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Impact of EGTN T&L innovations at the micro-level on connectivity at the macro level

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Abstract

We introduce and illustrate Integrated Green EU-Global Transport & Logistics Networks as being brought forward by the PLANET project. With adaptive routing as sample innovative transport concept that uses advanced technologies, we explain how performance enhancement can be attained at the micro level. We then explain how this logistics concept has an impact at the macro level, both in a positive and in a negative way. First, we show how adaptive routing has a positive impact on connectivity - in the context of the PLANET project, we elaborate on an extension of the notion of connectivity. Second, we show that adaptive routing also creates vulnerabilities at the macro level, as it creates dependencies between organizations through the need to communicate intensively.

Keywords: Sustainable transport policies

The project PLANET[1] (Progress towards Federated Logistics through the Integration of TEN-T into A Global Trade Network) takes a geo-economics approach in assessing the impact of emerging global trade corridors on the Transport & Logistics (T&L) infrastructure and operations, in particular the TEN-T network (Trans-European Transport Network). The project seeks to enable the European-Global Network by harnessing disruptive technologies and T&L concepts. In doing so, it aims to develop a so-called Integrated Green EU-Global T&L Network, to be explained in the introduction of this paper.

1 Introduction: Integrated Green EU-Global T&L Network (EGTN)

The EGTN concept can be understood as an advanced European strategy vision that implies the development of the Smart, Green and Integrated Transport and Logistics Network of the future. Its purpose is to efficiently interconnect infrastructure (TEN-T, Rail-Freight Corridors, etc.) with geopolitical developments, as well as to optimize the use of current & emerging transport modes and technological solutions. As efficiency and geo-economic developments do not necessarily lead to inclusivity and enhanced quality of life, the EGTN concept should be provided with the instruments to ensure equitable inclusivity of all T&L participants, increasing the prosperity of nations, preserving the

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environment, and enhancing Citizens' quality of life.

Being an advanced version of the TEN-T network concept, the EGTN concept is composed of several functional elements capable of: (1) strategy definition; (2) strategy implementation; (3) strategy possible outcomes, such as digital & physical infrastructures, new operational methods, etc.; (4) strategy monitoring; and (5) maximization of strategy impact.

From this component/capacity perspective, PLANET defines the attributes of the future EGTN. An attribute is a feature that the EGTN, as a strategic vision, should manifest. The EGTN concept extends the notion of the TEN-T concept by incorporating geo-economic awareness and take a global view. As such, the project challenges a within-corridor scope. PLANET defines the following attributes for the EGTN concept:

- Geo-economics aware: A European T&L network that is aware of the geo-economics aspects driving the development of new trade routes and flows to and from Europe and their impact on the TEN-T network;
- Innovation: A European T&L network that takes advantage of the potential of innovative logistics concepts, such as Physical Internet, and enabling technological innovation, including Industry 4.0, Blockchain, Industry of Things (IoT), and Additive Manufacturing (3D printing), in its operations;
- Impact: A T&L network that is more economically, environmentally and socially sustainable than the existing TEN-T
- Integrated: An EU T&L network integrated with the global network both in terms of physical and digital infrastructures, but also soft aspects such as skills and capabilities;
- Inclusive: Accessible to disadvantaged regions, supporting the development of workforce skills & knowledge.

In this technical paper, we explain the EGTN based on a focused discussion. We demonstrate how technological advance and T&L concepts at the micro level result in structure and performance at the macro level. In Section 2, we explain a particular T&L concept that makes use of advanced technologies, and then explain the impacts at the macro level in Section 4. We draw conclusions in Section 4.

