DIT4TraM

Distributed Intelligence & Technology for Traffic & Mobility Management

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Distributed Intelligence & Technology
for Traffic & Mobility Management

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Abbreviations	
AHP	Analytic Hierarchy Process
CBA	Cost-Benefit Analysis
ÉLECTRE	ÉLimination Et Choix Traduisant la REalité (ELimination and Choice Translating REality)
EU	European Union
KPI(s)	Key Performance Indicator(s)
MAMCA	Multi-Actor Multi-Criteria Analysis
MCA	Multi-Criteria Analysis
MCDA	Multi-Criteria Decision Analysis
PROMETHEE	Preference Ranking Organization METHod for Enrichment of Evaluations
SAW	Simple Additive Weighting
SMART	Simple Multi-Attribute Rating Technique
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
WP(s)	Work Package(s)

Executive summary

This report constitutes the first version of Deliverable 8.1 of DIT4TraM project, which reflects the work carried out under Task 8.1 (Impact assessment framework) as part of the Work Package 8 (Assessment methodology and Market Analysis) during the period M1-M12 (September 2021 – August 2022). The second and final version of Deliverable 8.1 is due to M30 (February 2024).

Following a brief introduction provided in Chapter 1, Chapter 2 presents a state-of-the-art literature review on the most commonly used Multi Criteria Analysis (MCA) methods in transportation and compares the advantages and disadvantages of each. Although these methods may differ significantly, it becomes clear that there is no best or worst approach, as the suitability of the method depends on the specific decision-making situation it applies. Later, the relatively novel concept of Multi Actor Multi Criteria Analysis (MAMCA) is introduced. MAMCA differs from classic MCA approaches because it presents a complete 7-step framework for the stakeholders' inclusion in the decision-making process. The concept of MAMCA has been widely used in previous EU transport-related projects, therefore, we try to build on this collectively acquired knowledge, drawing on the results of previous stakeholder consultations to identify the goals and objectives of the different distinct stakeholder groups around urban mobility, as well as to define key performance indicators that need to be measured in each DIT4TraM pilot.

Chapter 3 describes the evaluation process framework of DIT4TraM which follows a MAMCA approach. Meanwhile, for each criterion, as an exhaustive list of KPIs was developed, KPIs are prioritised. Through the prioritisation, weights are assigned to the KPIs. In a last instance, the measurements from the pilots and simulations provide measurements for the specified KPIs. The necessary input from the project stakeholders was collected through a 2-round survey that was distributed among them. Within the first round of the survey, stakeholders were asked to state the different objectives they had around the DIT4TraM project pilots as well as to propose Key Performance Indicators that they believed that should be measured. Many of the objectives and KPIs already identified from the literature, as well as from previous EU projects, were given as choices in the survey so that stakeholders were only requested to adapt the proposed structure to suit their needs and the needs of the DIT4TraM pilots. Subsequently, during the second round of the survey, they were asked to prioritize the previously identified objectives and relative KPIs using pair-wise comparisons and 0-100 score assignments.

In Chapter 4, the results of both surveys are presented. The stakeholders' objectives that derived from the first round of the survey were divided into the following categories: Network Performance, Network Efficiency, Traffic Safety, Energy/Environment and Socio-economic. The specific KPIs obtained can be found in the table below.

IMPACT ASSESSMENT KPIs				
Network Performance	**Network Efficiency**	**Traffic Safety**	**Energy/ Environment**	**Socio-eco**
Passenger throughput (Passengers served)	Average vehicle delay per trip	Accident frequency	Emissions	Average tra for use
Vehicle throughput (vehicles served)	Average vehicle density	Accident severity	Fuel consumption	Public tran usage
Average speed per trip	Average passenger delay per trip	Number of conflicts	Noise levels	Soft modes
Average speed per segment	Average vehicle delay per intersection	Speed variability		Jain's fairne
Total Distance Travelled	Average passenger delay per intersection	Traffic violations		Overall sy fairnes
Utilization - vehicles	Congestion level			
Utilization - passengers	Travel times variability			
Public Transport supply (in route-km or passenger-km) per hour	Vehicle occupancy			
	Resilience (response time to event)			

Finally, an AHP prioritization of the above criteria categories combined with a 0-100 score prioritization of specific KPIs per category led to the global weights of importance of each KPI in the impact assessment process that can be found in the table below.

Network Performance		Network Efficiency		Traffic Safety		Energy/ Environment		Socio-economic		Cost	
Passenger throughput	2,47 %	Average vehicle delay per trip	2,65 %	Accident frequency	7,74 %	Emissions	6,30 %	Average travel cost for user	1,30 %	Investment cost	2,70 %
Vehicle throughput	1,81 %	Average vehicle density	2,43 %	Accident severity	7,74 %	Fuel consumption	5,04 %	Public transport usage	1,49 %	Operating cost for the deployed system	2,93 %
Average speed per trip	2,47 %	Average passenger delay per trip	2,43 %	Number of conflicts	6,06 %	Noise levels	4,25 %	Soft modes usage	1,36 %		
Average speed per segment	2,14 %	Average vehicle delay per intersection	1,99 %	Speed variability	6,39 %			Jain's fairness index	1,17%		
Total Distance Travelled	1,97 %	Average passenger delay per intersection	2,21 %	Traffic violations	5,72 %			Overall system fairness	1,17%		
Utilization - vehicles	1,81 %	Congestion level	2,87 %								
Utilization - passengers	1,81 %	Travel times variability	2,65 %								
Public Transport supply per hour	2,14 %	Vehicle occupancy	2,43 %								
		Resilience (response time to event)	2,43 %								

The next step is the actual evaluation of the impact of the different DIT4TraM solutions that will be produced after the pilots' implementations. These evaluations will be based on the defined stakeholders' criteria using the TOPSIS methodology. Consequently, the final ranking of alternatives for each stakeholder group will be derived and the optimal solutions will be identified.

1. Introduction

Decision making associated with the transport sector is well known for its complexity. Decisions usually have a significant impact on various fields -society, environment, economy etc.- and a large number of individuals or organizations who usually have different priorities and objectives. This specificity very often leads to controversies and disagreements within transport projects making them hard to implement or leading to serious delays. For this reason, it is of great importance to always perform a thorough analysis for considering the implications, for the people or the environment, of proposed actions, especially when there is still an opportunity to modify -or even abandon- a proposal (IAIA, n.d.). This process helps to eliminate the controversy and makes the creation of commonly accepted solutions possible. Many national or international governmental organizations including European Commission (2021) require an impact assessment process in all proposals that are likely to lead to significant economic, environmental or social impacts or when the Commission has a choice between alternative policy options.

In the DIT4TraM project we develop control concepts and algorithms with swarm intelligence for the widest possible range of applications, with the four main applications being 1) cooperative connected traffic management, 2) cooperative distributed traffic management, 3) decentralized demand management and 4) cooperation between transport services. All these applications will be tested in practice in the pilots of Bordeaux, Utrecht, Amsterdam, Glyfada, Athens and Barcelona where the gains to be achieved for all the relevant impact areas will be evaluated.

1.1 Scope of this deliverable

This deliverable is part of the DIT4TraM's work package 8 "Assessment methodology and Market Analysis" and corresponds to task 8.1 "Impact assessment framework". The ultimate goal of this deliverable is to create a universal impact assessment framework to be used for estimating the impact of the simulations and pilots related to the DIT4TraM solutions and applications.

More specifically, this deliverable aims to select the proper methodologies from literature that can be adapted to a consistent and inclusive framework for assessing the impact of DIT4TraM management paradigm in cities and to compile a detailed list of KPIs for assessing impacts including but not limited to efficiency, energy efficiency, liveability, emissions, cost efficiency, resilience to be used across the different WPs.

The proposed framework will be applicable to pilots and simulation use cases. Moreover, it will be used to assess the stakeholders' perception about DIT4TraM applications during workshops and stakeholders' consultation.

