Progress towards Federated Logistics through the Integration of TEN-T into A Global Trade Network

D2.11 Multi-Actor Multi-Criteria Analysis DSS v1

Document Summary Information

Grant Agreement No	860274	**Acronym**	PLANET
Full Title	Progress towards Federated Logistics through the Integration of TEN-T into A Global Trade Network		
Start Date	01/06/2020	**Duration**	36 months
Project URL	www.planetproject.eu		
Deliverable	D2.11 Multi-Actor Multi-Criteria Analysis DSS v1		
Work Package	WP2		
Contractual due date	30/11/2021	**Actual submission date**	25/11/2021
Nature	Report	**Dissemination Level**	Public
Lead Beneficiary	VLTN		
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This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No 860274.

Revision history (including peer reviewing & quality control)

Version	Issue Date	% Complete[1]	Changes	Contributor(s)
v0.1	5/9/21	10	Initial Deliverable Structure	Kostas Zavitsas (VLTN)
v0.2	15/9/21	20	Literature review draft	Kostas Zavitsas (VLTN)
v0.3	28/9/21	50	Modelling capability draft circulated to contributing partners	Kostas Zavitsas (VLTN)
v0.4	10/10/21	70	Contributing modelling partners sections integrated.	Chris Wensink (PANTEIA), David Cipres (ITAINNOVA)
v0.5	15/10/21	80	Contributions on dashboard interactions and data collection	Philippos Philippou (EBOS)
v1	28/10/21	100	Draft 1 submitted for internal peer review & QA process	Kostas Zavitsas (VLTN)
v1.1	19/11/21	100	QA process feedback incorporated	Kostas Zavitsas (VLTN)

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[1] According to PLANET's Quality Assurance Process

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Glossary of terms and abbreviations used

Abbreviation / Term	**Description**
AHP	Analytic Hierarchy Process
ALICE	Alliance for Logistics Innovation through Collaboration in Europe
BAU	Business as Usual
CBA	Cost Benefit Analysis
EGTN	EU Global Trade Logistics Network
ETA	Estimated Time of Arrival
MAMCA	Multi Actor Multi Criteria Analysis
MCA	Multi Criteria Analysis
MCDA	Multi Criteria Decision Analysis
NUTS	Nomenclature of territorial units for statistics
PI	Physical Internet
PPP	PLANET Position Paper
TEN-T	Trans-European Transport Network
WMS	Warehouse Management System
UCC	Urban Consolidation Centres

Executive Summary

This deliverable focuses on the implementation of MAMCA (Multi Actor Multi Criteria Analysis) methodology for the development of the TEN-T network and its integration to global corridors. The approach adopted considers both infrastructural and technological advances, including the ones developed in PLANET's Living Labs. The report explores the innovative application of MAMCA in the context of the Physical Internet with the aim of identifying a fair investment roadmap with benefits distributed evenly across T&L stakeholders.

A literature review of the MAMCA methodology is undertaken, examining the main components of the methodology, extending back to predecessor methods, such as the Multi Criteria Analysis, and analysing implementations extending beyond national borders following the scope of PLANET project. The MAMCA steps and applications are also discussed as the methodology has multiple variations and applicability into various contexts.

The MAMCA is considered in the context of the strategic evolution of the TEN-T, contemplating the uncertainty of future scenarios based on PLANETs Positions Papers within its Analytic Hierarchy Process. Technological and infrastructural alternatives associated to the Physical Internet are assessed, and utilized for the identification of preliminary stakeholders, and relevant to the PI context stakeholder criteria. The DSS tool requirements for completing and automating the MAMCA application are also examined.

The modelling requirements for the strategic development of TEN-T are analysed in terms of network representation, as establishing a link between technological advances and network performance evaluation in terms of the stakeholder metrics is essential for meaningful MAMCA application. An inventory of suitable evaluation models based on PLANET partners capabilities is populated for quantifying network performance. The operationalisation of the quantitative and qualitative criteria is analysed considering network performance model outputs.

An additional application of MAMCA focusing on operational collaboration is discussed for the PI services being developed for PLANET Living Labs. The collaborations that arise between containership and the port operators, as well as between warehouse and last mile distribution operators are analysed. In this case the MAMCA enables the identification of mutually beneficial solutions, as well as the consideration of feasible collaboration criteria.

D2.11's purpose is the preliminary development of the building blocks for the successful implementation of the MAMCA methodology in the context of the TEN-T. The parameters for the steps of the MAMCA methodology are analysed and adapted for the context of PLANET outputs and LLs. Alternative development scenarios and stakeholders are also discussed, and evaluation criteria are identified. Finally, focusing on the modelling side, network performance evaluation models are presented, to reflect on the evaluation criteria, while considering technological and infrastructural investments.

1 Introduction

The Physical Internet (PI) promises to revolutionise how transport and logistics is practiced, and to improve on critical variables such as cost, utilisation rates, and emissions through improved multi-modal integration and open accessibility to static and mobile infrastructure. The core constraints, objectives and business processes involved in planning, coordinating, and executing the transport of goods from origin to destination remain largely unaltered in a PI approach. What changes under the PI is the standardisation and interoperability of transport, logistics systems and processes. For these features of the PI to materialise, several information and decision support systems as well as standardisation and integration services require to be introduced.

Performance of freight transportation is one of the crucial elements for the sustainability of logistics and supply chain. The costs for the freight transportation can reach up to 60% of the total logistics costs for shippers, Collignon (2016) and inefficiencies in transportation costs can be characterized by economic, social, and environmental inefficiencies and unsustainability. Despite efforts by transport companies, the frequency of empty trips remains high and average truck fill-rate is low. Overall, according to Eurostat (2017), at total transport level, most trucks in Europe fell in the range between 15 % and 30 % empty journeys. Moreover, freight transportation (in developed countries) is responsible for nearly 15% of greenhouse gas emissions. This ratio has been increasing despite ambitious reduction targets. Improved transportation efficiency is therefore an important objective of the Physical Internet.

Establishing an efficient system for moving goods, is an essential milestone for commerce while at the same time extracting higher capacity from legacy infrastructure such as railways, riverways and motorways. Furthermore, with sustainability becoming an increasing concern, logistical solutions in transport became more relevant, aiming to satisfy transportation demand in an environmentally friendly manner. Although methods and technologies for planning and executing transport and logistics have improved with time, the main principles and inefficiencies still apply today. Furthermore, as specialisation increases with agglomeration economy, supply chains tend to get longer, involving more stages and partners. At the same time, the products themselves are becoming increasingly varied and complex following the ever-increasing societal needs.

DTLF (2018) reports that customers of transport and logistics can have many and very different requirements. For example, requirements of individuals ordering products on websites (eCommerce), differ from those of suppliers producing their products in Asia and shipping them to retail stores in Europe, or manufacturers ordering parts from first tier suppliers and shipping their finished products to their customers. To cope with and support this diversity, Logistics Service Providers offer a variety of services, either specialising and/or combining various activities. For instance, same-day delivery services for parcels are offered via so-called hub-spoke networks, container transport services are offered in high-volume multimodal networks, and Vendor Managed Inventory (VMI) services are offered to support on-time delivery of parts to consignees. This variety in demand and processes emphasizes the need for a dynamic and robust supply chain that can flexibly adjust to gradual or abrupt changes.

T&L involves the coordinating effort of several organisations, each of them focusing on a different part of the supply chain process. A supply chain includes not only the customers and the manufactures, but also transporters, warehouses, retailers, and suppliers. Although this may include organisations that have only an indirect role such as for example banks and insurance companies, such organisations do not directly influence operational efficiency in the transport and logistics process and are therefore not considered further. Direct stakeholders in the transport and logistics processes can be due to them owning (initially or ultimately- i.e., as sellers and buyers), the goods that are transported, the equipment and other resources by which the goods will be processed and transported, or because they are integrators of the different processes and activities involved.

Supply chain stakeholders' perception of performance varies with the stakeholder role, operational context (e.g., urban, or long-haul), and function in the supply chain (e.g., warehouse or transport). The performance metrics each stakeholder utilises to measure operational efficiency do not always match and in cases are contradicting. Through interactive discussions with stakeholders, several studies (Macharis et al, 2012) establish criteria and their associated weights per stakeholder. Due to this variability, collected information and decision processes vary greatly in each T&L stakeholder setting, hindering the motivation for standardization and integration of processes that PI promotes.

In this report, following a literature review of Multi-Actor Multi-Criteria Analysis implementations in the context of T&L, a MAMCA is applied in the context of the PI. The analysis attempts to account for the various stakeholders and their unique priorities, in determining features and making decision about the expansion and operation of the Physical Internet.

*The **objectives** of Deliverable D2.11 is to explore the development of a Decision Support Tool that enables Transport and Logistics stakeholders to assess the impact of new developments and infrastructure components. Such a tool offers the possibility to be used for both strategic and operational decision making.*

The work presented in the report contributes towards the following PLANET project objectives:

- O1: Provide a Simulation Capability for analysing the impact of new trade routes and emerging innovations on the TEN-T and on European logistics operations and for designing a geo-economics aware and PI inspired Integrated EU Global Trade Logistics Network [EGTN]
- O4: Provide an EU Roadmap and Capacity Building program to steer innovation towards EGTN aligning with global T&L blockchain initiatives and the ALICE PI working groups.
- O5: Dissemination, Commercialisation, Strategy Impact Assessment and Policy recommendations endorsed through consultation, harmonising project experiences from the LLs with DTLF1.

1.1 Mapping PLANET Outputs

Purpose of this section is to map PLANET's Grant Agreement commitments, both within the formal Deliverable and Task description, against the project's respective outputs and work performed.

Table 0.1 Adherence to PLANET's GA Deliverable & Tasks Descriptions

PLANET GA Component Title	PLANET GA Component Outline	Respective Document Chapter(s)	Justification
DELIVERABLE			
D2.11: Multi-Actor Multi-Criteria Analysis DSS v1	Definition of the MAMCA model and DSS and interfaces to support customized versions of D2.11 for LLs.	*Chapter 3, Chapter 5*	*MAMCA is implemented for strategic decision making on TEN-T development and global corridor integration, considering the technological advances examined in LL2 and LL3. Initial concepts and functionality on the DSS components and interfaces are presented to enable the user to robustly choose the scope of the MAMCA application. An operational MAMCA implementation is considered for LL1 focusing on stakeholder collaboration.*
TASKS			
T2.4 Group multi criteria DSS for transport and PI Networks	This task develops: 1. Multi-user and multi-criteria models that will allow stakeholders to analyse and assess the effect of new T&L developments (e.g., new trans-continental freight routes) that cross or neighbour their regions. 2. Intelligent PI Nodes and PI Network services to optimise the efficiency of the whole transport system whilst reducing emissions	Chapter 2 Section 3.2 Section 3.3	*The T&L development in terms on new global connectivity is discussed, and the context of the MAMCA application is examined for analysing technological and infrastructural advances.*
ST2.4.1 Multi-Actor Multi-Criteria Analysis (MAMCA) DSS:	Multi-Criteria Analysis (MCA) will be used to enhance policy analysis by explicitly considering the opinions of various stakeholders regarding investment scenarios that maximize for economic impacts from new corridors and routes. Stakeholder groups will identify a specific set of criteria and allocate weights to	Section 3.2.2 Section 3.2.3 Chapter 4	In sections 3.2.2 and .2.3 a preliminary MAMCA stakeholder analysis is conducted. Based on the literature review of Section 2, criteria and weights are populated that reflect the core stakeholder needs. Chapter 4 populates a PLANET modelling tools inventory for

	each distinct criterion. Depending on the weights that the stakeholders give to each criterion, distinct weighting methods will subsequently be adopted as direct weights, direct allocation, and so on. The resulting DSS models will be incrementally calibrated and will be made available to the Project's Living Labs to be applied across specific transport and corridor decision challenges.		operationalising and quantifying the determined stakeholder criteria and enabling the development of the MAMCA into a DSS tool.

1.2 Deliverable Overview and Report Structure

Deliverable D2.11 is the first of a two-deliverable series on implementing a MAMCA analysis on PLANET outputs and LLs. This first version deliverable, discusses the unique PI context and the implications of integrating multiple stakeholders operations as part of undertaking a stakeholder analysis. It populates a list of PI relevant technological and infrastructural alternatives to consider in MAMCA, and identifies appropriate models for quantifying their effects in terms of multiple KPIs.

A literature review of the MAMCA methodology is undertaken in Chapter 2, examining the main components of the methodology, extending back to predecessor methods, such as the Multi-Criteria Analysis, and analysing implementations extending beyond national borders. The MAMCA steps and applications are discussed as the methodology has multiple variations and applicability in multiple contexts.

In Chapter 3 a MAMCA implementation for the strategic evolution of the TEN-T network is examined, for analysing technological and infrastructural investments in the PI context. The uncertainty of future scenarios is discussed based on the findings of PLANETs Positions Papers. The analysis points towards the development of PI principles in the TEN-T network as well as towards its integration to global corridors. In Section 3.2, the alternative strategies are outlines, and stakeholders and their criteria are discussed, while in Section 3.3. the requirements for a DSS implementation of the MAMCA are examined.

