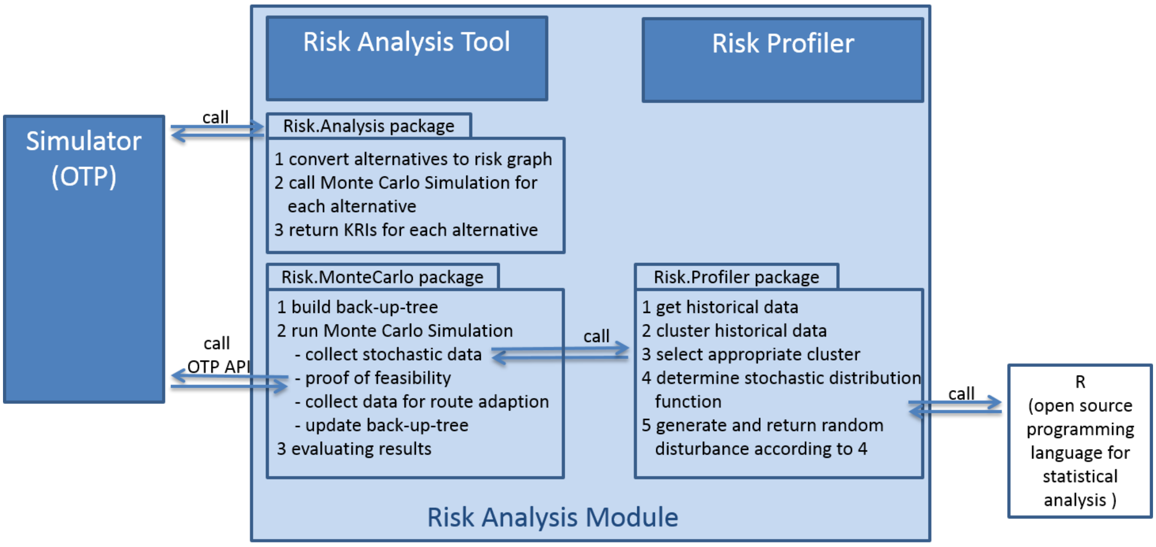

Fig. 3 Structure and interfaces of the risk analysis tool

3.3. Real-time synchro-modal logistics

3.3.1. Tracking, monitoring & re-optimising

Recent advances in data exchange and sharing technologies have made real-time supply chain information more readily available. For example, Automatic Identification Systems (AIS) such as *marinetraffic.com* and port community systems provide real-time visibility of shipping movements via APIs, Global Navigation Satellite Systems (GNSS) provide real-time truck and train positional data, and ERP systems provide real-time status updates about transport orders and resource availability. Furthermore, many initiatives have addressed efficient ways to transmit and share such information between supply chain actors (see, e.g., Natvig and Vennesland, 2010, González-Rodríguez et al, 2015, and eMAR, 2014).

However, visibility is a necessary but not sufficient condition for synchro-modality. The missing ingredient is a an optimisation engine capable of interpreting the data and responding to it when needed, such as finding an alternative solution for an urgent shipment delayed on its multimodal trip. The SYNCHRO-NET solution is designed to use the real-time data feeds above to first detect and warn about serious deviations from the plan, and then help the transport planner find the best alternative. Fig. 4 shows how the real-time synchro-modal optimisation algorithms manage an operational problem. Initially, the route involving a short sea movement was selected as the lower cost, greener option. Then, a delay of the shipping movement triggers an automated re-optimisation to find a new solution which is still cost-effective, environmentally friendly, and allows the goods to arrive on time. The ability to automatically reschedule increases the robustness of the supply chain. In fact, the shipper is more likely to choose the original (admittedly more complex, but greener) route if they are confident that SYNCHRO-NET can mitigate the impact of potential operational issues.

In such a setting, it easy to understand how the efficiency of the re-optimisation process is critical. Despite the complexity of such a task (there might be tens or hundreds of affected movements if a large container ship is delayed), SYNCHRO-NET is able to re-optimise in real-time, i.e. it can re-plan container movements in seconds. The combinatorial nature of the underlying problem makes this very challenging and has required the development of new algorithms and logistics scheduling techniques to ensure suitable performance.