1.2 Links to other Work Packages

This deliverable will take input from literature and other EU projects findings, as well as the conceptualization (WP1) and specifications of the DIT4TraM system (WP6) and each application area specifications (WP2, WP3, WP4, WP5). Later on, the created framework will be used to evaluate the demonstration through simulation and pilots to be conducted in WP7.

1.3 Structure

Section 2 provides a short review on the impact assessment methodologies that are used in Europe and internationally to evaluate solutions relevant to transportation systems. Section 3 then explains how these methodologies are integrated into the DIT4TraM paradigm. Section 4 thoroughly describes the data collection processes which include dedicated surveys and workshops with stakeholders. Section 5 presents the results of the surveys in terms of criteria prioritisation per stakeholder group and per pilot. Finally, the key points of this deliverable are summarised in the conclusion (Section 6).

2. Literature review

Traditionally, transport projects rely on a unique criterion (monetary) evaluation through Cost Benefit Analysis (CBA) or similar approaches (e.g., Social-CBA) (Prest & Turvey, 1966). CBA is a basic evaluation tool in many European countries (Florio et al., 2018; Odgaard et al., 2005) as well as in the rest of the world (Treasury Board of Canada, 2018). CBA uses money as the only measure unit to translate the costs and the benefits associated to an investment or a policy (Prest & Turvey, 1966). Apart from the direct monetary costs, non-market related costs are also translated into monetary values using a "willingness to pay" logic or hedonic pricing (Gössling & Choi, 2015). The core idea behind CBA is that there should be a positive benefit to cost ratio, or in other words a social surplus, for an action or a policy to be considered worth implementing.

While procedures such as stated preference or hedonic pricing provide ways to establish monetary values for some non-marketed impacts, for others it is not practicable (e.g., quality of public transport, value of human life, etc.). Also, especially in the field of transportation, policies often have insignificant or even zero monetary costs, aiming mostly to social or environmental benefits (Beria et al., 2012).

More and more people criticise CBA and its related methods for not being able to capture complex concepts like liveability or sustainability and for restricting the evaluation to specific criteria (Macharis et al., 2009). According to the interviews that Annema et al. (2015) conducted with twenty-one Dutch transport politicians, it is clear that policy-makers use the outcomes of CBA in a non-decisive manner. Within the interviews it is stated that politicians find the aggregate outcome of CBAs "pretentious" and that "they seem especially interested in appraisal tools which show clearly to them the politically important trade-offs of a transport policy".

For these reasons, Multi-Criteria Analysis (MCA) has gained a lot of popularity in the transportation field during the last years (Yannis et al., 2020). MCA is more suited to perform comprehensive evaluations, since it is able to examine social, economic and environmental aspects of sustainable transport projects against a range of criteria. MCA also allows the analyst to involve the objectives of different interest groups or stakeholders. Within the framework of MCA, all the objectives to reach and the corresponding indicators must be identified (Marques et al., 2011). The actual measurement of indicators can be objective as well as subjective. It does not need to be in monetary terms, but it is often based on scoring, ranking and weighting of a wide range of qualitative impact categories and criteria (Yannis et al., 2020).

One extension of MCA that is widely used for transport sector decision problems, allowing increased stakeholders' participation, is the Multi-Actor Multi-Criteria Analysis (MAMCA) (Macharis, 2005; Macharis et al., 2009). In traditional MCA techniques, the objectives and their associated criteria must be common for all stakeholders and each one of them can express their individual preferences through the use of criteria weights. However, in MAMCA, the objectives are not necessarily shared by everyone. A different MCA model is constructed for each stakeholder group, using the criteria contributing to the objectives of that specific stakeholder group. MAMCA has been used multiple times in transport related decision-making problems (Keseru et al., 2019; Sun et al., 2015).

Both methods are used to identify and compare different policy options (scenarios) by assessing their effects, performance, impacts, and trade-offs. Whereas MCA shows how the preference of a single stakeholder group for each scenario is ranked, MAMCA utilises the outcomes of MCA for every stakeholder group to give an overview of stakeholders' support for each scenario. With this approach, all the stakeholders' objectives are taken into account and win-win solutions are investigated. Since all stakeholders are involved in the decision making process, the support for the chosen option is expected to be high.

2.1 A taxonomy of MCA methods

A wide range of different issues as well as combinations among them may arise during impact assessments or evaluations. These could pertain to the ranking of different alternative solutions according to their effectiveness, the choice of the most effective solution as well as the classification of alternatives based on whether they are worth implementing or not. Numerous MCA approaches and related tools have been created in order to address these issues; however, different approaches often lead decision-makers to reach different decisions even when applying the same weights of criteria and the criterial evaluations of variants (Ceballos et al., 2016; Guitouni & Martel, 1998; Wątróbski et al., 2019). This is mainly due to the different assumptions made by each method and other differences related to its applicability. For example, some techniques allow for some degree of compensation between criteria while others do not; some are aggregative while others are not; some are simplified and user friendly while others are more sophisticated and require advanced mathematics; some take into consideration the uncertainty of input data, some others take into consideration the uncertainty of preference. A lot of these approaches have been proven to work in practice as an operational aid to handling complexity in multi-criteria multi-stakeholders' problems/decisions or negotiations – including in the context of EU policies (European Commission, 2021).

According to Yannis et al. (2020) and Broniewicz & Ogrodnik (2020), the most popular MCA method for decision problems in the field of transport is "Analytic Hierarchy Process" (AHP) (Saaty, 1987). Other popular methods are "Technique for Order of Preference by Similarity to Ideal Solution" (TOPSIS) (Hwang & Yoon, 1981), outranking methods like PROMETHEE and ÉLECTRE (Brans et al., 1986; Roy, 1990), or simpler and more user-friendly techniques like "Simple Additive Weighting" (SAW) (Sihombing et al., 2021). There is no best or worst approach, because the suitability of the method depends on the specific decision-making situation (Tsamboulas, 2007). Table 1 presents the main advantages and disadvantages of the most popular Multi Criteria Analysis methods.

Table 1. Comparison of popular Multi Criteria Decision Analysis methods

MCDA technique	Advantages	Disadvantages
AHP	Simple	Correlations between criteria
	Considers the human factor	Prone to rank reversal problem
	Adjustable hierarchy structure	High labour input
		Limitation of scales
TOPSIS	Simple and intuitive	Correlations between criteria
	Computational efficient	Higher subjectivity
Outranking methods	Handle uncertainty	More complex – Not easily interpretable
	Suitable for conflicting criteria	Require complete understanding by the decision maker
SAW	Ability to compensate among criteria	Estimates revealed do not always reflect the real situation
	Intuitive to decision-makers	Results obtained may not be logical
	Calculation is simple	

2.2 The layer of stakeholders

In addition to the numerous criteria against which they have to be assessed and the large number of alternatives, transport-related decision-making problems usually involve a variety of stakeholders (e.g., public transport operators, transport network companies, users, etc.), which increases the complexity and makes it even more difficult to find commonly accepted solutions.

Including the stakeholders in the decision-making process is a crucial factor for the successful development of any transport project. Some MCA approaches have group decision extensions (DeSanctis & Gallupe, 1987) that take into account the various interests and objectives of different stakeholders; however, they do not present a complete framework for the stakeholders' inclusion in the decision-making process.

To fill in this gap, the Multi-Actor Multi-Criteria Analysis (MAMCA) (Macharis, 2005; Macharis et al., 2009) was developed. In MAMCA, stakeholders are explicitly involved -at an early stage- during the process and the analysis. These stakeholders will be crucial to the identification and evaluation of the criteria, which here correspond to the stakeholders' objectives.

As defined by Macharis et al. (2009) the MAMCA methodology consists of 7 steps:

Step 1. Definition of the problem and identification of the alternatives. These alternatives can be different technological solutions, different policy measures, long term strategic options, etc.