Chapter 4 discusses the evaluation method for quantifying and operationalising the stakeholder criteria. A list of modelling tools, appropriate for quantifying various KPIs is populated and their strengths and weaknesses are discussed. Not all criteria can be quantified utilising PLANETs modelling inventory, so qualitative metrics are operationalised to make the MAMCA implementation feasible.

An alternative application of MAMCA focusing on operational collaboration is discussed in Chapter 5, fitting the profile of PLANET Living Labs. The collaborations that arise between the container liner operators and the port operators, as well as between warehouse operators and last mile distributors are analysed. In this case the MAMCA enables the identification of mutually beneficial solutions, as well as the consideration of feasible collaboration criteria. The report findings are summarized in Chapter 6, and future work is discussed.

2 MAMCA methodology overview

As part of the development of Logistical processes such as the Physical Internet, infrastructural, policy as well as technological advances are anticipated. MAMCA, which stands for "multi-actor multi-criteria analysis", allows evaluating different alternatives and directly comparing them against each other, pointing out their advantages and disadvantages. The methodology accounts for the complexity that arises in investment and development decisions from the multiple performance indicators and stakeholders' preferences. A sub-component of MAMCA is the Multi-Criteria Analysis (MCA). The main differentiation between the two is that MAMCA incorporates the objectives of the different stakeholders that are involved and influenced by the decision at hand. However, the basis of MAMCA is MCA, also referred as Multi-Criteria Decision Analysis (MCDA).

The driver for the development, utilisation and uptake of MCA based methods, is the need of decision makers to know more than just construction costs and traffic performance; they need information on long-term and indirect impacts on society's mobility, the environmental impacts/consequences, as well as the ability to serve diverse needs. Such performance criteria can be contradicting with each other, as for example the relationship between price and travel time, where faster transport is typically associated to higher costs. MCA allows the comparison of alternatives, regardless of which category the alternatives belong. To drive the need for efficient and effective decision making, a better understanding of such trade-offs between the social and political consequences of transport infrastructure and technology projects is required. Therefore, the ex-ante evaluation process for selecting a project or a portfolio of projects should include social and political issues in addition to technical and economic ones.

Transport infrastructure and technology projects, such as the development of the Physical Internet and the application of EGTN principles to global trade corridors can have impact of international/ global character. Such international/ intercontinental projects can produce benefits, not necessarily of the same magnitude for all regions or countries concerned. Due to the conflicting priorities amongst the different stakeholders, it is considered advantageous to deviate from the conventional evaluation methods that tend to use single criterion, like the cost-benefit analysis and apply multi-criteria models. MCA can be set up from a national, regional, or continental perspective, as long as all the diverse interests can be incorporated appropriately.

Additionally, to the unique regional and national perspectives, and the various criteria, MAMCA introduces stakeholders' perspective into the decision-making process accounting for stakeholder criteria, and unique stakeholder criteria weights. These weights incorporate stakeholder perceptions into MCA and identify the trade-offs between various stakeholders. MAMCA solves decision making problems, from the perspective of each stakeholder, and in essence enables decision makers to decide between solutions that highly benefit a few stakeholders over solutions with a wider stakeholder offering.

2.1 MAMCA steps and features

The MACMA is typically broken down into seven steps (Macharis et al, 2012), that are:

1. the identification of the problem or the alternatives. They can be different technological solutions, different policy measures, long term strategic options, etc.

2. identify stakeholders and people/ groups who have interests in this decision.
3. identify the key objectives of the stakeholders and give each a relative importance or priority (weights).

The first three steps are conducted interactively in a circular way. They are followed by the solution methodology steps that are:

4. each criterion, one or more indicators are constructed (e.g., direct quantitative indicators such as money spent, number of lives saved, reductions in CO2 emissions achieved, etc. or scores on an ordinal indicator such as high/medium/low for criteria with values that are difficult to express in quantitative terms, etc.). The measurement method for each indicator is also made explicit (for instance willingness to pay, quantitative scores based on macroscopic computer simulation, etc.). This allows to measure each alternative performance in terms of its contribution to the objectives of specific stakeholder groups.
5. construction of the evaluation matrix. The alternatives are further described and translated into scenarios which also describe the contexts in which the policy options will be implemented.
6. The different scenarios are then scored on the objectives of each stakeholder group. For each stakeholder group an MCDA is performed. The different points of view are brought together in a multi actor view. This yields a ranking of the various alternatives and reveals their strengths and weaknesses. Afterwards, the stability of the ranking can be assessed through sensitivity analyses.
7. The actual implementation. Based on the insights of the analysis, an implementation can be developed, taking the wishes of the different actors into account

As illustrated in Figure 2.1, the MAMCA starts by populating the alternatives and conducting a stakeholder analysis. Then, performance criteria are agreed upon by the stakeholders, and weights are defined, and measurement methods and scales are provided. Then the components from the first three steps are integrated into an MCA overall analysis, that yields the results in a stakeholder neutral way. The features of the seven steps of MAMCA are discussed into further detail as initially presented in Macharis et al (2010).

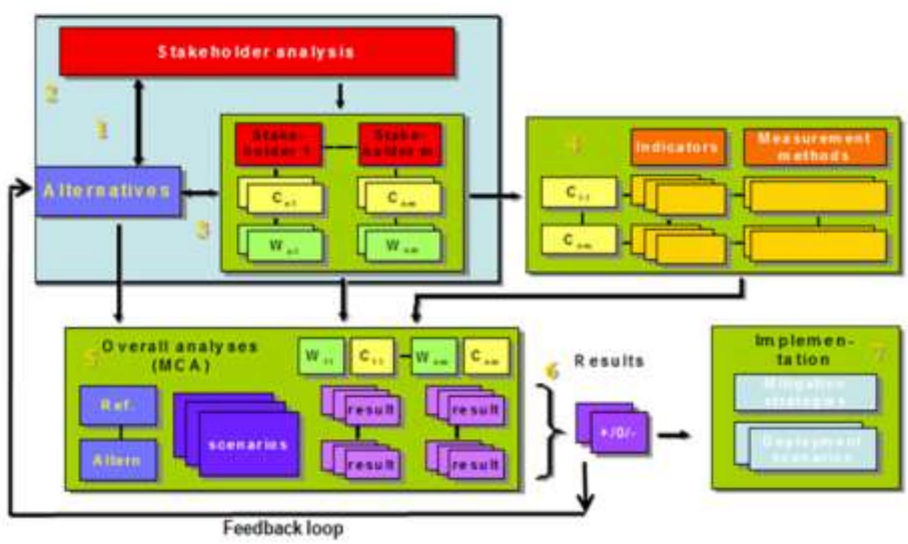

Figure 2.1 Representation of the MAMCA steps (Macharis et al, 2012)

2.1.1 Step 1: Scenario development/ Definition of Alternatives

The first step of MAMCA involves defining the development options to be considered in the analysis. Macharis et al (2010) [1] define the first step to include "the identification and classification of the possible alternatives submitted for evaluation. They recognize that "alternatives can take various forms according to the problem setting. They can range from the evaluation of policy measures in passenger and freight transport to technological solutions, infrastructure investments, location analysis, policy measures with long-term strategic options, and so on." They also point to the requirement for a performance benchmark to be included in the process against which other alternatives will perform differently. It is advised, that in cases where a broad range of alternatives are available such as in the case of global PI corridor development, a screening step can be added with the involvement of stakeholders to consider their feasibility from a technical, environmental, legal, and/or economic point of view.

2.1.2 Step 2: Stakeholder analysis

Stakeholders are people who have an interest, financial or otherwise, in the consequences of any decisions taken. Stakeholder analysis should be viewed as an aid to properly identify the range of stakeholders to be consulted and whose views should be considered in the evaluation process. There are various approaches for undertaking the stakeholder analysis and identifying relevant stakeholders, the choice of which typically depends on the context of the study, and the alternatives defined in step 1. Stakeholder analysis commonly adopts a regional classification, that might seek for stakeholders at a local, regional, European, or even worldwide level. Another approach is to consider the demand and supply sides of the problem at stake. For example, for technological solutions such a break-down could be between manufacturers and users. Another way of identifying stakeholders, is by examining the actors participating in a product's supply chain.

2.1.3 Step 3: Evaluation criteria and stakeholder weights

The choice and definition of evaluation criteria are primarily based on the identified stakeholder objectives and the purposes of the alternatives considered. With this information, a hierarchical decision tree can be set up. In the MAMCA methodology, the criteria for the evaluation are the goals and objectives of the stakeholders, and not the effects or impacts of the actions per se as is usually done in a multi-criteria analysis. In a natural way, these impacts will be reflected in the goals of the stakeholders (if all relevant stakeholders are included). The weights are then determined by the importance the stakeholder is attaching to each of his or her objectives. For the determination of the weights, existing methods can be used such as the allocation of 100 points or direct allocation.

At regional development studies, the chosen criteria may be the same for all stakeholders, namely attracting logistic activities with a large added value, realizing fluent and widely accessible mobility, a huge increase in traffic safety and a decrease of the environmental impact of transport. Although these goals were common for all stakeholders, each stakeholder then assigns weights, representing its own preferences and opinions.

2.1.4 Step 4: Criteria, indicators, and measurement methods

At this stage, the previously identified stakeholder criteria are 'operationalized' by constructing indicators (also called metrics or variables) that can be used to measure whether, or to what extent, an alternative contributes to each individual criterion. Indicators provide a 'scale' against which a project's contribution to the criteria can be judged. Indicators are usually, but not always, quantitative in nature.

More than one indicator may be required to measure a project's contribution to a criterion and indicators themselves may measure contributions to multiple criteria. For qualitative criteria, stakeholders can be asked to judge the effects of the policy measures on a Likert Scale ranging from minus 2 (important negative effect) to plus 2 (important positive effect).

2.1.5 Step 5: Overall analysis and ranking (MCA)

To assess the different strategic alternatives, any Multi-Criteria Decision Analysis (MCDA) can be used. In fact, the second-generation multi-criteria analysis methods, the Group Decision Support Methods (GDSM), are well suited for application in the MAMCA methodology as they can cope with the stakeholder concept. For examples the Analytical Hierarchy Process (AHP) model the problem as a hierarchy (see Fig. 2), where the top of the hierarchy consists of a single element, which represents the overall objective. When implementing a MAMCA this hierarchy consists further of different actors. In the second layer, criteria are being attached for each of these actors. Finally, the measures or alternatives are found at the bottom of the hierarchy.

Within AHP, the different measures or alternatives are first compared to each other for each criterion. Secondly, the weights of the criteria were determined by the respondents by allocating 100 points over the different criteria. Finally, also the stakeholders could be given a weight. However, it is usually preferred not to do so in order to indicate that the same importance is attached to the point of view of each stakeholder.

2.1.6 Step 6: Results and sensitivity analysis

The multi-criteria analysis developed in the previous step eventually leads to a classification of the proposed alternatives. The scores result from the information gathered among the stakeholders. Based on this information, the relative weights or priorities are calculated, using the eigenvalues. In this stage of the MAMCA process, a sensitivity analysis is performed in order to verify if the result changes when the weights are modified. More important than the ranking, the multi-criteria analysis reveals the critical stakeholders and their criteria. The Multi-Actor Multi-Criteria Analysis provides a comparison of different strategic alternatives and supports the decision-maker in making his final decision by pointing out for each stakeholder which elements have a clearly positive or a clearly negative impact on the sustainability of the considered alternatives.

2.1.7 Step 7: Implementation

Once the decision is made, deployment schemes must be created in order to implement the chosen alternative. The information on the points of view of each stakeholder, gathered from the previous steps, helps tremendously to define the implementation paths. Possibly new alternatives or modified ones could be proposed for further analysis as more insight into the advantages and disadvantages of a certain alternative for each stakeholder is generated. This would then create a feedback loop towards the beginning of the procedure. This feedback loop is optional and not imperative in the MAMCA methodology.

2.1.8 Multinational MCA

For the prioritization of multinational transport infrastructure investments, a decision tool is proposed by Tsamboulas [8] which could be used for decisions at strategic level to form multinational transport infrastructure programmes. The tool comprises of four components, which constitute the procedural phases of the tool, the most critical of which being the ex-ante evaluation/assessment.

The first phase, labelled ''Identification'' enables the inclusion of all transport projects proposed by the countries, constituting the elements of the transport network under development, and simultaneously those under evaluation. This phase employs sufficient but limited generic criteria reflecting the societal values, the priorities and the available financial resources of the regions/ countries concerned, as well as their capabilities for the timely realization of the investments related to the proposed projects. The generic criteria definition is based on an interactive process of consultation with the stakeholders steering group, so that the most relevant criteria—for the group of stakeholders—can be included. At this phase the tool also uses threshold values for the criteria, which determine the eligibility of a project to be considered further in subsequent phase of the ex-ante evaluation.