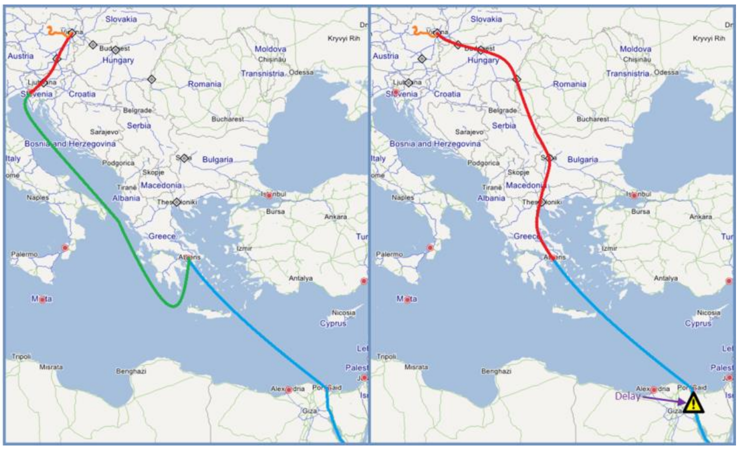

Fig. 4 Real-time re-optimisation - The left-hand side shows the planned route for a shipment. A long-haul shipping route finishing at Piraeus is shown in blue, the green route represents a feeder vessel along the Adriatic Sea, the red route a train to Vienna, and the orange the last-mile truck movement. The right-hand side shows how the system responds to a real-time detected delay through the Suez Canal, affecting the arrival time at Piraeus and invaliding the green route. As an alternative, a faster connection via train is automatically proposed (red route).

3.3.2. Real-time de-stressing

Queuing and congestion is a serious problem at major logistics terminals. Many terminals have adopted slot booking systems to try to address this and have achieved some degree of success. However, there are many opportunities to further de-stress busy terminals by intelligent load distribution and resource utilization. Furthermore, a significant delay of a large ship or rail movement may invalidate the previously carefully planned bookings in and out of the terminal and it is hard to reschedule efficiently.

Load balancing is intrinsically complex, but for a multimodal terminal many other factors need to be considered. For example, if it is necessary to change booking schedules for trucks arriving at the port this will have a knock-on effect on the haulier, who will suddenly have an under-utilized driver/vehicle at one time and a new movement to cover at the last minute. Availability of resources is finite, so this can lead to delays or other inefficiencies for the hauliers, which affect their ability to achieve the newly imposed deadlines and their costs. SYNCHRO-NET addresses this by including a real-time haulier optimisation model which reduces haulier costs and congestion at the port using several strategies:

- **dynamic equipment re-use**: by selecting appropriate combinations of import and export movements it is possible to reduce the total number of movements in and out of the terminal as well as the total truck kilometres, thus limiting cost and emissions;
- **arrivals balancing**: use availability flexibility in arrival and departure times for container movements to smooth the profile of truck movements at the hubs. For example, empty container repositioning may have more flexibility than urgent export shipments, so there is no need to attempt to have both sets of movements arriving at the same time;
- **driver hours optimisation**: by intelligently combining long- and short-distance movements, again using availability flexibility in arrival time windows, it is possible to allocate more loads to drivers while giving

them a fairer distribution of work and better work-life balance. This reduces haulier costs directly (reduction in overtime payments) and indirectly (making it easier to recruit drivers).

To achieve these benefits, it is necessary to couple the real-time de-stressing algorithms with the synchro-modal logistics planning solution, so that as operational disruptions and deviations occur an automatic synchro-modal re-optimisation "cascades" down the supply chain in response. Only by providing this capability can (often sceptical) transport operators be convinced to adopt a greener, de-risked synchro-modal strategy.

4. Case studies

Three case studies will be used to assess efficiency and effectiveness of the SYNCHRO-NET platform. Each case study is related to the real needs of a company involved in the project. The commercial, environmental and operational scenarios adopted to test the system (or some of its components) are described below.