Step 2. The relevant stakeholders are identified.

Step 3. The key objectives of the stakeholders are identified and given a relative importance or priority (weights). These first three steps are executed interactively and in a circular way.

Step 4. For each criterion, one or more indicators are constructed (e.g., direct quantitative indicators such as money spent, number of lives saved, reductions in CO_2 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. This allows measuring each alternative performance in terms of its contribution to the objectives of specific stakeholder groups. Steps 1 to 4 can be considered as mainly analytical, and they precede the "overall analysis", which takes into account the objectives of all stakeholder groups simultaneously and is more "synthetic" in nature.

Step 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. The different scenarios are then scored on the objectives of each stakeholder group. For each stakeholder group a MCDA is being performed. The different points of view are brought together in a multi actor view.

Step 6. Ranking of the various alternatives and reveals their strengths and weaknesses. Afterwards, the stability of the ranking can be assessed through sensitivity analyses.

Step 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.

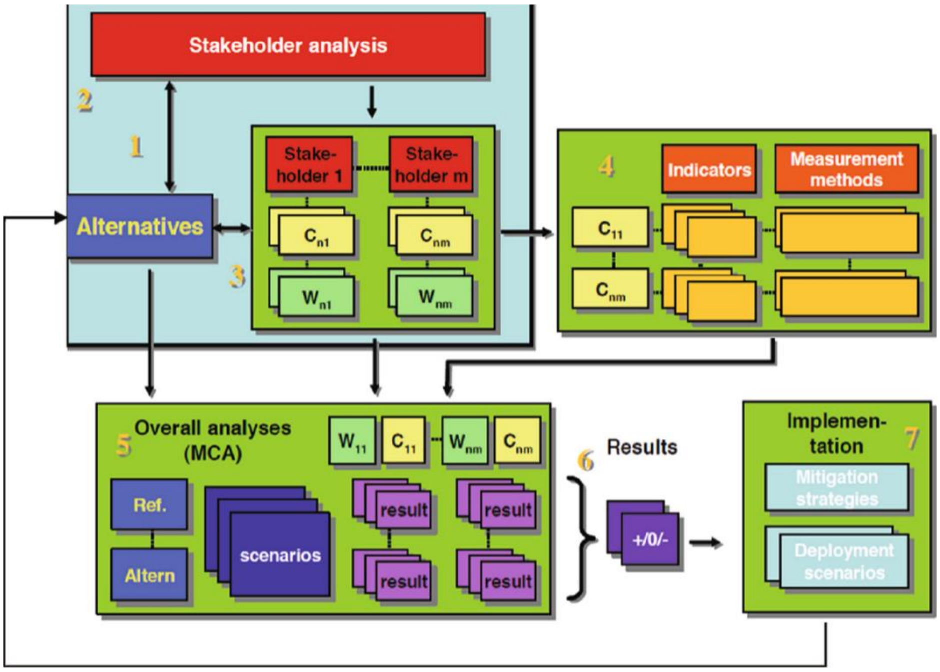

Figure 1. The 7 steps of MAMCA (Macharis, 2005)

Many MCDA methods as well as combinations among them are suited to perform the MAMCA (e.g., AHP, SMART, PROMETHEE, etc.) but simple, transparent and user-friendly techniques are preferred over more sophisticated ones that require an understanding of advanced mathematics (Dean & Hickman, 2018). Different MCDA methods can lead to different rankings of the alternatives, so selecting the MCDA method that fits better to a certain situation is crucial.

When selecting the MCDA method, the following attributes should be taken into consideration:

- Degree of compensation allowed between the criteria (possible thresholds that cannot be exceeded)
- Type of indicators (qualitative, quantitative or mixed)
- Treatment of uncertainty in preference or input data
- Capacity to handle many criteria and alternatives
- Expected output (e.g., choice, partial ranking, complete ranking)
- Ease of use – interpretability

The output of the MAMCA is an overview of the advantages and the disadvantages of the different alternatives for all the involved stakeholders. All the stakeholder objectives are taken into account and win-win solutions are investigated. Since all stakeholders have been involved in the decision process, the support for the chosen option should be high.

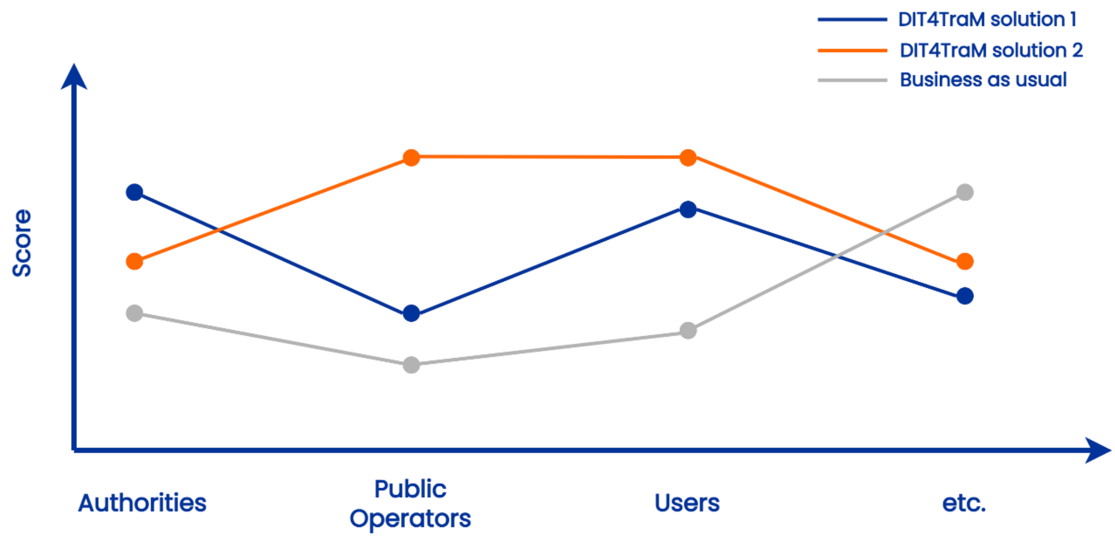

Figure 2. Example of the output of MAMCA

2.3 Previous EU project experience

Impact assessment is a critical process in most EU transport-related projects. The MAMCA methodology has been used many times in the past mainly in the context of freight transport but also in the context of mobility (e.g., Drive2theFuture, CityLab, STRAIGHTSOL, etc.). In DIT4TraM, we have tried to build on this collectively acquired knowledge, drawing on the results of previous stakeholder consultations on the goals and objectives of the different distinct stakeholder groups, as well as the defined key performance indicators that needed to be measured in each pilot in order for the evaluation to be accurate. These results formed the basis around which we prepared the DIT4TraM surveys and workshops that were necessary in order for the impact assessment framework to fit the specific needs and unique characteristics of each pilot city.

The first EU project we took into consideration when designing the DIT4TraM impact assessment framework was Drive2theFuture (Usami et al., 2020). This project aimed at enhancing users' acceptance of automation within the four transport modes: road, rail, maritime and air transport. For the evaluation of the different proposed solutions, the framework of MAMCA was followed. Table 2 presents the stakeholder groups selected for the mobility workshops of Drive2theFuture EU project, alongside with their associated selected criteria (objectives). Key performance Indicators (sub-criteria) were also determined for every distinct criterion, an overview of which is shown in Table 3.