Regarding the ex-ante evaluation/assessment phase, the method applied, although it employs well-established evaluation methods (as the proposed MCA), it incorporates several innovative elements, to cope with the nature of the projects considered. It introduces criteria that are associated with the project's types, the political and socio-economic environment of the countries, as well as environmental issues. It proposes ways for criteria measurement, especially in the case of incomplete or insufficient data. It could be argued that the use of Cost-benefit Analysis (CBA) is more appropriate, since it is the preferred method by the lending agencies. This is true, provided that the evaluation is carried out on a project level, and for the cases of simultaneous evaluation of several projects, all the underlined economic assumptions are the same. Nevertheless, the latter is not possible for multinational investments, where economic values might differ from country to country. Thus, a more strategic evaluation approach is needed, that overcomes such difficulties.

2.2 Real-world MAMCA applications

MAMCA is a widely used methodology that has been applied into multiple contexts. MAMCA applications range from improving transport sustainability [1], to assessing alternatives for improving city logistics [2], to identifying optimal location of intermodal terminals [3]. As the EGTN and the Physical Internet cover a wide range of logistics from oceanic transport to urban last mile delivery, studies in a variety of contexts are examined in this literature review section. This section focuses on the scenario development and stakeholder involvement in each case and does not delve into the technical details of the MAMCA implementation.

2.2.1 City and regional logistics

In a study [2] focusing on the impact of freight distribution in the context of city logistics in the Brussels-Capital Region, a MAMCA has been used with the aim to identify scenarios that improve efficiency and reduce emissions. Scenarios are developed based on a mix of infrastructure and policy interventions, including:

- establishment of a logistical pole at a tri-modal site
- the establishment of a network of urban consolidation centres (UCCs)
- a road pricing scheme for heavy goods vehicles
- night distribution, and,
- the purchase of electric vehicles.

Based on the above technological, operational and policy measures, the following scenario have been defined that utilise one or more of the interventions:"

Scenario 1: One UCC is introduced in the North of the Brussels- Capital Region. A distance-based road pricing scheme is applied on heavy goods vehicles. In this framework, the UCC is an alternative for transporter to avoid the higher cost of transport in urban areas. Diesel trucks are operating the last mile from the UCC.

Scenario 2a: Two UCCs are introduced, one in the North, the other in the South of the Region. No road pricing scheme is applied. However, night distribution is allowed for the vehicles delivering the goods to the UCC, stimulating its use by carriers. Diesel trucks are operating the last mile from the UCC.

Scenario 2b: Two UCCs are introduced, one in the North, the other in the South of the Region. No road pricing scheme is applied. However, night distribution is allowed for the vehicles delivering the goods to the UCC, stimulating its use by carriers. Battery electric trucks are operating the last mile from the UCC.

Scenario 3a: Four UCCs are introduced, in the North, the South, the West and East of the Region. A distance-based road pricing scheme is applied on both heavy goods vehicles and light commercial vehicles, except for battery electric vehicles. The four UCCs offer viable alternatives for all transport operators to avoid the higher cost of transport in urban areas. Moreover, night distribution is allowed for the vehicles delivering the goods to the UCC, stimulating its use. Diesel vans are operating the last mile from the UCC.

Scenario 3b: Four UCCs are introduced, in the North, the South, the West and East of the Region. A distance-based road pricing scheme is applied on both heavy goods vehicles and light commercial vehicles, except for battery electric vehicles. The four UCCs offer viable alter- natives for all transport operators to avoid the higher cost of transport in urban areas. Moreover, night distribution is allowed for the vehicles delivering the goods to the UCC, stimulating its use. Battery electric vans are operating the last mile from the UCC."

To compare the scenarios with the current situation, a baseline scenario is also considered, as Business as Usual (BAU) that does not consider any UCC, night distribution is not allowed, and no road pricing scheme is implemented.

The stakeholders involved in the analysis include:

- Logistic Service Providers,
- Shippers,
- Receivers,
- Citizens, and
- (Local) authorities.

Each stakeholder assigns weights to criteria involving:

- Transport costs,
- Profitability and business climate
- Cost for UCC support
- Congestion
- Transport emissions
- Noise level
- Safety
- Space occupancy
- First delivery rate

- Level of service and
- Citizen support

An MCA is undertaken and identifies that scenario 3b as the best viable option considering all stakeholders perspectives.

Another MAMCA study focusing on city distribution conducted as part of STRAIGHTSOL EU research project, considers the following alternatives:

- BAU: the surveillance of the cargo on location and the status on rail transport and respective communication are done manually. This is done for the 806 rail wagons per month that travel from Sopron to Sindos. After rail transport (first leg), cargo is either stored in operator's warehouses or transhipped via the cross-docking area to trucks for last mile distribution to the City of Thessaloniki (second leg). Because of a gap in communication some trucks for the second leg are rented unnecessarily.
- Scenario 1 (S1): the demonstration whereby the rail freight was monitored by using 6 GPS tracking devices affixed on the rail wagons. This was interconnected with the warehouse management system (WMS) which enabled real-time information on location and status of cargo. 24 wagons per month were monitored. In total 36% of the trips was successful. There were return costs (responsible for 89% of the generated costs) because the GPS devices were sent back to Hungary by plane.
- Scenario 2 (S2): the scaled version of the demonstration. All 806 rail wagons per month are monitored by using 202 GPS devices connected to the WMS. It is assumed that 36% of the trips are successful and there are return costs.
- Scenario 3 (S3): the scaled scenario with 100% successful trips, where- by 806 rail wagons per month are monitored by using GPS devices connected to the WMS. In this scenario the GPS devices are installed permanently on the wagons and therefore there are no return costs.

The stakeholders and criteria considered in the study align to the ones used in [2]. After operationalising and quantifying the results, and applying an MCA, it is found that Scenario 3 outperforms the other two scenario in terms of all aspects, for all stakeholders.

In the context of transport infrastructure development and investments for regional mobility and logistics in the Flemish region of Belgium [5], the relevant stakeholders were identified to be:

- the users of public transport,
- the suppliers of public transport,
- the users of logistic services,
- the suppliers of logistic services,
- the building sector,
- environmental organisations,
- unions,
- government,
- politicians,
- academics, and
- others.

Focusing on city logistics, urban freight transport initiatives and policies clearly involve multiple stakeholders who need to be explicitly considered in the decision-making process and range from professional stakeholders such as carriers and suppliers to citizens living and working in this urban environment. Macharis et al. [6] undertake a literature review of urban logistics stakeholders and identify a categorical pattern of stakeholders that can be classified into three broad categories: trade and industry, society, and public policy makers. Trade and industry include suppliers, carriers, receivers, wholesalers, and distribution companies. Society consists of inhabitants, employees, commuters, consumers, and tourists. Public policy makers are local, regional, and national governments. Variations of the above classification are observed depending on the purpose studied. For freight transport, four key stakeholders are considered: shippers, residents, freights carriers, planners, and regulators. For urban freight transport in the railway sector: local authorities, carriers, shippers and receivers, and residents are considered. Focusing on urban sustainable development, three groups are used, namely: shippers and receivers, authorities, and transport operators.

Table 2.1 Instances observed in literature per stakeholder type [2]

Stakeholder type	**Instances observed in literature**
Local authorities, Administrators, Policy makers	12
Carriers, Logistics service providers, Transport operators, Freight carriers	13
Citizens, Residents, Customers	8
Receivers, Retailers	8
Forwarders, Shippers	10
Others	2

A more recent literature review conducted by, Lebeau et al. [2] establishes the most relevant stakeholders to urban logistics by popularity in research consideration. They break down stakeholders into six main groups and they point out the ones that have been considered in most studies. The findings illustrated in Table 2.1, align with the classification proposed by Macharis et al. [6], identifying the main actors being:

- shippers,
- freight transport operators,
- authorities, and
- customers (receivers and citizens).

2.2.2 Logistics terminals and network

MAMCA has also been applied in the context of network/ terminal expansion [5], for the strategic evaluation of the possible extension of DHL at Zaventem International Airport. In this case, the definition of the alternatives was led by DHL's strategy, with the three options being:

- the choice of a new super-hub in Europe, namely the 'super-hub' choice, which meant the concentration of all European traffic at Brussels Airport,

- the 'multi-hub' choice, which meant the concentration of all intercontinental traffic at Brussels Airport, but with the continuous existence of capacity in other regional sub-hubs in Europe, and,
- the 'external super-hub' choice, which meant the relocation of the DHL hub from Brussels Airport.

The relevant stakeholders to this decision were found to be the Government (as a hypothetical, 'constructed' stakeholder), DHL as the operator, the airport operating company, BIAC and the local community (as night flights cause noise, leading to a possible decrease in quality of life). The decision tree presented in Figure 2.2 captures the criteria relevant to each stakeholder. Using the AHP to assess the alternatives, it was found that assuming equal weights for all stakeholders, the multi-hub strategy is the preferred choice.

Figure 2.2 AHP criteria tree [1]

Another MAMCA application [5], investigates the choice of location for an intermodal barge terminal. In this study, prior to the definition of alternatives, the traffic potential of each terminal project is determined as a preliminary step. To have a sustainable terminal, the traffic potential in the surrounding area of the terminal must be large enough to support it. Furthermore, the impact of the new projects on the market area of the existing terminals must be analysed. A network model allows the determination of the traffic potential and the impact on the existing terminals.

2.2.3 Transport sustainability

When transport and sustainability are considered simultaneously [1], it is essential to clearly define the (physical) border of the transport problem. The first aspect of this decision has to do with governance and knowing which policy level (commune, province, region, country, European, worldwide) should be included as governmental actors.

The second aspect is to check if there is a demand and supply side of the problem at stake. For example, when evaluating driver assistance systems, manufacturers are incorporated on the supply side, and users on the demand side. A supply chain perspective can also be adopted, like in the biofuel case, where all actors from the supply side are included (the agricultural sector, biofuel convertors, fuel distributors, end users, car manufacturers, government and NGOs & North–south organizations). Once certain stakeholders are identified, they can be asked, according to them, who should also be involved.

So, although there are no strict rules on whom to include, it is important to see that all actors who could be affected or can affect are in the list of stakeholder groups.

2.3 Concluding remarks

In this chapter the MCA and MAMCA methods have been discussed, looking in detail into their structure, functionality, and applicability. The literature review conducted, points to the wide-range applicability of the MAMCA methodology, as well as its implementation versatility. Particular attention has been paid to the first two steps of the methodology, that investigate the definition of scenarios and alternatives in various transport and logistics related context, and the subsequent stakeholder analysis. It is observed, that whenever there is uncertainty about the stakeholders or criteria that require to be considered in the methodology, additional clarification steps are introduced, where with the help of the stakeholders', relevance can be established.

3 TEN-T development for global corridor integration

In the context of PLANET, a MAMCA methodology is considered for introducing a stakeholder perspective to the analysis of the impact of new trade routes and emerging innovations on the TEN-T and on European logistics operations and for designing a geo-economics aware and PI inspired Integrated EU Global Trade Logistics Network [EGTN]. This is achieved, utilising the analytic methods presented into more detail in Chapter 4. Utilising the decision making and dispute solving capability, of MAMCA, its implementation enables the development and provision of an EU Roadmap and Capacity Building program to steer innovation towards EGTN aligning with global T&L blockchain initiatives and the ALICE PI working groups.

3.1 TEN-T development context

Making development and steering decisions in the context of global PI corridors is particularly challenging, due to the multiple parameters that require to be simultaneously considered. PI corridors can be improved by either introducing infrastructural and technological features at one or multiple locations of the network. Such technological features can have short-term, or long-term effects, and influence strategic, tactical and/or operational features of the transport network. Furthermore, there is a multinational aspect, and ensuring an even impact of the project across multiple regions, as well as considering political impacts beyond European Union boarders.

PLANET's position paper 1 (PPP1) points out to the logistics network externalities and identifies significant trade route shifts and assesses their potential to influence continental geo-economics. PPP1 analyses the aspects that can potentially influence the operation of a PI enabled continental transport network and proposes the consideration of:

- multiple transport modes,
- direct and intramodal shipments,
- hub and link infrastructures,
- perception of multiple stakeholders
- environmental impact.

3.1.1 TEN-T corridor infrastructure development scenarios

The European TEN-T network consists of nine major corridors as illustrated in Figure 3.1. There are currently 30 major axis development projects being implemented, out of which, 18 are railway projects, 3 are mixed rail-road projects, 2 are inland waterway transport projects and one refers to Motorways of the Sea. This choice reflects a high priority to more environmentally friendly transport modes, aiming at addressing sustainability challenges.