4.1. East-West case study

In the *East-West* case study, *COSCO Shipping Lines Spain S.A.* aims to optimise import and export operations between the Far East (Shanghai) and an inland destination in Spain via one of the ports of Valencia, Barcelona and Algeciras (Fig. 5). The desired solutions are expected to consider slow/smart steaming strategies and compatible inland transport planning operations. Two scenarios will be evaluated:

- **land transport planning optimisation**: the purpose is to optimise the inland transport planning by matching compatible import/export operations (triangulations), and therefore minimise empty container movements. The system will support the company with integrating the maritime leg information, selecting and booking the best transport option, and planning trucks and hauliers in real-time;
- **ship route planning optimisation**: the aim is to demonstrate the benefits of using maritime route optimisation and real-time smart steaming strategies. The system will support the line planner for daily decision-making by evaluating the impact of unplanned events occurring at ports or during the trip (e.g., bad weather, ship competition for berth availability, strikes) and re-calculating in real-time the vessel's speed and a new steaming strategy according to the evaluated impact.

Fig. 5 East-West case study: import and export intermodal transport scenarios

4.2. Pan-European case study

In the *Pan-European* case study, *COSCO Shipping Lines Spain S.A.* aims at optimizing the management freight flows through the Piraeus hub (Greece). The solutions are expected to enhance a modal shift from truck to railway (Fig.6a) and short sea shipping for long-haul logistics, keeping truck as the option for last mile distribution. Two scenarios will be evaluated:

- **transport options and quotations assessment:** identify and evaluate, during the preparation of quotations, alternative routes that fulfil client transport orders' requirements. Through its simulation processes, the system will support the identification of different solutions in line with clients' needs and evaluation of these alternatives in terms of different KPIs (trip length, transit time, CO2 emissions) and KRIs to find the most suitable one;
- **synchro-modal planning and scheduling:** the purpose is to manage two different processes related to import and export shipments to be scheduled into the port of Piraeus (Greece), i.e. developing weekly plans of inland shipments and supporting the Rail Control Tower (RTC) to match rail and maritime services to comply with clients' transport orders' requirements. In the first case, the system will support the transport department in selecting modes/providers, in scheduling shipments to optimize routes and truck capacity, and in estimating the relative pollutant emissions. In the second case, the RTC is supported in matching train/truck services with the outgoing shipping ones to optimize the transport planning and the ship's capacity for export operations, and in matching the incoming shipments by ship with the nearest train service for import operations.

4.3. Regional case study

The *Regional* case study focuses on the logistics movements of the *Kuehne-Nagel-Dell EMC*'s Irish supply chain to explore business opportunities. The main aims are to de-stress the supply chain by consolidating freight into fewer shipments, explore re-routing and smart steaming options to increase container traffic through the port of Cork on Ireland's south coast (see Fig.6b), and aid informed decision-making in terms of environmental consequences, risk, and service level. Two scenarios will be evaluated:

- **customer cumulative freight transport weight and volume optimisation**: the aim is to demonstrate to customers that they can increase the overall efficiency of their supply chain by optimizing the volumes of each movement and thereby reduce the number of shipments over e.g. a year. The system will support the company by proposing consolidation processes over a defined horizon. Smart steaming strategies may also be applied, to reduce the effects of berth congestion and resulting impact on ship's estimated time of arrival;
- **roll-on/roll-off to lift-on/lift-off modal shift and emissions benchmarking:** *roll-on/roll-off*, in which wheeled cargo is directly loaded onto a ship, is currently the predominant mode. Through simulations, the system will show in which situations *lift-on/lift-off* (containerized movements through the port) can be a cost-effective and greener option, by calculating the emissions produced by shipping a specific cargo unit via a particular route using a particular mode.