Table 2. Drive2theFuture stakeholders' objectives

Stakeholder group	Criteria
Users	• Safety • Security • Traffic Efficiency • Environment • Socio • Economic
Public Transport Operators	• Safety • Security • Market penetration • Environment • Socio • Economic
Local Authorities	• Environment • Socio • Economic • Policy • Regulatory
Manufacturers	• Safety • Security • Environment • User acceptance • Market penetration • Economic
Mobility service providers	• Security • Market penetration • Socio • Economic • Policy

Table 3. Key Performance Indicators measured in Drive2theFuture

Criterion	Key Performance Indicators
Safety	• Rate of accidents caused by human errors • Rate of accidents caused by machine errors • Number of single-vehicle & multi-vehicle accidents • Number of persons killed, seriously injured, slightly injured per 100 accidents • Number of involved vulnerable road users in accidents • Frequency of emergency stops • Frequency of conflicts. Number of traffic conflicts that could lead to an accident
Security	• Data protection level

	• Number of attacks due to cyber security breaches • Number of traffic violations • User's perception of security while riding the vehicle
Environment	• Greenhouse gas emissions within measurement period • Average daily vehicle consumption of energy • Estimation of environmental impacts • Impact on space and land use • Local air quality • Overall traffic volume
Traffic efficiency	• Vehicle density in congested roads for efficiency of traffic flow and infrastructure capacity • Number of users per vehicle • Public transport reliability • Traffic congestion change • Average commercial speed of AV
User acceptance	• Vehicle operators' acceptance on a user acceptance scale • User acceptance hands on experience of autonomous vehicles • Comparative willingness to have/pay before/after the pilots • Accessibility for all users • Feeling of safety • User perception of privacy • User experience • Comfort and stress levels of the users
Market penetration	• Number of sales of autonomous vehicles • Total miles/km spent in automated mode • Number of cars that belong to a specific SAE level
Socio	• User opinion/rating of autonomous vehicles • Impact on elderly and mobility restricted people • Average passenger-km travelled per day • Average number of passenger trips per day • % Modal shift and travel time in collective transport • Travel time savings
Economy	• Number of sales of autonomous vehicles • Consumer willingness to have and to pay for autonomous vehicles • Manufacturing and implementation costs • Estimate of cost of purchased autonomous vehicle • Operating costs - yearly cost of the personnel • Maintenance cost • Operating revenue • Estimate of training course costs • Transport cost savings • Infrastructure cost change
Policy	• Expectation level of stakeholders • Size and weight implications of changed fleet composition • Vehicle to infrastructure used by automation
Regulatory	• Number of laws oriented to AV support, utilisation and deployment • Amount of financial support in euro • Areas of potential liability

Table 4 presents the stakeholder groups and the associated criteria and KPIs in the project of STRAIGHTSOL (Milan et al., 2014), a project that aimed at improving the efficiency of freight transport and logistics operations. In this project, not all criteria were translated into specific and quantizable KPIs but most of them were evaluated qualitatively using the help of experts.

Table 4. STRAIGHTSOL stakeholders' objectives

Stakeholder group	Criteria	KPIs
Shipper	Successful pick-ups	-
	Low-cost deliveries	-
	High level service	Punctual deliveries
		No damage
		Supply chain visibility
	Green concerns	-
Logistics Service Providers	Profitable operations	-
	Viability of investment	-
	High level service	Punctual deliveries
		No damage
		Supply chain visibility
	Employee satisfaction	-
	Green concerns	-
Receiver	Convenient high-level deliveries	Punctual deliveries
		No damage
		Supply chain visibility
		Suitable deliveries
	Attractive urban environment	-
	Green concerns	-
	Security	-
	Low transportation costs	-
Citizens	Low emissions	-
	Low noise nuisance	-
	Low visual nuisance	-
	Urban accessibility	-
	Road safety	-
Local authority	Positive business climate	-
	Quality of life	-
	Enforcement	-
	Social political acceptance	-
	Network optimization	-
	Low-cost measures	-

Table 5 presents the stakeholder groups and the associated objectives in the project of CITYLAB (Nesterova et al., 2018), a project that also aimed at improving the efficiency of freight transport and logistics operations at city scale and reducing emissions and urban waste. The objectives were not translated into more specific and quantizable KPIs but were evaluated qualitatively using the help of experts.

Table 5. CITYLAB stakeholders' objectives

Stakeholder group	Objectives
Transport operators	Profitable operations
	Viable investments
	High quality service
	Satisfied employees
	Positive effect on society
Society	Road safety
	Air quality
	Fluent traffic
	Noise
Shipper	High quality pick-ups
	Low cost for transport
	High quality deliveries
	Positive effect on society
Receiver	Low cost for receiving goods
	High quality deliveries
	Positive effect on society
	Shopping environment

Table 6 presents the selected stakeholders and the objectives identified for the EU projects of CiViC (Van Lier et al., 2017) and MiMiC (Brusselaers et al., 2019). The common aim of these projects was to minimise the disruption caused by construction-related transport to the surrounding communities and to optimise energy efficiency.

Table 6. CiViC and MiMiC stakeholders' objectives

Stakeholder group	Criteria
Residents	Safety
	Noise
	Emissions
	Dust
	Accessibility of home
	Accessibility of public transport
	Construction time
Local government	Level of responsibility

	Enforceability of measures
	Impact on voters
	Construction time
Contractor and utility companies	Construction time
	Costs
	Accessibility of construction site
	Safety
	Allowed working space
Institutions and companies	Accessibility for employees
	Accessibility for clients
	Accessibility for suppliers/services
	Safety
	Air pollution
Transport infrastructure users	Connectivity losses
	Time losses
	Safety
	Construction time

Finally, Table 7 presents the selected stakeholders and the objectives identified for the EU project of Mobility4EU (Keseru et al., 2017). The aim of the project was to deliver a vision of user-centeredness and cross-modality for the European passenger and freight transport system in 2030 as well as an Action Plan that aims to implement that vision.

Table 7. Mobility4EU stakeholders' objectives

Stakeholder group	Criteria
Terminal infrastructure operators	• Security of terminal infrastructure (against terrorism and crime) • Environmental impact of terminal infrastructure and operations (CO_2 emissions, air pollution and noise) • Level of utilization of existing capacity • Contribution to social sustainability (satisfaction of employees) • Possibilities for growth and expansion • Economic efficiency (profitability) • Service quality for customers (accessibility, efficiency of handling freight and passengers) • Intermodal accessibility for customers
Network infrastructure operators	• Cost of operations and maintenance • Service quality for transport users • Traffic safety • Level of utilization of existing capacity • Resilience of network infrastructure • Environmental impact of transport infrastructure • Lifetime of infrastructure • Efficiency of operation and maintenance

Private vehicle manufacturers	• Market share of company • Safety of vehicles produced • The company's contribution to social sustainability • Economic efficiency • The company's contribution to environmental sustainability • Quality of products and services
Public transport vehicle manufacturers	• Market share of company • Safety of vehicles produced • The company's contribution to social sustainability • Economic efficiency • The company's contribution to environmental sustainability • Quality of products and services
IT/ITS solution developers	• Traffic safety in the transport system • Availability of real-time information for travellers and transporters • The company's contribution to environmental sustainability • Market share of company • Economic efficiency
Passenger service operators	• Economic efficiency • Reliability of service • Level of integration with other transport modes • Safety of operations 23.84% • Security in vehicles, stations and stops 18.84% • Customer satisfaction (with service frequency, on-board services) 15.81% • Level of accessibility for disabled and elderly persons 12.23%
Representatives of disabled and/or older transport users	• Cost of the use of transport infrastructure and public transport • Level of accessibility to public transport by disabled and elderly • Ease of access to travel information in formats suitable for people with disabilities • Safety during travel • Level of accessibility of everyday services and facilities without special assistance
Representatives of public transport passengers	• Cost of the use of transport infrastructure and services • Travel comfort in vehicles and at stations • Time spent on travel • Level of privacy of personal data • Ease of access to reliable, real-time travel information • Easy and integrated payment and booking for services and user charges • Capacity of infrastructure and services to satisfy demand • Accessibility to jobs, services and leisure
Representatives of pedestrians and/or cyclists	• Accessibility of public transport stations by walking and cycling • Accessibility of everyday services and facilities by walking and cycling • Traffic safety • Crime and fear of crime in streets • Walkability and availability of bicycle friendly infrastructure • Traffic noise • Air quality