TEN-T projects aim to:

- Establish and develop the key links and interconnections needed to eliminate existing bottlenecks to mobility
- Fill in missing sections and complete the main routes - especially their cross-border sections
- Cross natural barriers
- Improve interoperability on major routes

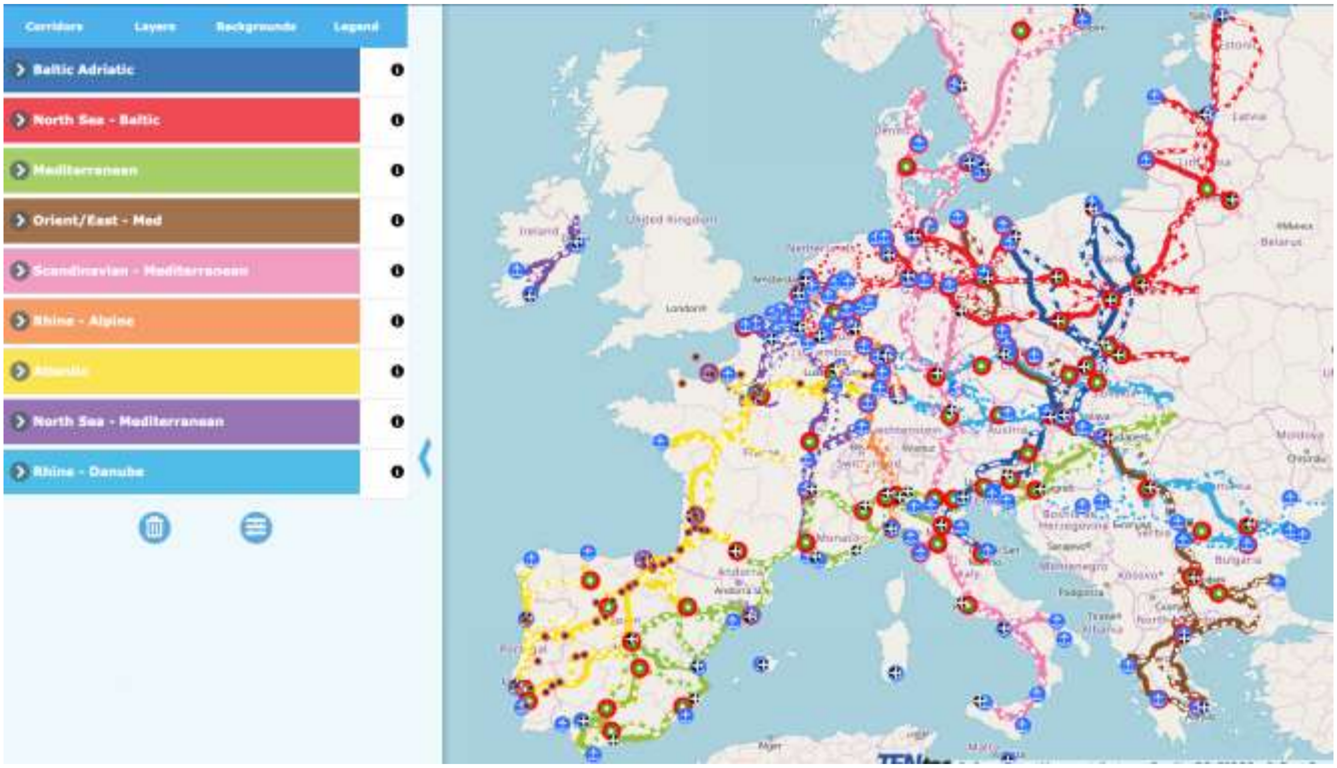

Figure 3.1 Representation of the TEN-T network corridors [11]

In the context of PLANET, the future development of the TEN-T network is also linked to external transport and logistics developments. PPP1 considers the key factors and forces in terms of emerging trade routes that bypass the Suez canal such as the One Belt One Road (OBOR), the Arctic route and the International North-South corridors. Monitoring traffic on those routes is essential for driving future decision making for the infrastructure development of EGTN.

For the connection of TEN-T to existing and developing global corridors, rail interconnectivity and standardisation, as well as appropriate intermodal capability both of inland terminals and ports are essential.

3.1.2 PI Roadmap and PI development components

The current methods for determining the development strategies for the TEN-T network are often based on political parameters rather than quantitative evidence. A particularly disregarded aspect is that of technological innovation, that can have an impact on the efficiency and operational utilisation of existing assets. From a technological perspective, the PI is an open global logistics system founded on physical, digital, and operational interconnectivity, through encapsulation, interfaces, and protocols.

Logistics networks are still highly fragmented, mainly dedicated to a company or a specific market, as promoted by the supply chain concept and vertical coordination. The Physical Internet (PI) addresses logistics integration and collaboration issues and paves the way forward to deploying efficient supply chains. In a scenario in which all Physical Internet potential technological, standardization and infrastructural elements are enabled, a 300% increase in transport demand could be achieved with only 50% increase in assets [3].

The ALICE platform has published a document with a comprehensive roadmap towards the Physical Internet. The roadmap sketches a path from now to 2040 showing important milestones, required technologies and first implementation opportunities for the PI. Advanced pilot implementations of the Physical Internet concept are expected to be operational and common in industry practice by 2030, contributing to a 30% reduction in congestion, emissions, and energy consumption from the transport sector.

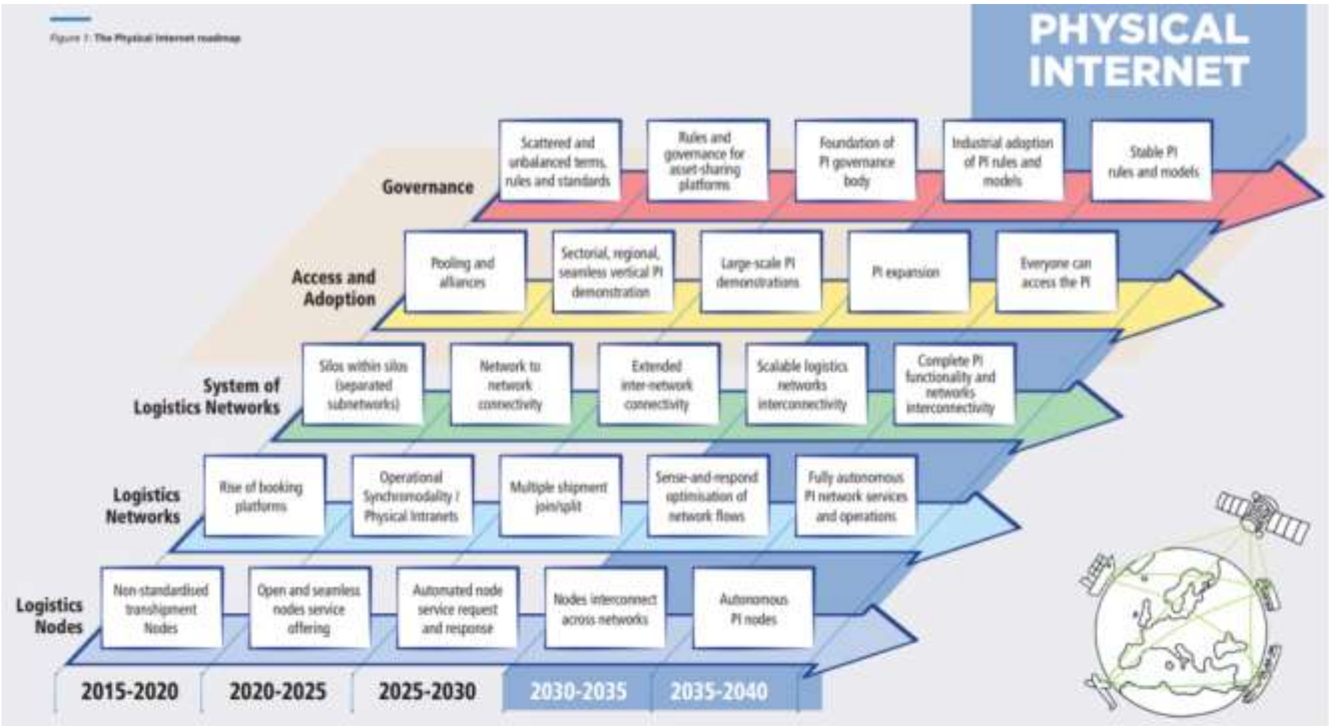

Figure 3.2 Physical Internet development roadmap by ALICE [10]

The Physical Internet utilizes open warehouses and transport networks as the means for achieving systemic load consolidation and optimization in which the capacity in the logistics sites and transport networks could be increasingly available for the use of stakeholders in a more optimized way: reducing energy consumption, environmental emissions, and economic cost. An additional element that PI utilizes to contribute to the improvement of transport efficiency is the standardization and modularity of transport packaging, focusing on the redesign of product packaging, transport boxes and containers for optimal fit to product and for modularity, to allow efficient handling, consolidation, and pooling. This can be combined with re-usable containers (RCs), in anticipation of the implementation of the full Physical Internet concept.

3.1.3 EGTN scope

The simultaneous consideration of the technological and infrastructural solutions available enables the development of a more efficient and robust transport network. To advance the European Commission's strategy for Smart, Green and Integrated Transport and Logistics by efficiently interconnecting infrastructure (TEN-T, Rail-Freight Corridors) with geopolitical developments (e.g. future New Silk Road and emerging trade routes), as well as optimizing the use of current & emerging transport modes and technological solutions, while ensuring equitable inclusivity of all participants, increasing the prosperity of nations, preserving the environment, and enhancing citizens quality of life. The realization of this vision is what PLANET calls the Integrated Green EU-Global T&L Network (EGTN). The main attributes of the EGTN include:

- Geo-economics aware: A European T&L network that is aware of the geo-economics aspects driving the development of new trade routes to/from Europe and their impact on the TEN-T.
- Innovation: A European T&L network that takes advantage of the potential of innovative logistics concepts (e.g., PI) and enabling technological innovations (Industry 4.0, blockchain, hyperloop, IoT, etc.) in its operation
- 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 hard & soft infrastructure
- Inclusive: Accessible to disadvantaged regions; supporting the development of workforce skills & knowledge

The formation of steering scenarios towards the development of EGTN and integration of TEN-T to global corridors while considering both infrastructural and technological investments, and accounting for multiple stakeholder perspectives is fundamental for utilizing the MAMCA decision support tool in a PI context.

3.2 MAMCA EGTN implementation

For assessing geopolitical and geo-economic impacts, as well as the impacts of new trade routes, PPP1 proposes a scenario development strategy that outlines key factors for network operation. Key factors considered include port capacity, container throughput, service frequency, service quality, digital connectivity, port infrastructure, efficiency of processes, emissions (Co2, NOx, PM), Logistics activities (employment/added value), Foreign Direct Investment (FDI). External forces that require to be considered in scenario building include:

- Social: pressure from society on sustainability, ageing population, dematerialization, social connectivity, and global awareness,
- Economic: regionalisation of trade blocks, shifting trade patterns (BRI, Arctic route, INSTC), supply chain strategies, new market entrants, near-sourcing, reshoring, Chinese investments in ports and logistics, emergence of transhipment hubs, boom of E-commerce, economies of scale
- Environmental: CO2 pricing in shipping and logistics, de-carbonisation of transport system, opening of arctic route, EU Green Deal, impact of global warming on inland waterways, circular supply chains
- Political: TEN-T governance, geo-economic strategies, tariff regimes, Chinese investments in EU transport system, Tensions about Arctic area, 17+1 strategy, disadvantaged regions in EU
- Technological: transport equipment life cycle, (digital) transport platform providers, control towers, cleaner transport, cyberthreats, Physical Internet (autonomous transport, IoT)

This breakdown of external forces and factors, reflects to a certain extend the stakeholders and the criteria that are of relevance in implementing a TEN-T development roadmap. This should also align to the MAMCA stakeholders and criteria for assessment. It is observed that some of the factors identified are of operational nature, such as container throughput, or service frequency and quality, while other factors are tactical and strategic, such as port capacity and infrastructure. Therefore, to operationalise the factors, both strategic and operational models are required for quantifying economic, social, environmental as well as political factors. In the context of the MAMCA application, technology is not treated as an external factor, but rather as part of an established list of alternatives that can be utilized.

Furthermore, PPP1 introduces four possible future scenarios as well as their implications, considering uncertainties with respect to external forces. The four scenarios that arise are:

- Dry Europe, where summer draughts reduce waterway traffic, and reliance on road and other modes increases
- Eurasia Connected, where the intercontinental land bridges keep growing moving higher volumes via rail
- Green Europe, where high carbon pricing drives higher intermodal transport and local production, and
- Globalisation, where China continuous to grow as a producer, and CO2 footprint remains high due to long routes.

The parametrisation of the four scenario is illustrated in Figure 3.3, in terms of impacts on infrastructure, various mode tariffs, and throughput.