2 EGTN-enabled adaptive routing

The PLANET project aims to accelerate the collaborative transition towards the Physical Internet (PI) in the context of the new emerging trade routes. One important step toward establishing the PI is the deployment of Synchromodal Transportation (Behdani et al. 2016), as summarized in the roadmap toward PI by the European Technology Platform ALICE (Alice 2020). Synchromodal Transport involves the use of multiple modes of transportation in a dynamic fashion. It requires horizontal collaboration through the sharing of transportation resources as alternatives, e.g. transporting a container by truck when transportation by inland vessel does not result in timely arrival at the final destination. It also requires vertical collaboration when different modes of transportation are used in sequence, in particular when those modes of transport are operated by different carriers. In the PLANET project, we developed a novel dynamic routing concept, which is based on opting for capacity reservations along multiple routes. The dynamic routing approach distinguishes itself from existing approaches by allowing for the adaptive routing of a population of containers instead of a single one (Giudici et al. 2019). Figure 1 illustrates the point by means of a very simple example. Instead of booking a single route and establishing a non-adaptive plan on the full network, more links are booked in advance, allowing for an adaptive plan.

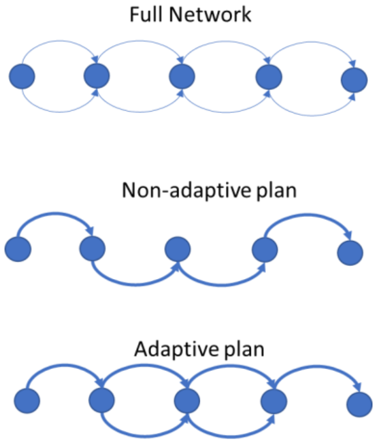

Figure 1 – Non-Adaptive versus Adaptive plan on a very simple network.

The adaptive plan allows to choose the route, which is the most appropriate under changing circumstances. Relevant circumstance are those that impact the availability and transit times of the various modes of transport along the links in the network. In case a certain route faces congestion, for example, another route can be chosen that allows for expedited transport. In order to demonstrate the benefit of adaptive routing, we consider both total transport cost (vertical) and reliability (horizontal) of adaptive (blue) vs. non-adaptive transport plans in the example network in Figure 2. Here reliability refers to the relative amount of timely arrivals.

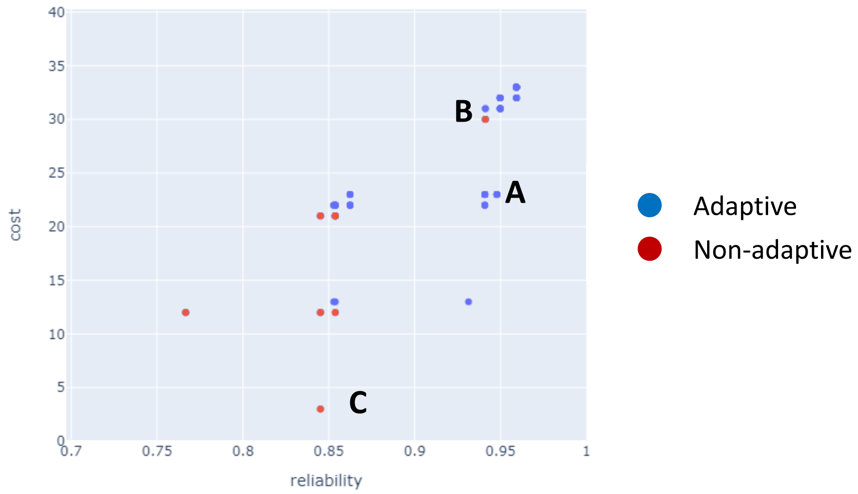

Figure 2 – Non-Adaptive versus Adaptive performance.

As usual, one always needs to make a trade-off between total transport cost and reliability. Making a lot of reservations of transport capacity in the network will result in higher cost. The best possible performance is low cost and high reliability, the lower-right corner in Figure 2. We can compare the two planning approaches (non-adaptive versus adaptive) based on the achieved trade-off between costs and reliability. The result is that adaptive solutions can achieve a better reliability-cost trade-off. Indeed, the adaptive solutions in (A) are better than the non-adaptive (B) both in terms of reliability and transport cost, although when accepting lower reliability levels, costs can be reduced by not making additional reservations (C). As such, we have illustrated that a particular innovation at the micro level, in this case adaptive routing, creates better performance at the network level. In the next section, we will explain two thigs. First, how such an innovation has an impact on performance at the macro level, i.e., connectivity. Second, how the dependency of the innovation on communication and information infrastructures, since adapted plans need to be communicated between organizations in a dynamic fashion, also create vulnerabilities that emerge at the macro level.