Shippers of goods	• The company's contribution to social sustainability • Cost of deliveries • Security of delivery of goods • The company's contribution to environmental sustainability • Capacity of goods delivery channels • On-time and complete delivery of goods
Freight service operators	• The company's contribution to social sustainability • Economic efficiency • Level of integration with other transport modes • Customer satisfaction • The company's contribution to environmental sustainability
Local policy makers, transport authorities	• Level of integration of transport modes • Land consumption of transport infrastructure • Air quality • CO2 emissions • Traffic safety • Accessibility of the population to jobs, services and education • Level of participation of citizens in decision making • Health of citizens
National or regional policy makers	• Health of citizens • Cost of operation and maintenance of transport infrastructure • Resilience of transport infrastructure • Traffic safety • CO2 emissions • Economic growth (GDP) • Accessibility of the population to jobs, services and education
Future generation	• Availability of internet connectivity on vehicles and at stations • Flexibility in choosing transport modes and operators • Reliability of transport services • Ease of access to reliable, real-time travel information • Availability of environmentally friendly travel options
Car drivers	• Time spent on travel to access jobs, education, services and shopping • Level of privacy of personal data • Capacity of infrastructure and services to satisfy demand • Travel comfort in vehicles • Easy and integrated payment and booking for services and road or parking charges • Cost of the use of transport infrastructure • Ease of access to reliable, real-time travel information

Previous experience from EU projects has also been useful in selecting the appropriate procedures and methodologies for assigning priority weights to criteria and for comparing the different alternatives. Table 8 presents the methodologies of selected EU projects that were thoroughly examined.

Table 8. Multi-Criteria Decision Analysis methodologies followed by previous EU projects

EU project	Weights assignment	MCDA methodology
Mobility4EU	AHP	PROMETHEE
LOOPER	AHP	PROMETHEE
Drive2theFuture	1-100 score	TOPSIS
CiViC	AHP	PROMETHEE
MiMiC	AHP	PROMETHEE
STRAIGHTSOL	AHP	PROMETHEE
CityLab	Used the weights of STRAIGHTSOL	AHP

The review of the literature and relevant previous EU experience resulted in the identification of the observed strengths and limitations of the methodologies already used in group decision making processes. This understanding of existing approaches led to the design of the DIT4TraM approach for performing the impact assessment. The proposed methodology is thoroughly described in the next section.

3. DIT4TraM approach

New traffic management strategies aim to offer the most appropriate trade-offs among a variety of performance areas (e.g., capacity, safety, environment) and balance between individual versus collective needs, which highlights the need to follow a decision analysis approach which incorporates multiple actors and multiple criteria. Therefore, the framework of Multi-Actor-Multi-Criteria-Analysis (MAMCA) is chosen as the most appropriate approach.

In the DIT4TraM project, the traffic management solutions that will be developed are intended not only to relieve the network from congestion, but also to meet additional objectives set by the different stakeholders in each case study. It can therefore be seen how the involvement of stakeholders is considered necessary to identify these objectives and, in addition, to explore their perception on the importance of the impact assessment criteria and the corresponding Key Performance Indicators (KPIs). Key performance indicators (KPIs) measured by pilots and simulations will be prioritised within each criterion with a subjective assessment by the stakeholders.

The evaluation process is summarised through the framework presented in Figure 3. The stakeholders will evaluate criteria and the performance of the scenarios regarding these criteria through the MAMCA approach. Meanwhile, for each criterion, as an exhaustive list of KPIs was developed, KPIs will be prioritised. Through the prioritisation, weights are assigned to the KPIs. In a last instance, the measurements from the pilots and simulations will provide measurements for the specified KPIs.

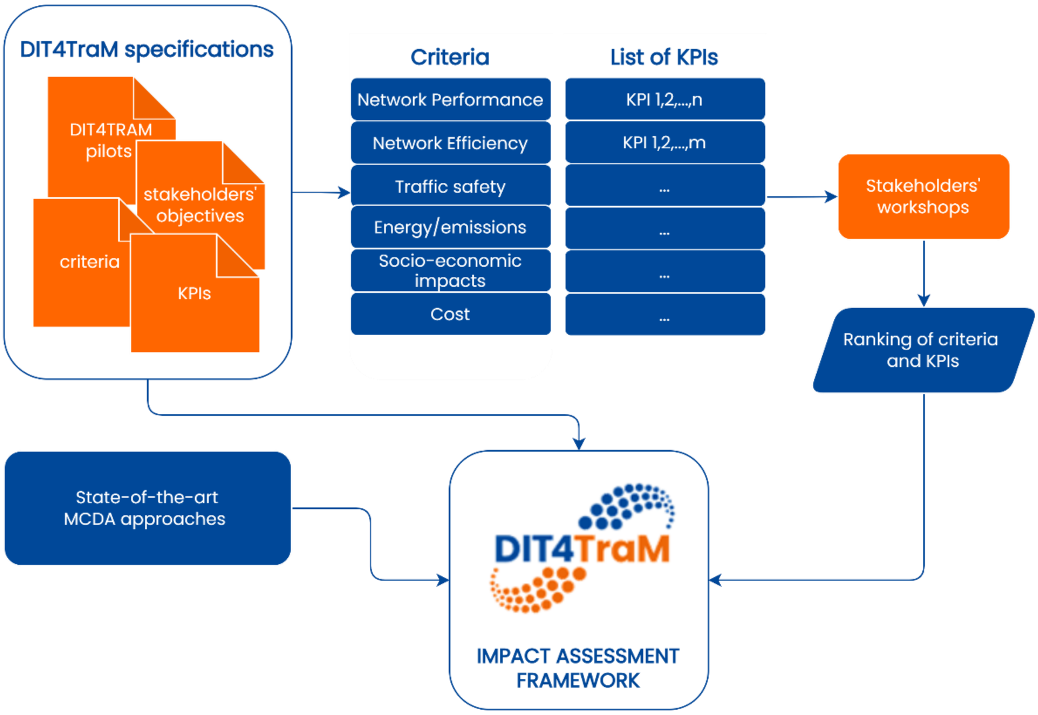

Figure 3. DIT4TraM Impact Assessment Framework

In order to collect the necessary input from the project stakeholders (see 3.2), a 2-round survey was distributed among them. Within the first round of the survey, stakeholders were asked to state the different objectives they had around the DIT4TraM project pilots as well as to propose Key Performance Indicators that they believed that should be measured. Many of the objectives and KPIs already identified from the literature, as well as from previous EU projects, were given as choices in the survey so that stakeholders were only requested to adapt the proposed structure to suit their needs and the needs of the DIT4TraM pilots. Subsequently, during the second round of the survey, they were asked to prioritize the previously identified objectives and relative KPIs using pair-wise comparisons and 0-100 score assignments. A more detailed description of the survey can be found in Chapter 4.

3.1 Scenarios

The first step when conducting a multi-actor multi-criteria analysis is to define alternatives. The alternatives for each pilot analysis will be at least the business as usual (BAU) and the proposed DIT4TraM solution. Different scaling of the proposed DIT4TraM concepts can also lead to multiple other scenarios. The scaling might imply geographical extension or increased operational efficiency. The BAU alternative will be considered as the status quo or baseline alternative.

The scenarios will be generated by DIT4TraM partners taking into consideration the opinions of the stakeholders (see 3.2).

3.2 Stakeholders

Once the problem definition is set and the alternatives have been identified, the following step is to identify stakeholders. All the stakeholder groups who are likely to be influenced either directly or indirectly by the implementation of the proposed alternatives should be included. In order to understand the objectives of all these different groups, a survey was shared among multiple stakeholders from all the pilot sites. The results of this survey are presented in the next section.