Parameter	Dry Europe	Connected EurAsia	Green Europe	Maritime Europe
Infrastructure	Waterway capacity is reduced to 20% between June-Sept	Waterway capacity is reduced to 20% between June-Sept	More rail terminals	Infrastructure gradually develops, but in favour of road transport
Barge tariffs	Factor 3 between June-Sept	Factor 3 between June-Sept	Remains equal	Remains equal
Road tariffs	Factor 2 between June-Sept	Factor 2 between June-Sept	Factor 1.2 per TKM due to carbon pricing	Remains equal
Rail tariffs	Factor 2 between June-Sept	Factor 2 between June-Sept	Factor 0.9 to make rail more competitive	Remains equal
Modal split *	Rail: 17,5% Barge: 2,5% Truck: 80%	Rail: 30% Barge: 2,5% Truck: 67,5%	Rail: 35% Barge: 15% Truck: 50%	Rail: 20% Barge: 5% Truck: 75%
Continental divide ratio	Northern seaports: 70% Southern seaports: 25% Eurasia land bridge: 5%	Northern seaports: 55% Southern seaports: 30% Eurasia land bridge: 15%	Northern seaports: 75% Southern seaports: TBD: 15% Eurasia land bridge: 10%	Northern seaports: 78% Southern seaports: 20% Eurasia land bridge: 2%
Inland port throughput	Decline in barge volumes	Increase in rail volumes	Increase in rail and barge volumes due to regionalisation and greening	Throughput development follows gateway volumes

Figure 3.3 Future uncertainty consolidated into four scenario [9]

A network development strategy can be assessed against all four scenarios and analysed in terms of robust performance, by introducing an additional layer in the AHP of the MAMCA methodology. This accounts for global perspectives that are otherwise underrepresented, and therefore enables a unilateral implementation of MAMCA.

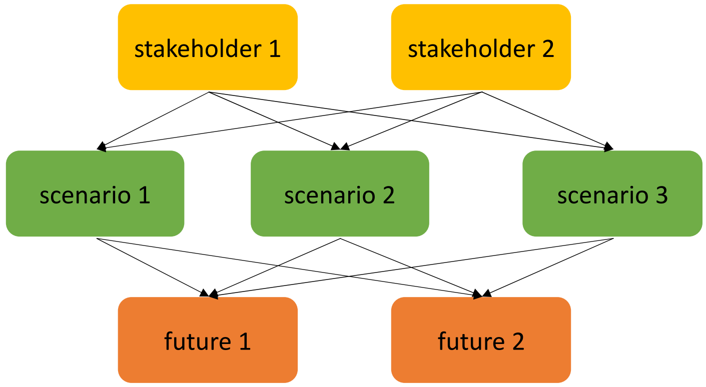

Figure 3.4 Integration of future scenario in the AHP of a MAMCA methodology

3.2.1 Scenario development in the PI/ EGTN context

The first step of the MAMCA concerns the development of scenarios and definition of alternatives to consider in the analysis. In the EGTN context, scenarios can be composed of both infrastructural and technological interventions to the network operation. Transport policy can also be considered, focusing on long-haul logistics, for example in the context of information sharing.

In the case of the PI/ EGTN development, where the alternative scenarios are not pre-determined, a broad range of alternatives, which can possibly be tracked from an extensive literature overview, can be screened in terms of their feasibility from a technical, environmental, legal and/or economic point of view. Furthermore, this screening can be potentially combined with an insight into the stakeholders' objectives. An early involvement might not only stimulate discussions and help decision-makers to understand the problem, their priorities and those of the involved stakeholders, but it will also considerably help to enhance the acceptance of the final result. In that case, steps 2 and 3 of the MAMCA methodology will precede the first step, which highlights their strong interconnection.

Similar to infrastructural investments, technology investments typically follow a sequence of development, where one cannot exploit a technology without having invested into preceding technological requirements. This is for example reflected, in the PI roadmap illustrated in Figure 3.2, where the 'automated node service request and response', precedes 'autonomous PI nodes' operation. To account for the PI technology integration to the TEN-T, a SOTA technology list requires to be populated, considering technologies with established network performance impact. PLANET D1.2 [13] describes some of the analytic capability that can be integrated into the TEN-T network smart decision making through appropriately customized Decision Support Tools.

Furthermore, technology investments can have geographic focus and be local, regional, or even TEN-T corridor specific. Once, technology and infrastructure investment alternatives, have been identified, a geographical context requires to be considered as well. Technology investments may also be associated to specific operators, which also requires to be captured in the modelling and quantification of network performance. For example, two container terminals in the same port might operate at different technology levels, and efficiencies. The network representation requires to include the provision of services at terminals, as well as the operation of services running on multiple mode links. The network representation for quantifying the network performance in the context of a MAMCA analysis and the operationalisation of the criteria, is further discussed in Chapter 4.

A comprehensive list of infrastructure and technology investments requires to be populated, utilising the assistance of matter experts. Then, through further consideration and screening a list of alternatives for PI development and global corridor integration for use in MAMCA can be finalised.

3.2.2 Preliminary stakeholder analysis

The main stakeholders observed across most MAMCA studies include:

- Logistic Service Providers,
- Shippers,
- Receivers,
- Citizens, and
- (Local) authorities.

In an EGTN/ PI context, a political perspective (local government) is of interest as it has been a significant factor in the to-date development of the network. Furthermore, with an increasingly significant environmental agenda, the inclusion of environmental organisations in the form of NGOs, might also be beneficial. Finally, technological development in relation to the PI can probably be best represented by a combination of academics and technology providers. Utilising the contact list and Advisory Board of PLANET project partners, it is observed that several of the stakeholder categories are represented. There is limited representation in the Shippers, Receivers and Environmental organizations representation. To address this challenge the ALICE network can be utilised that multiple members in shipper and retail (receiver) categories [12].

Table 3.1 PLANET project partners and Advisory Board members per MAMCA stakeholder category

Stakeholder category	PLANET project partner
LSP	COSCO, DHL, CITYLOGIN, Valenciaport, Zaragoza Logistics Centre, Jing Dong Logistics, Port of Rotterdam, Polish National Post, ROHLIG SUUS, VTG, CSP Iberian Valencia Terminal, S.A.U. (CSPV), Duisport, Suardiaz Multimodal Transport and Global Logistics,
Shippers	European Shippers Council, KWS SAAT, Electrolux
Receivers	Electrolux
Environmental organizations	Gemini Corporation
Local government	TEN-T Interregional Alliance for the Rhine Alpine Corridor, Instytut Logistyki i Magazynowania, Regional Customs and Excise Duties Office of Valencia, International Union for Road-Rail Combined Transport, Malaysia Institute for Supply Chain Innovation, Ningbo Supply Chain Innovation Institute China, UTLC ERA (United Transport and Logistics Company), Alastria, European Maritime Safety Agency
Academics/ technology providers	CERTH, CATS, KONNECTA, EBOS, VLTN, ERASMUS, HARDT HYPERLOOP, IBM, ITAINOVA, New Generation Sensors, SIRMA AI, PANTEIA, Wuppertal Institute, Panasonic, Samsung, MIT Centre for Transportation and Logistics, Ederlog, e-track, Texas A&M, Strome College of Business, GS1

The stakeholders associated to the PLANET project, and the ALICE network, provide a sufficiently wide base for establishing the technology inventory and developing the investment alternatives that are required for implementing MAMCA.

3.2.3 Stakeholder criteria

Based on the literature review presented in Chapter 2, the criteria that are associated to the stakeholders of Table 3.1, are

- Transport costs,
- Profitability and business climate
- Congestion
- Transport emissions
- Level of service

The criteria are typically associated to specific stakeholders as illustrated in Figure 3.5, however, the weight of each link requires to be determined by each stakeholder separately, through a pairwise comparison questionnaire.

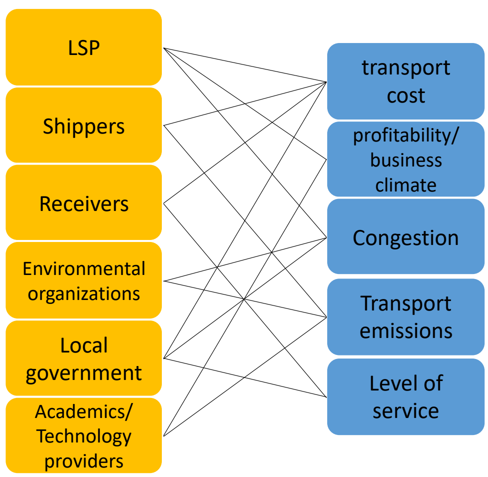

Figure 3.5 Criteria tree without weights per stakeholder

Additional criteria that may be considered include political criteria such as employment, regional competitiveness, and health. Local community criteria, such as product availability, safety perception, and local employment, or business criteria, such as proximity to the market, growth of market share, and diversification.

3.3 DSS deployment and use

The aim of T2.4.1 is ultimately the development of a DSS tool with the capability to introduce a stakeholder perspective to the outcomes of a simulation-based solution. Considering the MAMCA steps, described in section 2.1, once the performance of a scenario is assessed in terms of the common KPIs, the weights determining the significance of each KPI for each stakeholder can be applied, to determine the performance of each scenario against each stakeholder interests. Considering that this implementation of MACMA focuses on PI development and integration with global trade corridors, it is anticipated that the technological and investment alternatives available will not alter much, but rather their geographic implementation will. Therefore, the associated stakeholders and the criteria defined in this first implementation of MAMCA, will remain relevant. The collection of stakeholder weights and the illustration of the MAMCA outputs, constitute the two essential interfaces with perspective users.

The weight data collection from the stakeholders is typically undertaken through pairwise comparisons as illustrated in Figure 3.6. Such pairwise comparisons between all the criteria, enable the population of the AHP matrices. By means of the rectangular bars, stakeholders can attach different gradations of importance, ranging from extremely more important to extremely less important.

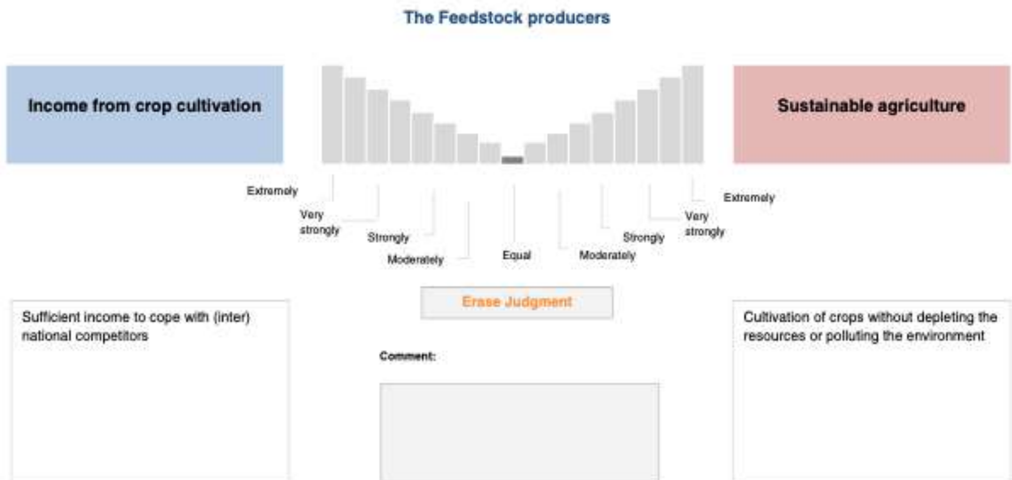

Figure 3.6 Example of pairwise criteria comparison [1]

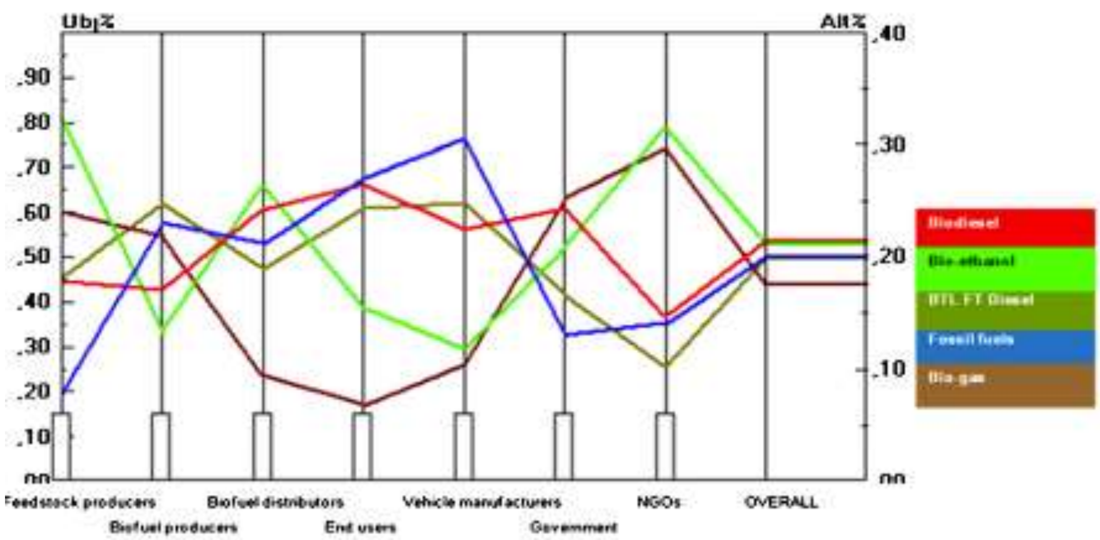

Figure 3.7 Multi-actor MAMCA results output [1]

The MAMCA output of the AHP, is presented as a sensitivity graph as illustrated in Figure 3.7. It shows directly who finds which alternative the most preferred one. Furthermore, if the weights of the decision makers are imbalanced it will also be easy to see, which stakeholders have which weight (the rectangles) at the bottom.