3 Macro-level impact of adaptive routing implementation

The implementation of adaptive routing does not only have an impact on the individual routing decisions, but also has macro-level implications. First, there is an impact on the general structure of the physical transport service network. Second, adjustments at the information-technical level need to be made to enable adaptive routing.

3.1 Impact on network of transportation services

The possibility to adjust routes on-the-fly and to establish Synchromodal transport chains results in individual route adaptations. These individual adaptations lead to the emergence of new flow patterns, which in turn can lead to a change of strategic positioning of (inland) ports. The focus of the notion of connectivity so far has been on performance of seaports as entry nodes to the hinterland for incoming oversea cargo. Cargo used to be transported from the sea port to its final destination by truck or with a single rail or barge service. With the rise of Synchromodal transport and adaptive routing involving transshipment at inland ports, it becomes necessary to see sea ports as well as inland ports as nodes in a bigger network (Harter et al., 2022). In fact, inland ports are actively pursuing strategies to strengthen their competitive position in the network, thereby taking a multi-gateway perspective (Veenstra et al., 2012).

As a result, measuring the macro-level impact of adaptive routing and Synchromodal transport requires a new way of measuring port connectivity, while looking at a connected hinterland network rather than a collection of sea ports with hinterland access. This is important, since port connectivity eventually translates into port attractiveness as more trade can be attracted. By composing a Port Connectivity index (PLANET, 2021), complex, multidimensional concepts can be summarized and reduced the visible size of a set of indicators without losing the underlying information. The focus components are service frequency, port capacity, port infrastructure, digital infrastructure, ease of process, and service quality.

A very important criterion with regards to Synchromodal transport is multimodal connectivity, i.e., the availability of transport services with multiple transport modes and the ability to perform transhipment between these modes. As transshipments enable the consecutive use of different transport modes, the rail and barge service networks need to be considered in an integrated way. (Inland) ports that provide transshipment between rail and barge services strengthen their positioning taking a connector role between the two service networks. Figure 3 shows the combined rail and barge connectivity index of the largest European inland ports in terms of service frequency. Figure 4 visualizes how new roles emerge from the new positioning of (inland) ports under Synchromodality. While pure size, i.e., the number of services offered represented by overlapping degree (the total number of unique destinations served by any transport mode), is still relevant, the access to both the rail and the service network (Participation coefficient) is now important as well. As shown in Figure 4, a set of small and medium sized 'Connector' hubs are able to strengthen their position under Synchromodality disproportionally, being well connected to both service networks despite being relatively small.

Inland Port	Index overall	Index Rail	Index Barge
Duisburg	100,00	93,75	100,00
Mannheim	85,45	100,00	60,00
Basel	78,18	81,25	68,00
Ludwigshafen	63,64	84,38	32,00
Neuss	50,91	28,13	76,00
Köln	49,09	62,50	28,00
Novara	36,36	62,50	-
Kehl	25,45	18,75	32,00
Melzo	21,82	37,50	-
Karlsruhe	21,82	18,75	24,00
Busto Arsizio	20,00	34,38	-
Germersheim	18,18	15,63	20,00
Düsseldorf	18,18	12,50	24,00
Gernsheim	18,18	18,75	16,00
Andernach	12,73	6,25	20,00
Bonn	12,73	-	28,00
Emmerich	12,73	-	28,00
Terminal Intermodale di Mortara	12,73	21,88	-
Gustavsburg	10,91	-	24,00
Emmelsum	10,91	-	24,00

Figure 3 - Rail and barge connectivity indices (service frequency) of the largest European inland ports.