Before the survey was circulated, the following distinction of stakeholder groups was created to serve the purpose of a common framework between pilots:

- Authorities
- Operators
- Mobility providers and transport companies
- Industry
- Users

However, at a local level, pilot leaders are welcome to adjust the stakeholder structure to better reflect their pilot needs. For example, they could make a further distinction between users that are mainly using their car for their daily mobility needs and users that are using public transportation or soft modes. Also, they could disregard a stakeholder group if it is not relevant to their pilot. Stakeholder groups should be homogeneous in the sense that the different stakeholders within the group should have the same objectives. Their priorities and weights could differ a little, so the weights given by the different members of a stakeholder group will be aggregated.

A critical issue that arises, is the assignment of importance weights between the stakeholder groups. Some could argue that satisfying some stakeholder groups should be more important than satisfying others. However, in MAMCA evaluations, all stakeholders are usually considered as equals. In any case, it is up to the decision maker to value the importance of each stakeholder group and the purpose of MAMCA is to present all the trade-offs that should be considered.

For the identification of the stakeholders in each pilot site, stakeholder participation forms were shared among the DIT4TraM partners. The partners were asked to include as many stakeholders per stakeholder group as possible and fill their contact info. These local stakeholders were later contacted (step 4) through online surveys to provide input for the weighting of the multiple criteria.

3.3 Objectives, criteria and KPIs

The most common objectives among each stakeholders' group, as stated in the survey, were then translated into criteria and KPIs. These were discussed with the stakeholders and were finally determined by all the academic, industrial and governmental DIT4TraM partners. Previous experience from other EU projects was also leveraged.

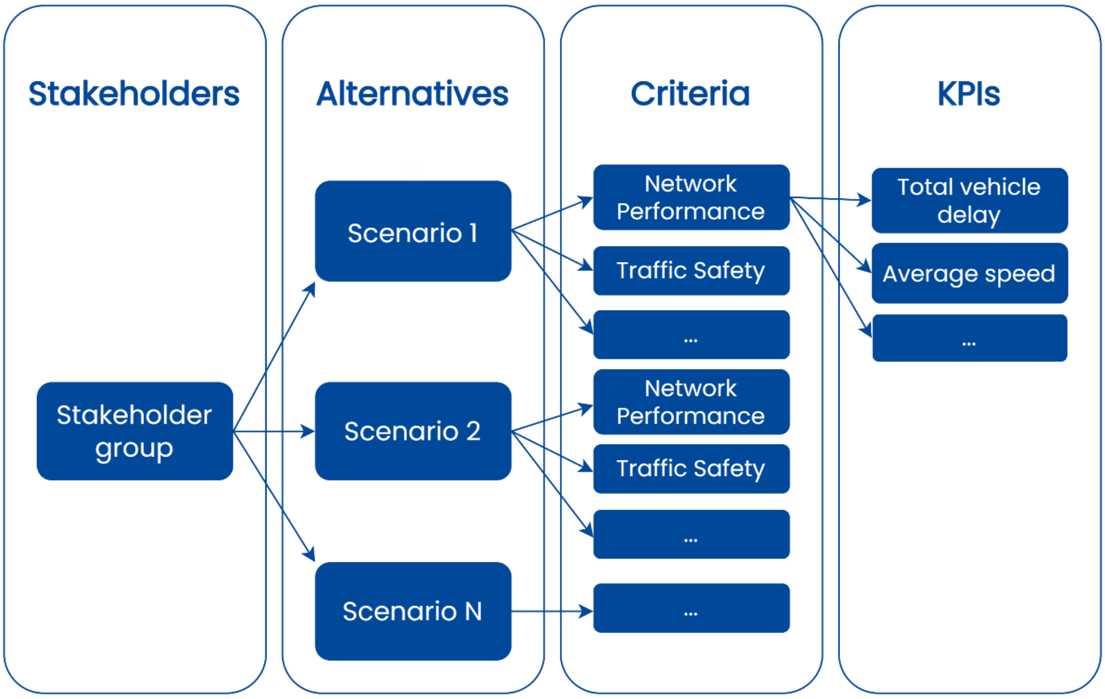

Figure 4. The process of the impact assessment

The DIT4TraM impact assessment framework distinguishes between two main categories of criteria; quantitative and qualitative. The first relates to measurable and quantifiable effects, or direct monetary effects, while the latter describes effects that are better defined in terms of quality rather than quantity. The performance of these effects is still evaluated in numbers; however, these numbers are assigned to them by experts and are not measured during the pilots.

3.4 Weights

The weighting of the criteria was derived by online surveys. In these surveys, local stakeholders of each pilot were asked to compare the importance of criteria (e.g., safety, socio-economic etc.), two at a time, through pairwise comparisons. Analytic Hierarchy Process (AHP) (Saaty, 1987) converted these evaluations into subjective criteria weights for every group of stakeholders. When multiple KPIs were associated to one criterion, stakeholders were asked to assign these KPIs with a score between 0 and 100 (Simple Multi Attribute Rating Technique) (Edwards, 1977) so that their global weights could be calculated.

3.5 Multi-criteria method

In this step, the impact of alternatives on the stakeholders is evaluated through the use of an appropriate MCDA methodology. Numerous methodologies are suited to fit the MAMCA but within DIT4TraM, the methodology of TOPSIS (Hwang & Yoon, 1981) which stands for 'Technique of Order Preference Similarity to the Ideal Solution' was selected. The criteria weights calculated in the previous step will be used within TOPSIS, along with the performances of the scenarios in the different KPIs, in order to create a complete ranking of the acceptance of the proposed use cases for every stakeholder group (for each pilot).

The TOPSIS method requires minimal user input and its output is easily interpretable. The only subjective parameters are the weights associated with the criteria. It has been successfully performed multiple times in transport related decision-making problems in the past (Broniewicz & Ogrodnik, 2020). A short description of the methodology by Ishizaka & Nemery (2013) can be found next.

"The fundamental idea of TOPSIS is that the best solution is the one which has the shortest distance to the ideal solution and the furthest distance from the anti-ideal solution. For example, in Figure 5, where both criteria are to be maximised, alternative B is closer to the ideal solution than A and further from the anti-ideal solution if the criteria weights are equivalent. As a result, TOPSIS presents alternative B as a better solution than alternative A.

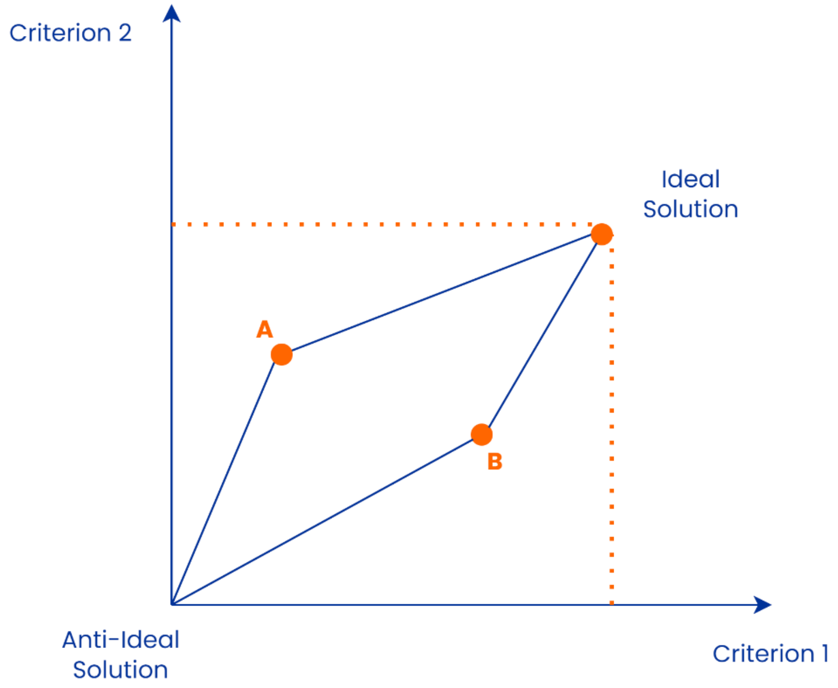

Figure 5. TOPSIS methodology (Ishizaka & Nemery, 2013)

The TOPSIS method is based on five computation steps. The first step is the gathering of the performances of the alternatives on the different criteria. These performances need to be normalised in the second step. The normalised scores are then weighted and the distances to an ideal and anti-ideal point are calculated. Finally, the closeness is given by the ratio of these distances. These five steps are explained in more detail below.