The output of the MAMCA assists in identifying fair solutions that benefit all stakeholders roughly evenly, rather than solutions that might benefit a subset of the stakeholders considerably and others little, not at all, or even have a negative impact.

3.4 Concluding remarks and future work

In this section the context of implementing a MAMCA in PLANET has been analysed, indicating a focus towards mixing technological and infrastructural interventions to the TEN-T network aiming to achieve the efficiency gains of the Physical Internet while effectively integrating to global corridors and alleviating future uncertainty risks. For the implementation of the MAMCA, a comprehensive list of technological and infrastructural alternatives requires to be populated and converted to viable development scenarios with the assistance of matter experts. The participates in PLANET and ALICE are found to cover sufficiently the main stakeholder categories for effectively defining development alternatives. Furthermore, the stakeholders require to participate into a custom questionnaire for determining the criteria weights, while the process can be facilitated together with the output presentation on the EGTN platform dashboard.

4 Multicriteria evaluation models

The operationalisation of the stakeholder criteria presented in Section 3.2.3, requires appropriate modelling capability that adequately reflects and quantifies the criteria with respect to variations in technological and infrastructural features of the transport and logistics network. The impact of infrastructural changes can typically be handled by aggregate flow models, or transportation assignment models. However, the generic cost function that such models typically utilise focusing on operational costs and/ or travel time. Considering the multiple criteria that require to be considered in an enhanced measurement system requires to be introduced that will classify network performance and integrate it with qualitative metrics.

4.1 EGTN and PI network representation

In the context of a PI Network, there are multiple infrastructures and terminal services that require to be considered in order to reflect the various stakeholder criteria that require to be operationalised, such as:

- Multiple terminals with modal shift capability
- Multiple links between the hub's terminals
- Multiple terminal operations, that can be further broken down to mandatory such as customs or non-mandatory such as short-term storage, and
- Multiple bottlenecks, that inflict capacity and operational limit constraints on both transport and operational PI Hub link components.

At the same time, considering the European-wide reach of the PI Hubs and their hinterland, the network representation requires to connect and explore the entire European transport network (TEN-T) at a PI Hub level. Therefore, two different aggregation levels require to be considered as a more detailed representation of the PI Network and PI Hub assets is required. Within a PI Hub, specific terminals, routes, and bottlenecks are considered as they are critical for the representation of routing decisions, while for the hinterland, aggregation is limited to the generic functionality of PI Hubs as transshipment locations.

Figure 4.1 illustrates an example the PI hub network representation of the Port of Antwerp [14]. The PI Hub network is composed of terminal nodes with transshipment capability between various modes, such as the 'Deep Sea Container Terminals' that can transship containers from containerships to trains and trucks or vice-versa. Rail terminals and a barge terminal are also considered for transshipments to rail and to river barges respectively. For each of the terminals, the modal shift services offered are associated to performance properties that can impact the routing decision in terms of travel time and cost.

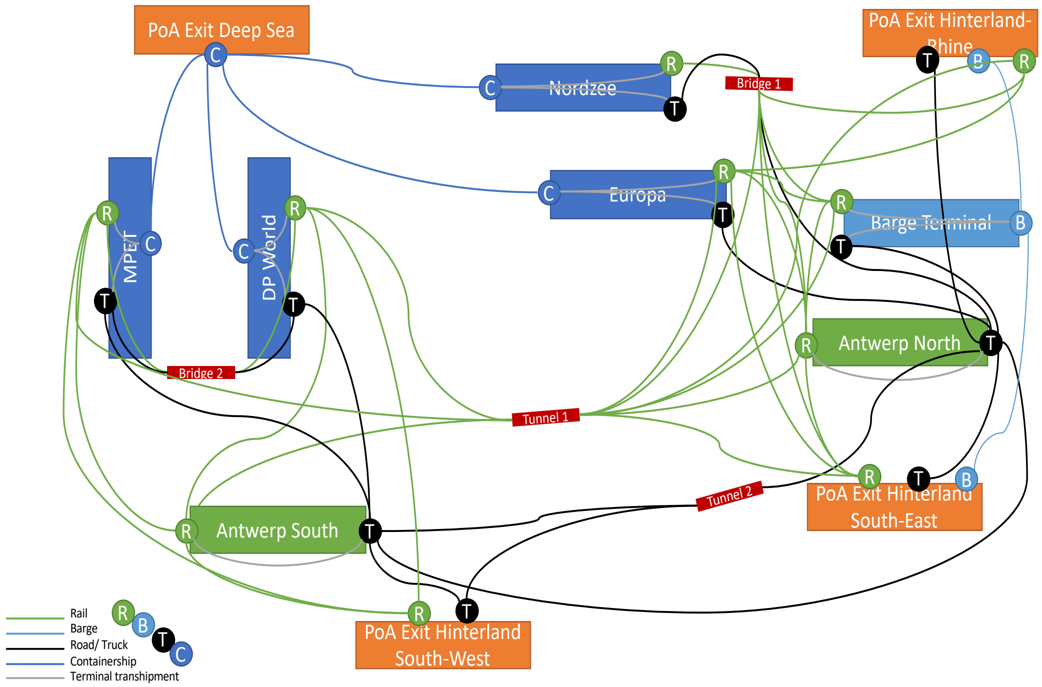

Figure 4.1 Disaggregate PI Hub representation for technology evaluation in MAMCA

Furthermore, four fictional nodes are considered, that represent the entries and exits of the port for each different mode. The four fictional nodes facilitate the boundary between the disaggregate representation of PoA as a PI Hub and the aggregate representation of the port's hinterland. As illustrated in Figure 4.2, in the context of TEN-T, Antwerp (checkered node) is connected to Gent to the West/South-West, Brussels and Liege to the South/ South-East, and to Rotterdam on the North/ Northwest. These three connections are linked to the respective 'PoA Hinterland Exit' in the disaggregate PI Hub representation.

Figure 4.1 captures the various link options that are available within the PI Hub, such as the two-rail links between Antwerp South and Antwerp North rail terminals. Each of the PI Hub links, is associated to specific distance, travel time, cost, and capacity. The last parameter is only used in the PI Hub context and represents an important feature of the port's operations. For example, the more efficient rail link from Antwerp South to Antwerp North, has a limited capacity, which if exceeded, the operational cost changes (as the longer route is used). The capacity feature is also used for the representation of the port's bottleneck locations such as the Tunnels and Bridges. Capacity limitations also apply on the transshipment capability of the PI Hub terminals. Transshipments are also associated to cost and duration that is measured and reflected on the Transport Cost and Level of Service stakeholder criteria.

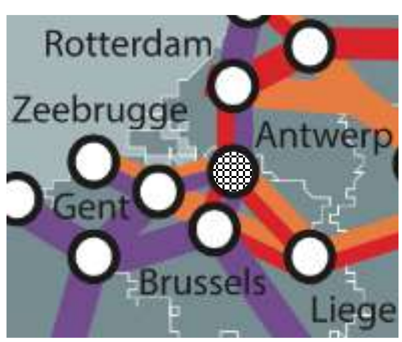

Figure 4.2 Pi Hub and hinterland connectivity representation

For the aggregate hinterland representation, the TEN-T PI hubs are represented as nodes, with short-term storage and transshipment. By adopting this detailed disaggregate representation of PI Hubs, the network representation enables enhanced visibility in operations status within the port, which reflects changes in operational efficiency when infrastructure and technology investments are considered as required by MAMCA. By recording information on queues and travel times for transshipments at different terminals of the PI Hub, it becomes feasible to promote more efficient and less congested hubs. This enables routing cargo by considering both the hinterland transport and the transshipment legs cost components.

4.2 PLANET model inventory

4.2.1 NEAC

NEAC specializes in modelling the inter-relationships between economic development, trade, and transport. Normally transport models focus upon analysing detailed patterns of road traffic flows within limited regional scope; and this may extend to national transport models or cross-border "corridor" models. However, the main differentiating features of NEAC are that it addresses:

- Multimodal transport, at a
- Regional to European scale.

NEAC is a suitable system for analysing medium to long-distance traffic flows, for analysing macro-economic impacts, global trade patterns, and for measuring wider-scale impacts such as greenhouse gas emissions. The system covers all of Europe and neighbouring countries and provides the link between traffic and economic development across European regions. Applications typically focus upon forecasting, transport policy, transport infrastructure, port competition, containerisation, and environmental impacts of transport. The basic units within the system are NUTS3 regions, and a multimodal transport network. Goods are traded between regions depending on their socio-economic needs and routed from origin to destination via the transport network. The volumes being traded, and the route/mode choices used determine the system's cost, measured as user (internal) and non-user (external) cost.

Levels of economic development are linked to their levels of trade, which is constrained by transport costs, which increase over longer distances, resulting in the familiar pattern in which shorter distance traffics tend to dominate. The major trade routes connect urban centres, but flows are dispersed across thousands of links. Such a polycentric/dispersed pattern makes it difficult to develop new markets for transport systems such as rail and inland shipping which rely on scale economies. The development of European multimodal corridors is a way to focus the major flows onto priority routes which can be adapted in an efficient way to provide multimodal capacity and impact-amelioration methods in order to minimise internal and external costs.

The complexity of the spatial patterns of traffic flows are illustrated below in Figure 4.3. NEAC uses the extended networks developed by the WORLDNET project connecting to neighbouring regions in the Middle East, North Africa, and Central Asia. Ports have a special role within the system as the primary gateways for intercontinental traffic. Sea transport is included within the multimodal network structures in NEAC. Naturally, sea transport which offers high capacity and relatively low greenhouse gas emissions and low transport costs per tonne kilometre is a key element in NEAC. Port choice also has a major bearing upon inland patterns of goods distribution.

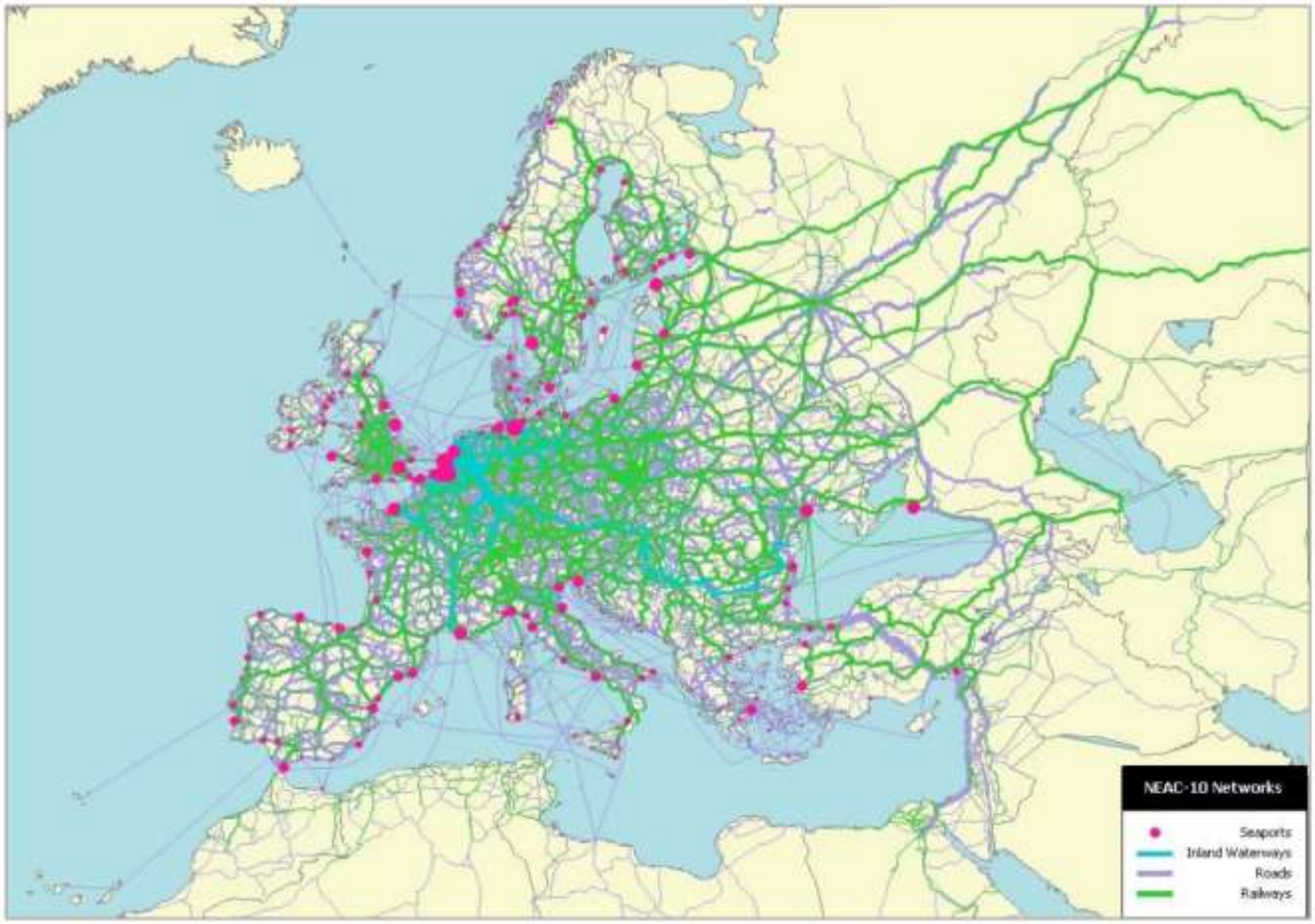

Figure 4.3 NEAC-10, Multi-layered European Transport Model. [15]

The NEAC model offers the following level of detail:

- The system applies a common regional structure (EZ2006-Level3), based on NUTS3, as developed for the ETISplus project Excluding the Russian Federation, there are 1585 regions defined in Europe. There are 2321 Level-3 regions worldwide.
- A core European area including all EU Member States, Norway, Switzerland, and neighbouring countries including Serbia, Bosnia, Albania, Montenegro, North Macedonia, Moldova, Ukraine, Belarus, and Turkey.
- Worldwide flows to and from the core European area detailed by 52 product types (NSTR 2 Digit).
- Cross-border and domestic flows within the European core area detailed by 52 product types (NSTR 2 Digit).
- Five transport modes for freight; road, rail, inland waterway, sea, and others.
- 250 Seaports.
- 10,231 Railway links.
- 58,639 Road links.
- 2,005 Waterway links.