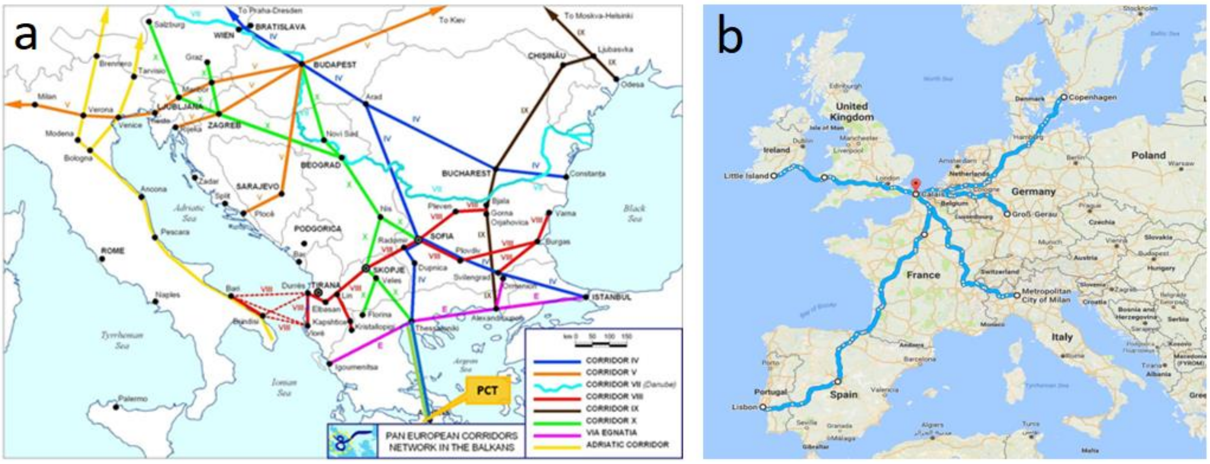

Fig.6 Sample routes involved in the considered case studies. a) Rail corridors network in the Balkans (*Pan-European* case study). b) Land-bridge routes from Cork, Ireland, to the rest of Europe (*Regional* case study).

5. Conclusions

The SYNCHRO-NET project is two thirds of the way through its duration. The structure of all modules has been completely developed. Cooperation with complementary European projects and research initiatives have been profitably set in motion. Many stakeholders across Europe have been involved and their inputs have greatly improved the effectiveness of the optimisation system. In the upcoming last phase, the project will focus on the integration of all modules into an overall automatic procedure, which will be tested in the described case studies.

Some preliminary tests have shown the efficiency and quality of the simulator, the supply chain de-stresser and the real-time tools. Encouraged by this, SYNCHRO-NET is expected to achieve very impressive results by the end of its duration, in particular:

- 25-30% increase in modal shift to rail, resulting in a further 12-15% reduction in truck kilometres;
- 12-18% reduction in hinterland transportation costs and fewer empty movements;
- 20-25% decrease in fuel emissions, especially for ships (above the existing slow-steaming savings);
- 20-30% decrease in turnaround times, thanks to reduced congestion and waiting times at ports;
- 5-10% reduction in required safety stocks throughout the supply chain.

Moreover, as a consequence of all previous improvements, it is expected an average saving of 5-8% of inland last-mile truck costs, which is around 5 billion Euros.

Acknowledgements

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Appendix

A.1. Data feeding and editing

As explained in Section 3, all the route optimisation processes of the system rely on a collection of geo-spatial, temporal, and commercial information related to freight transportation. To simplify such a database, we have decided to incorporate this information into a GTFS-like format, duly extended to include all the data needed for the optimisation e.g. the shape of the routes, length, costs, characteristic of the vehicle (type, emission, restriction), scheduled date and time of the services, and so on.

The quality of the solutions returned by the system depends greatly on the precision, correctness and completeness of the information stored. Therefore, the creation and updating of this information is important. To facilitate these operations, the following have been developed:

1. **creation of a data core**: to be useful from the very beginning, the system has been fed with a sufficiently large set of realistic routes and schedules for different types of vehicles. Truck, rail and ship routes linking thousands of main cities, harbours and intermodal ports have been stored along with their schedules and frequencies. Of course, this core data is focused mainly on the geographical areas corresponding to our three case studies (Section 6), i.e. on European and East-West trade lanes. Where possible, geo-spatial data have been automatically extracted from *Geographical Information Systems* whereas commercial details (schedules, times, costs) have been taken from several freight shipping companies directly (*DHL*, *COSCO Shipping Lines Spain S.A.*, *Kuehne-Nagel*, *RSSB*), partners of the project;
2. **implementation of a data editor**: we have developed a series of interactive and map-based interfaces that allow the user to add and modify routes (together with their own starting and ending locations, features, and schedules) into the system's database. This tool makes the system potentially unlimited, fully customizable, and easily updatable. Each agency will have the possibility to add its own services and make them available in the searching/optimisation phase.

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