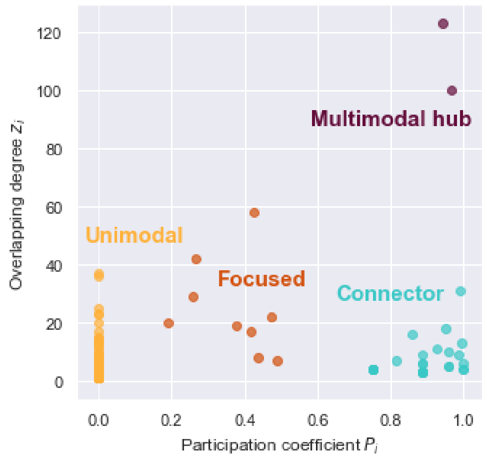

Figure 4 – Roles of inland ports emerging from multimodal integration.

3.2 Impact on information-technical layer (vulnerability)

Adaptive routing requires the provision of sufficient and integrated information-technical infrastructure to exchange data and coordinate adaptive transportation chains. Strong information-technical integration is crucial to create the individual and system benefits promised by adaptive routing and Synchromodal transport. However, it also establishes new technological interdependencies among transport carriers and other stakeholders. A transportation system that is capitalizing on technological interconnectedness is heavily reliant on technology being intact (Cardillo et al. 2013).

As a result, impacts such as technical failure, or cyberattacks do not only have an impact on the targeted company, but also on its collaboration partners who rely on the target company to participate in practicing adaptive routing, and on the system as a whole (Kumar and Van Dissel 1996). Research in cyber-physical systems has shown that stronger integration at the cyber level can lead to high vulnerability at the cyber-level (Buldyrev et al. 2010; Schneider et al. 2013) up to a point, where a single failure can lead to a disruption cascade dismantling the entire system. This new vulnerability comes on top of the physical risks of transportation systems such as low water levels for barges or rail infrastructure breakdown for train sets. With cyber incidents increasing in quantity and impact (Tonn et al. 2019), it is crucial to understand how increased technological integration across different stakeholders affects vulnerability of a system to such incidents.

We developed a multi-layer network model capturing the risk of failure cascades at the information-technical level depending on the level of integration as well as the impact of such cascades on physical transport performance. Figure 5 shows how robust transportation systems are depending on the level of connectivity at the information-technical level. Increasing technological connectivity (x-axis) does not have a monotone effect on performance, but there is a threshold, beyond which an additional increase has an adverse impact on the system under disruption. Below this threshold, stronger integration has a mostly positive impact on performance, since unused synergy potential is high while the risk of disruption causing a cascade is low. Above it, failure cascades become larger and more likely while the marginal added synergies are diminishing.

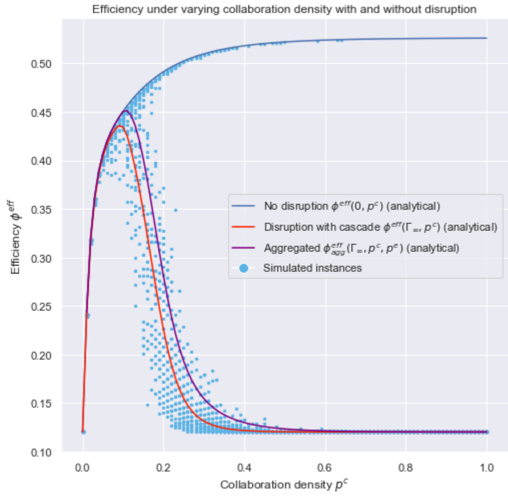

Figure 5 - Robustness (preservation of efficiency) to disruption at the information-technical level under variation of technological integration level (collaboration density).

4 Conclusion

In this technical paper, we discuss the concept of Integrated Green EU-Global T&L Network as proposed by the PLANET project and illustrate how Transport & Logistics innovations at the micro level impact network performance at the macro level. We illustrate this by means of a novel approach of dynamic routing through a network at the micro level, and discuss performance impacts at the macro level, while introducing two novel elements there as well. First, we discuss and extension of the notion of connectivity, and second, we discuss an approach that allows us to quantify vulnerability at the macro level in networks, caused by dependencies between organizations that collaborate and share information. In the ongoing project PLANET, we will further develop and apply these concepts in real-life settings as organized in the Living Labs of the project.

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