4.2.2 Terminal model

The Terminal Model is a flexible transport model offering extensive policy and scenario evaluation options. In its core, the terminal modal calculates transport costs and time between regions for various modes of transport and different commodities. It uses a complex network (road and intermodal, including transhipment points) including associated transport cost to establish transport costs from a particular location within the study area (municipality level) to any other area within Europe (NUTS-3 level) or outside Europe.

The terminal model requires the following inputs:

- Detailed regional structure based on NUTS2006, including the neighbouring countries Norway, Switzerland, Serbia, Bosnia, Albania, Montenegro, and North Macedonia. All other countries are included on the country level. For PLANET, China has been included on the province level.
- Trade data from various sources depending on the application of the model, including Statistics Netherlands for trade related to the Netherlands; ETISplus for inter-EU trade; Eurostat COMEXT for EU-extra EU trade and UNCTAD for extra-EU – extra EU trade (non-EU trade).
- Rail network & internal and external transport costs
- Road network & internal and external transport costs
- Sea network & internal and external transport costs

The terminal model follows a classical macro modelling approach. Using generalized transport costs and random utility theory, transport flows are modelled across the network. Transport is modelled as multimodal chains describing the transport of a commodity from its region of production, via transhipment locations to the region of consumption.

4.2.3 EU flow model

This is a multi-modal multi-commodity flow model, that is based on a PI enabled TEN-T network. The model considers links connecting European cities for road, rail, sea, and river modes. The PI enabled nodes are represented as transhipment locations where multimodal terminals are available. To run, the model requires the export and import flows for single or multiple commodities between at least two network nodes. It then calculates the optimal routes based on distance, travel time, or other parameters, while considering the throughput capacity for each node and link. It allows for the representation of the PI Hubs at a different aggregation level that accounts for terminals and other PI Hub functionalities. Network data can be amended to investigate the impact of new network components, infrastructure and services in the operation and serviceability of the network.

Figure 4.4 captures the high aggregation representation of the TEN-T network for multi-modal and multiple OD pair flows. It integrates a low aggregation representation of PI Hubs, that enables the accurate appreciation of within the port operations and costs, that have a significant impact on transhipment potential.

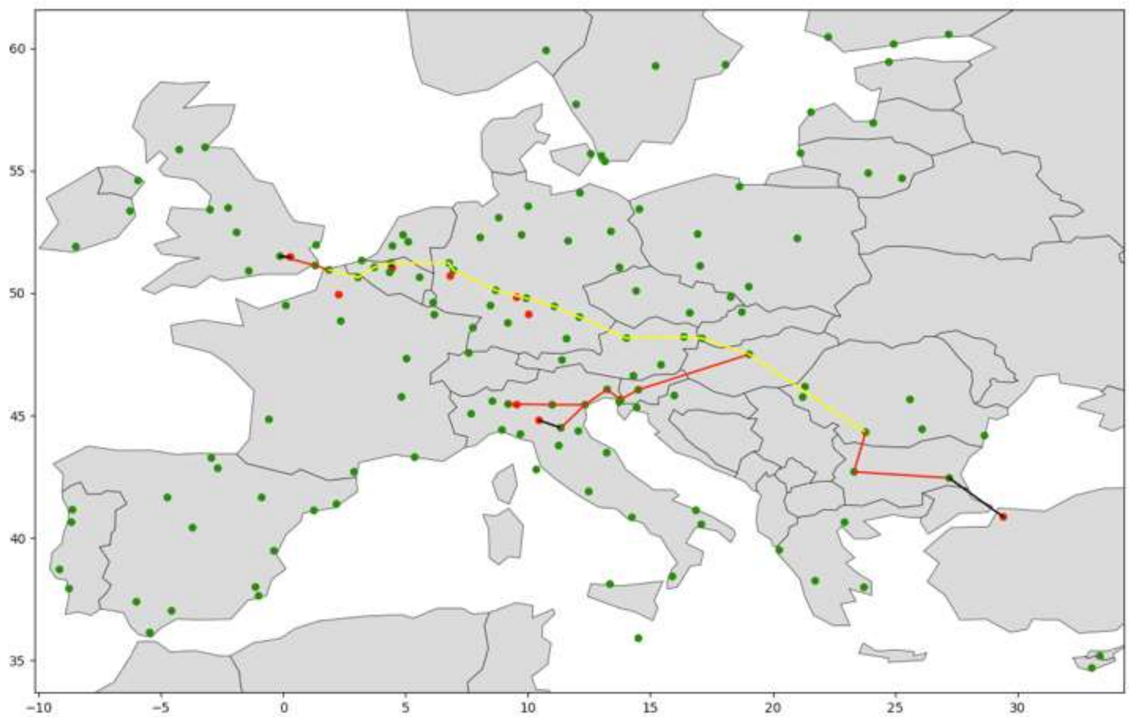

Figure 4.4 EU multi-modal flow model

4.2.4 PI integrated model

The Physical Internet Network Simulator is a tool that helps visualize the movement of products over a PI network. This simulation model has been created based on multi-agent simulation technology. Agents can represent very diverse features including:

- vehicles,
- units of equipment,
- projects,
- products,
- people in different roles, etc.

The agents are the main components of the simulation model and can be attributed behaviour, memory (history), timing, contacts, etc. The basic elements of this model correspond to the fundamental elements of the physical internet: containers, orders, nodes, connections, and transports. In summary, the orders contain information about the origins and destinations of the containers that are moving through the network. They can contain additional information, such as ETA constraints. Each container has an origin node and a destination node. During the container's trip, at each node, decisions are made about the next leg of the network, selecting the best transport. The nodes are connected by links. The transports travel through the links.

The data needed to set up a simulation model are associated with the physical internet elements. For example, information on node position (location, capacity), transport (speed, type of transport, capacity), connections (road status, congestion level) and orders (origin, destination, number of containers, estimated ETA). The model is prepared to use data from local tables (excel type) or connect to services that offer this data via API. The scope of the model is limited, computation time can increase exponentially with model complexity (i.e., Preferable use 100 nodes, not thousands). For living lab simulation model some scale hypotheses are needed. (i.e., test with the 10% of the network and extrapolate the results).

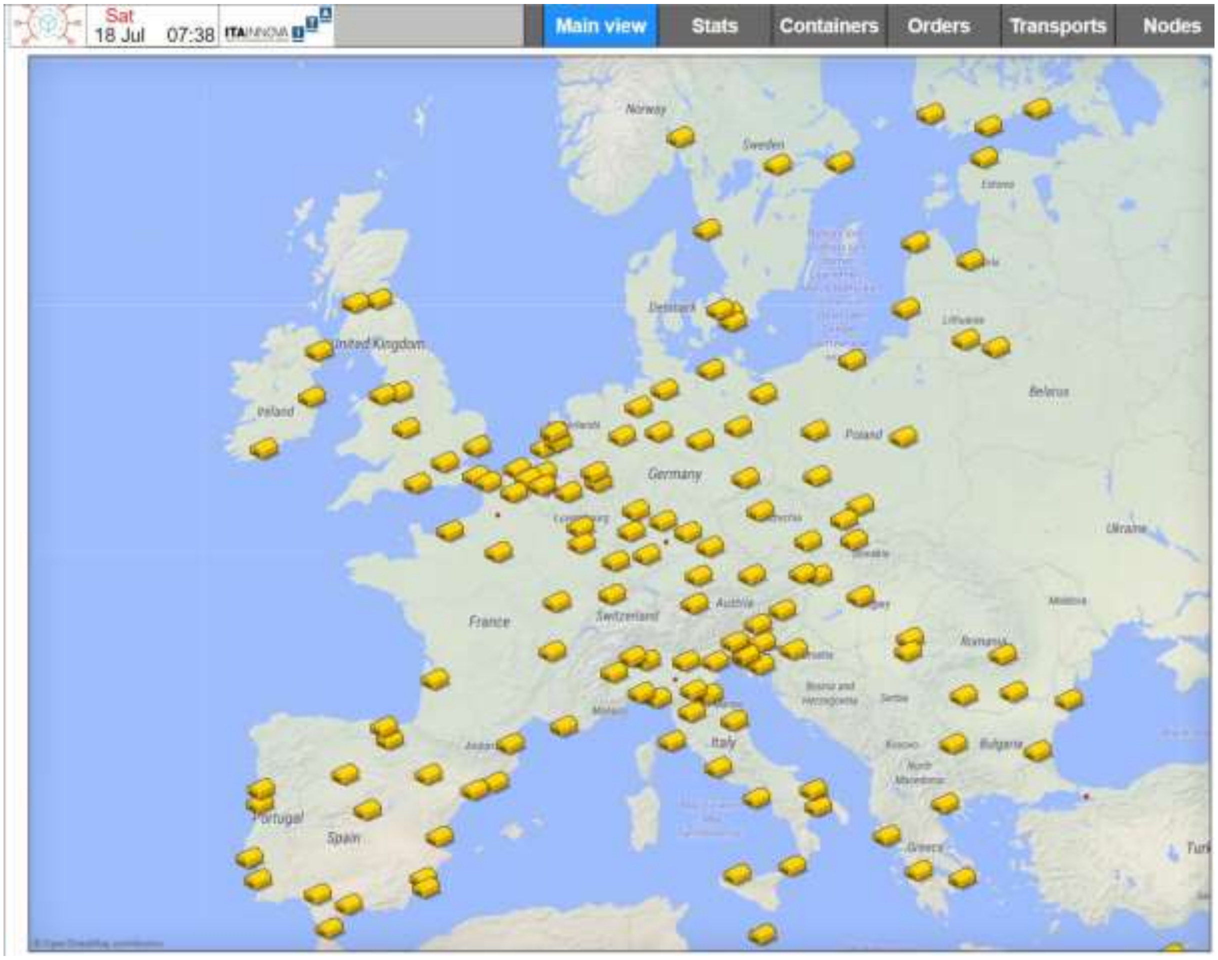

Figure 4.5 PI integration model [13]

The simulation is a powerful tool to visualize how the movement of products over a PI network can be, including flows from other companies. The models are used to quantify the impact of the different services, economic (transport and handling costs), operational (reducing lead time) and environmental (CO2 emissions) indicators have been obtained. Results obtained with data from the living lab companies.

4.3 Criteria operationalization

The evaluation model for the MAMCA requires to reflect to the fundamental stakeholder criteria discussed in Section 3.2.3. Therefore, the network model requires to quantify, the performance of the baseline scenario against the alternative scenarios, in terms of:

- total transport cost for satisfying trade needs,
- level of service and the ability of the network to address delays and uncertainty (robustness),
- level of service in terms of travel/ serviceability time considering the impact of congestion,
- profitability and business climate, and
- transport emissions.

The modelling environment should capture the overall network performance in terms of the above metrics, for various technological and infrastructural investment alternatives considered.

For example, LL2 examines the utilization of blockchain technology for securely handling cargo travel documents, making them available to relevant parties involved in the transport process, eventually making it more efficient, more reliable, and faster. Expediting cargo customs and processing at multimodal terminals, implies a technological improvement that influences all operators using the service. Therefore, a modelling tool, capturing operator specific transshipment and transport services at each multimodal terminal or between terminals, can capture the network performance benefits of such technological advancement.