The performances of n alternatives a with respect to m criteria i are collected in a decision matrix X = (X_{ia}) as in where i = 1, . . ., m and a = 1, . . ., n.

1. *The performances of the different criteria are normalised in order to be able to compare the measure on different units (e.g., dollars, minutes, etc.). Several normalisation methods can be found for this purpose, but the most common one is the distributive normalisation that requires the performances to be divided by the square root of the sum of each squared element in a column.*

$$r_{ia} = \frac{x_{ia}}{\sqrt{\sum_{a=1}^{n} {x_{ia}}^2}}, for\ a = 1, \dots, n\ and\ i = 1, \dots, m \quad (1)$$

2. *Now the weights are taken into account. A weighted normalised decision matrix is constructed by multiplying the normalised scores r_{ai} by their corresponding weights w_i*

$$v_{ai} = w_i \cdot r_{ai} \quad (2)$$

3. *The weighted scores will be used to compare each action to an ideal (zenith) and anti-ideal (or nadir or negative ideal) virtual action. There are three different ways of defining these virtual actions.*
    a. *By collecting the best and worst performance on each criterion of the normalised decision matrix.*
        i. *For the ideal action we have*

$$A^{+} = ({v_1}^{+}, \dots, {v_m}^{+}) \tag{3}$$

        ii. *and for the anti-ideal action*

$$A^{-} = ({v_1}^{-}, \dots, {v_m}^{-}) \tag{4}$$

    b. *Assuming an absolute ideal and anti-ideal point, which are defined without considering the actions of the decision problem,*

$$A^{+} = (1, \dots, 1) \tag{5}$$

and

$$A^{-} = (0, \dots, 0) \tag{6}$$

    c. *The ideal and anti-ideal points are defined by the decision maker. These points must be between the ideal and anti-ideal points calculated with the two other methods explained above.*

4. *Calculate the distance for each action to the ideal action*

$${d_a}^{+} = \sqrt{\sum_i ({v_i}^{+} - v_{ai})^2}\ , a = 1, \dots , m \tag{7}$$

And the anti-ideal action,

$${d_a}^{-} = \sqrt{\sum_i ({v_i}^{-} - v_{ai})^2}\ , a = 1, \dots , m \tag{8}$$

We usually calculate the Euclidean distance; however, another distance metric could also be adopted (e.g., Manhattan or any Minkowski distance).

5. *Calculate the relative closeness coefficient of each action:*

$$C_a = \frac{{d_a}^{-}}{{d_a}^{+} + {d_a}^{-}} \tag{9}$$

The closeness coefficient is always between 0 and 1, where 1 is the preferred action. If an action is closer to the ideal than the anti-ideal, then

C_a approaches 1, whereas if an action is closer to the anti-ideal than to the ideal, C_a approaches 0."

3.6 Inputs and outputs

Summing up, in order to clarify the described process, we define the inputs and outputs of the proposed approach. The DIT4TraM framework requires inputs at 3 different levels:

- Identification of objectives and KPIs
- Prioritization of objectives and KPIs through weight assignments
- Performances of alternatives based on KPI measurements

The first two levels of inputs come from the stakeholder consultation process, while the latter is based on actual measurements in the pilots.

The output of the DIT4TraM framework will be a figure -similar to that of Figure 2- for every pilot, containing the TOPSIS evaluation scores of each alternative per stakeholder group. The overview of this figure will provide a complete comparison of the different alternatives and will support the decision-maker in making their final decision by highlighting for each stakeholder the elements that have a clear positive or clear negative impact on the sustainability of the alternatives considered (Macharis et al., 2009).

4. Initial Survey results

4.1 Survey description

The survey was conducted in two rounds. The aim of the first round was to identify all the different goals of stakeholders regarding the DIT4TraM project pilots and the Key Performance Indicators needed to be measured. Subsequently, on the second round of the survey, the local stakeholders around the cities of DIT4TraM pilots were asked to prioritize the different objectives and assess the relative Key Performance Indicators according to their organizations' objectives. The survey was addressed to representatives from public and private operators, service providers, transport network companies, MaaS platforms, other enterprises in the wider industry, as well as authorities from countries of European Union with a greater focus on the stakeholders operating in DIT4TraM pilot cities.

In the first round of the survey, all stakeholders were asked to indicate the areas of impact that they believed were relevant to the pilot(s) of their interest and then to indicate the goals of their organization regarding these areas of impact as well as to propose the Key Performance Indicators that they believed were the most appropriate to measure. As areas of impact, we considered network performance, network efficiency, traffic safety, energy/environment, socio-economic and cost. In the second round of the survey, the stakeholders were asked to prioritize the previously defined criteria and indicators according to how important they were to their organizations using Analytic Hierarchy Process and 0-100 scoring technique.

The questionnaires of both rounds of the survey can be found in Appendix A and Appendix B respectively.

4.2 Objectives and Key Performance Indicators

An overview of the stakeholders' objectives as well as the defined KPIs can be seen in Table 9. As already mentioned, the framework is flexible and the structure can be adjusted during the local evaluations.

Table 9. KPIs for different impact assessment criteria

IMPACT ASSESSMENT KPIs								
Network Performance	**Unit**	**Network Efficiency**	**Unit**	**Traffic Safety**	**Unit**	**Energy/ Environment**	**Unit**	**Soci econo**
Passenger throughput (Passengers served)	number of passengers ending their trips per hour	Average vehicle delay per trip	minutes/ trip	Accident frequency	number of accidents / vehiclekm	Emissions	g/ vehicle	Avera travel for u
Vehicle throughput (vehicles served)	number of vehicles ending their trip per hour	Average vehicle density	vehicles/ km	Accident severity	number of injuries and fatalities/ vehiclekm	Fuel consumption	lit/ 100km	Pub trans usag
Average speed per trip	km/h	Average passenger delay per trip	minutes/ trip	Number of conflicts	conflicts/ vehiclekm	Noise levels	dB	Sof mod usag
Average speed per segment	km/h	Average vehicle delay per intersection	sec/ vehicle	Speed variability	km/h			Jain fairn inde
Total Distance Travelled	km	Average passenger delay per intersection	sec/ passenger	Traffic violations	events/ vehiclekm			Over syste fairn
Utilization - vehicles	vehiclekm travelled	Congestion level	-					
Utilization - passengers	passengerkm travelled	Travel times variability	%					

Public Transport supply (in route-km or passenger-km) per hour	vehiclekm travelled	Vehicle occupancy	%					
		Resilience (response time to event)	minutes					

4.3 Weights

As of the time of submitting this first version of deliverable 8.1 (Month 12) the second round of the survey is still ongoing and valuable input from stakeholders around the DIT4TraM project pilots is being collected. Below, we present two summary tables containing the aggregated results (so-far) of all the stakeholders' KPI prioritizations, regardless of their pilot of interest. However, in the final submission of the deliverable (Month 30), these results will be presented per pilot and per stakeholder group. Table 10 presents the aggregated results of AHP criteria prioritization, while Table 11 presents the results of KPI prioritizations per criteria group (impact area). Global weights of each KPI are presented in Table 12.