Then, to operationalize the network performance benefits, artificial classification scale is created, with borders set to, up to 5% improvement, improvement between 5-10%, or between 10-15%, or above. Typically, a 10-point scale is used for this type of classification.

This approach can also be adopted for qualitative metrics, such as the profitability and business climate, that cannot be quantified by the models proposed. For such criteria, the stakeholders will be asked to assess the impact and performance of each alternative against the baseline scenario, by adopting a classification scale similar to the one illustrated in Figure 3.6.

4.4 Concluding remarks and future work

The PLANET project network evaluation models inventory offers a powerful and diverse toolbox for analyzing multicriteria performance in the context of MAMCA. The NEAC and terminal models have embedded detailed commodity flow representations. All models offer the capability to quantify the impact of new infrastructure, as well as the capability to adjust network properties for technological improvements. The limitation of NEAC and terminal models, lies with the preparation effort required for running a specific use case and the limited perception of the PI smart decision making, which is best integrated in the PI simulation model. The EU flow model also offers a very robust and simple to prepare model. Its ability to capture disaggregate components for PI Hubs, offers an excellent network representation that can accommodate the unique features of both technological and infrastructural investments. The tool can be utilized for screening alternative TEN-T development scenarios. Once a final list of development scenarios has been populated, an evaluation and operational plan can be developed utilized the PLANET models' inventory.

5 Collaborative logistics development

In the context of the PLANET project and its Living Labs, multiple alternative technologies, infrastructures, and policies are considered [13]. The aim of all alternatives is to drive operational efficiency in a Physical Internet enabled supply chain. The planning impacts of the decisions' considered in PLANET project living labs range from strategic (discussed in Section 3), to tactical and operational level. Considering the multitude of stakeholders involved in a supply chain, the open ended and uncertain nature of the Physical Internet, as well as the different operational contexts, the development of commonly accepted plans is particularly challenging. MAMCA can offer a multi-stakeholder multi-criteria perspective in developing such plans, and potentially expand to automatically determine optimal operational collaborative decisions.

5.1 Scope of PLANET Living Lab Use Cases

The three PLANET Living Labs investigate three unique aspects of technological and infrastructural development. Focusing on the connectivity of the TEN-T network to global trade corridors:

- LL1 examines how new technologies (IoT, AI and blockchain) and concepts (Physical Internet) can improve processes, operations and efficiency along the door-to-door transport chains linking the Maritime Silk Road with EU internal corridors.
- LL2 examines how synchro-modal dynamic management of TEN-T & intercontinental flows promoting rail transport and utilizing the Port of Rotterdam (PoR) as the principal smart EGTN Node coordinating the rail focused transport chains linking China through Rotterdam to/from USA, and Rhine-Alpine Corridor destinations, and
- LL3 examines streamlining logistic processes in flows from China to Europe along the Silk Road by implementing IoT technologies (based on the EPCIS platform) and GS1 standards that facilitate transmission of data between the partners involved in the e-commerce operations.

LLs 2 and 3 offer specific technological services that influence the operational efficiency of every network component and are considered as part of the generic technologies for the development of the TEN-T as a PI network. LL1 additionally investigates the integration of TEN-T operations and hinterland operations for global corridors as illustrated in Figure 5.1. As part of this exercise, three types of stakeholder collaborations are identified. The first focuses on the sea-side collaboration, between ocean liner operators, and port operators. The second focuses on long-haul hinterland connections, between port and terminal operators and LSP and warehouse operators. The third focuses on urban distribution and the collaboration between regional warehouse operators and last mile logistics companies.

The first Use Case of Living Lab 1 focuses on:

1. smart decisions at PI hubs aiming to utilise real-time synchro-modal tools to optimise container routes based on capacity, cost, and level of service.
2. Application of intelligent algorithms for assessing route changes (both arrival port, and inland transport)
3. Extension of analysis to last mile logistics considerations
4. Blockchain technology at Valencia port and hinterland
5. Worldwide tracking of containers (IoT)

A MAMCA methodology may help capture the different criteria and weights these stakeholders base their operations on, and potentially help identify mutually beneficial solutions. This concept may be applied to tactical decisions, such as data sharing, and collaboration agreements, to operational collaborations between subsequent or even competing services.

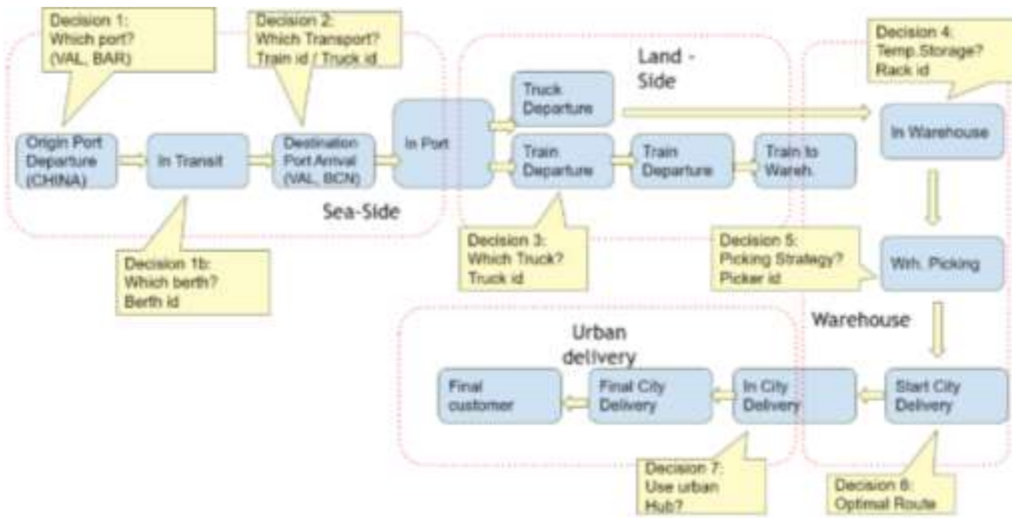

Figure 5.1 Living Lab 1 collaboration sequence map [13]

5.1.1 Subsequent services

In a PI enabled transport network, capable of dynamically redistributing flows, subsequent services operators have more flexibility in optimizing their operations. Queueing and uncertainty in multimodal terminals are a significant disadvantage for freight transportation. Avoiding or bypassing long queues, when dynamic rerouting is possible, offer operators an ideal tool for addressing delays due to congestion.

The complex interface between sea operators, ports, and hinterland LSPs, is currently difficult to manage dynamically. However, a MAMCA enabled tool, can potentially identify commonly beneficial rerouting options, and promote their implementation.

One of the examples analysed in LL1 is that of two of COSCOs shipping lines, namely aem1 and aem2 illustrated in Figure 5.2. Both lines connect China's south-eastern territory to Europe, calling at multiple Mediterranean ports including Piraeus, Valencia, Barcelona, Genoa, etc. With port congestion being a significant cost for operators, there is scope for dynamically making rerouting choices for the vessels to avoid calling some of the ports. This immediately, transfers a load to transport the cargoes to their final destinations through the hinterland transport infrastructure and services.

Once alternative routes are identified, implementing a MAMCA methodology in this context, can facilitate the different stakeholder perspectives, and potentially to establish a commonly acceptable solution, for forwarding cargoes to their destination. Such solution is mutually beneficial, for both seaside and land-side operators. However, it remains unclear how such decisions influence other related stakeholders.

Figure 5.2 COSCO East Asia to Mediterranean containership routes

5.1.2 Competing services

Another major challenge considered in the context of LL1 is that of last mile uncertainty. Last mile operators, frequently need to dynamically redesign urban delivery rounds, to alleviate delivery delays. This challenge is highly relevant to the concept of the Physical Internet and EGTN as it utilises the benefits associated to dynamic tracking of parcel deliveries and vehicle fleet. The problem is of practical nature at an operational level. Delivery rounds are typically fully designed prior to initiating their implementation every day. The design of delivery rounds takes into account, the fleet (i.e., the number and capacity of delivery vehicles available) and local accessibility constraints such as Low Emissions Zones (LEZs) or Zero Emissions Zones. LEZs that are increasingly popular in European cities as they are one of the most effective measures towns and cities can take to improve air pollution. Low emission zones reduce emissions of fine particles, nitrogen dioxide and (indirectly) ozone by not allowing vehicles with higher emissions to enter the area.

To expedite a late delivery round completion time, operators sent assistance vehicles, that share the delivery load. This involves undertaking the following actions:

- Identify which vans can be sent for assistance without inflicting severe delays in their delivery obligations,
- Identify how many and which parcels require to be transferred from the late vehicle to the helping vehicle,
- Identify a common meeting point, and
- Dynamically redesign the delivery round for both vehicles featuring the common meeting point.

A critical factor for effectively addressing delivery delays, is the availability of helping vans, which is typically limited as operators aim to utilise all their resources in the planning phase. Offering fair and balanced criteria for determining helping rounds contributes to promoting collaboration between otherwise competing operators. However, operators tend to seek solutions internally, rather than handing over their deliveries to other operators.

The MAMCA can help resolve this, by defining appropriate operational decision criteria, that will consider individual operator's weights, for late running deliveries, and sharing deliveries with other operators. Through this approach an operator can prioritise collaboration with non-competitive or less-competitive operators, by assigning appropriate collaboration weights. The MAMCA output in this case is to identify solution that meet the qualification criteria of both stakeholders and can potentially be further expanded to include the criteria of all stakeholders associated to last mile deliveries.

5.2 Future work

This section investigates the application of MAMCA for resolving operational challenges and encouraging collaboration in the last mile delivery, and seaside, port, and hinterland collaboration. Analytic tools being developed as part of PLANET T2.4, can be operationalized to define the alternatives available. Then for each of the two-scenario discussed, the stakeholders, their criteria and weights remain the same, making feasible running MAMCA and determining commonly beneficial solutions.

Following from the literature discussed in Sections 2.2.1 and 2.2.2, to further develop this operational variation of MAMCA, clear definitions of the stakeholders, their criteria and weights require to be defined in each case.

6 Conclusions

This deliverable focused on the implementation of MAMCA methodology for the development of the TEN-T network and its integration to global corridors. The approach adopted considers both infrastructural and technological advances, including the ones developed in PLANET's LL2 and LL3. A literature review of the MAMCA methodology is also undertaken, examining its main components, extending back to predecessor methods, such as the Multi-Criteria Analysis, and analysing implementations extending beyond national borders. The MAMCA steps and applications are discussed as the methodology has multiple variations and applicability into multiple contexts.

The MAMCA is applied in the context of the strategic evolution of the TEN-T, considering the uncertainty of future scenarios based on PLANETs Positions Papers within its Analytic Hierarchy Process. The technological and infrastructural alternatives are analysed, and utilized for the identification of preliminary stakeholders, and relevant to the PI context stakeholder criteria. The DSS tool requirements for completing and automating the MAMCA application are also examined.

The modelling requirements for the strategic development of TEN-T are analysed in terms of network representation, as establishing a link between technological advances and network performance evaluation in terms of the stakeholder metrics is essential for meaningful MAMCA application. An inventory of suitable evaluation models based on PLANET partners capabilities is populated for quantifying network performance. The operationalisation of the quantitative and qualitative criteria is analysed considering model outputs.

An alternative application of MAMCA focusing on operational collaboration is discussed for the PI services being developed for LL1. The collaborations that arise between the container liner operators and the port operators, as well as between warehouse operators and last mile distributors are analysed. In this case the MAMCA enables the identification of mutually beneficial solutions, as well as the consideration of feasible collaboration criteria.

The deliverable contributes to the application of MAMCA on PLANET outputs and LLs from the planning, implementing and distribution perspectives, making substantial advances on all three fronts. In terms of planning, the deliverable covers both strategic and operational perspectives, and identifies relevant stakeholders and their criteria. In terms of implementation, quantification requirements are defined, and multiple analytic network performance evaluation models are considered. Finally, in terms of results distribution, the integration with the DSS and the interfaces for collecting missing data and illustrating the analysis outputs are presented.

D2.11 delivers all preliminary components for implementing the MAMCA methodology on PLANET outputs and LLs. It contributes to PLANET's core objectives:

- to develop a simulation capability for analysing the impact of new trade routes,
- a stakeholder aware EU roadmap and capacity building program for EGTN, and
- the dissemination of this capability through the development of a DDS tool.

For the further development and implementation of MAMCA methodology, three stakeholder workshops will take place, to:

1. formulate clear technological and infrastructural inventories, and use them to construct appropriate strategic development scenarios as well as to develop operational scenario alternatives for fostering collaborative logistics, utilizing MAMCA as a tool for streamlining collaboration criteria

2. qualitative evaluation of pending criteria
3. criteria definition and weight data collection through pairwise comparisons conducted on the DSS tool and presentation of results

The workshops outputs will contribute to formulating scenarios, identifying criteria, and quantifying them. The first two workshops' outputs will contribute to the analysis of qualitative criteria, that will then be operationalised together with the network performance evaluation model outputs. The results of the analysis will be presented to all PLANET partners in the final workshop, where the criteria weights will be populated through the DSS tool.

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