Table 10 Criteria prioritization results

Criteria	Weights
Network Performance	16.4 %
Network Efficiency	22.1 %
Traffic Safety	33.6 %
Energy/emissions	15.8 %
Socio-economic	6.5 %
Cost	5.6 %

Table 11 KPI prioritization results

Network Performance		Network Efficiency		Traffic Safety		Energy/ Environment		Socio-economic		Cost	
Passenger throughput	15%	Average vehicle delay per trip	12%	Accident frequency	23%	Emissions	40%	Average travel cost for user	20%	Investment cost	48%
Vehicle throughput	11%	Average vehicle density	11%	Accident severity	23%	Fuel consumption	32%	Public transport usage	23%	Operating cost for the deployed system	52%
Average speed per trip	15%	Average passenger delay per trip	11%	Number of conflicts	18%	Noise levels	27%	Soft modes usage	21%		
Average speed per segment	13%	Average vehicle delay per intersection	9%	Speed variability	19%			Jain's fairness index	18%		
Total Distance Travelled	12%	Average passenger	10%	Traffic violations	17%			Overall system fairness	18%		

		delay per intersection									
Utilization - vehicles	11%	Congestion level	13%								
Utilization - passengers	11%	Travel times variability	12%								
Public Transport supply per hour	13%	Vehicle occupancy	11%								
		Resilience (response time to event)	11%								

Table 12 Global key performance indicators' weights

Network Performance		**Network Efficiency**		**Traffic Safety**		**Energy/ Environment**		**Socio-economic**		**Cost**	
Passenger throughput	2,47 %	Average vehicle delay per trip	2,65 %	Accident frequency	7,74 %	Emissions	6,30 %	Average travel cost for user	1,30 %	Investment cost	2,70 %
Vehicle throughput	1,81 %	Average vehicle density	2,43 %	Accident severity	7,74 %	Fuel consumption	5,04 %	Public transport usage	1,49 %	Operating cost for the deployed system	2,93 %
Average speed per trip	2,47 %	Average passenger delay per trip	2,43 %	Number of conflicts	6,06 %	Noise levels	4,25 %	Soft modes usage	1,36 %		
Average speed per segment	2,14 %	Average vehicle delay per intersection	1,99 %	Speed variability	6,39 %			Jain's fairness index	1,17%		
Total Distance Travelled	1,97 %	Average passenger delay per intersection	2,21 %	Traffic violations	5,72 %			Overall system fairness	1,17%		
Utilization - vehicles	1,81 %	Congestion level	2,87 %								
Utilization - passengers	1,81 %	Travel times variability	2,65 %								
Public Transport supply per hour	2,14 %	Vehicle occupancy	2,43 %								
		Resilience (response time to event)	2,43 %								

5. Conclusion

The impact assessment framework formulated in this deliverable aims to provide a consistent and inclusive approach for evaluating the impacts of DIT4TraM management paradigm in cities. Any transport-related initiative can only be successful if it is supported by all stakeholders and, therefore, the evaluation framework had to take into account the objectives and needs of all the different stakeholder groups. For this reason, the framework utilizes Multi-Actor Multi-Criteria Analysis (MAMCA), which can be seen as an extension of traditional Multi-Criteria Analysis (MCA), explicitly taking all stakeholders' opinions into account. Within this report, the first three steps of the MAMCA are described: i) definition of stakeholders, ii) identification of stakeholders' criteria and iii) prioritization of criteria.

Five stakeholder groups were identified based on an extensive literature review, primarily on previous EU projects, and input from DIT4TraM partners:

- Authorities
- Operators
- Mobility providers and transport companies
- Industry
- Users

For each of these stakeholder groups, a set of criteria and KPIs was determined based on a survey circulated among DIT4TraM pilot cities' stakeholders. The Analytic Hierarchy Process (AHP), which is based on pairwise comparisons, as well as 0-100 weighting were the tools used to derive the global weights of Table 12.

The next step is the actual evaluation of the impact of the different DIT4TraM solutions that will be produced after the pilots' implementations. These evaluations will be based on the defined stakeholders' criteria using the TOPSIS methodology, as described in 3.5. Consequently, the final ranking of alternatives for each stakeholder group will be derived and the optimal solutions will be identified.

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Appendix A

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DIT4TraM - Identifying Stakeholders' goals

Organization Info

Organization: ____

Name and Surname of Representative: _____________________________

E-mail: _______________ Role inside the organization: _______________

What is the type of the organization? (Please choose the option that best represents the entity)

- Operators (TMCs, Public Transport)
- Transport network companies, MaaS platforms, service providers
- Authorities (Cities, Regions, Policy makers etc.)
- Industry
- Users
- Other ____

My organization is interested in the pilot(s) of: (Select all that apply)

- Bordeaux, France
- Utrecht, the Netherlands
- Amsterdam, the Netherlands
- Glyfada, Greece
- Athens, Greece
- Med. Highway, Spain
- Not related to a single DIT4TraM pilot - Interested in all pilots

Stakeholder goals

1. For your pilot(s) of interest, please indicate the impact areas that you believe that are relevant. (You can select more than one)
   - Network Performance
   - Network Efficiency
   - Traffic safety
   - Energy / Environment
   - Socio – Economic

- Cost
- Other ____

2. Please indicate which of the following goals are relevant to your organization regarding Network Performance. (Choose all that apply)
    - Network Performance is of no interest to my organization
    - Reducing the delays of vehicles within the network
    - Increasing the speed of vehicles within the network
    - Decreasing congestion levels within the network
    - Other ____

3. Which of the following key performance indicators that should be used to measure the impact of the DIT4TraM solutions in your pilot(s) regarding Network Performance? (Choose all that apply)
    - Total vehicle delay per trip (minutes/trip)
    - Congestion level (actual traffic volume/ design capacity)
    - Average speed per trip (km/h)
    - Average speed per segment (km/h)
    - Vehicle delay per segment (minutes)
    - Other ____

4. Please indicate which of the following goals are relevant for your organization regarding Network Efficiency. (Choose all that apply)
    - Network efficiency is of no interest to my organization
    - Increasing the number of total vehicles served by the network in a specific timespan
    - Increasing the Level of Service of the network
    - Other ____

5. Which of the following key performance indicators should be used to measure the impact of the DIT4TraM solutions in your pilot(s) regarding Network Efficiency? (Choose all that apply)
    - Vehicles served (number of vehicles ending their trip during a timespan)
    - Vehicle density in congested roads (vehicles/km)
    - Utilization - vehicles (total vehicleskm traveled during a timespan)
    - Relative critical speed (%)
    - Throughput per point of interest (number of vehicles passing through a specific point during a timespan)
    - Other ____

6. Please indicate which of the following goals are relevant to your organization regarding Traffic Safety. (Choose all that apply)
   - Traffic safety is of no interest to my organization
   - Reducing accident frequency within the network
   - Reducing accident severity within the network
   - Reducing traffic measures' violations within the network
   - Other ____

7. Which of the following key performance indicators should be used to measure the impact of the DIT4TraM solutions in your pilot(s) regarding Traffic Safety? (Choose all that apply)
   - Accident frequency (number of accidents/vehiclekm)
   - Accident severity (number of injuries and fatalities/vehiclekm)
   - Conflicts (number of conflicts per type of conflict)
   - Speed distribution across lanes (km/h)
   - Traffic measures' violations (events/vehiclekm)
   - Other ____

8. Please indicate which of the following goals are relevant for your organization regarding Energy/ Environment. (Choose all that apply)
   - Energy/ Environment is of no interest to my organization
   - Reducing air pollution caused by vehicles
   - Reducing energy consumption of vehicles
   - Other ____

9. Which of the following key performance indicators should be used to measure the impact of the DIT4TraM solutions in your pilot(s) regarding Energy/Environment? (Choose all that apply)
   - Air pollution (Changing in air pollutants' levels (CO_2, CO))
   - Fuel consumption (lit/100km)
   - Other ____

10. Please indicate which of the following goals are relevant for your organization regarding Socio-Economic Impacts. (Choose all that apply)
   - Socio - Economic characteristics of the system are of no interest to my organization
   - Decreasing average travel cost for users
   - Increasing public transport usage

- Increasing soft modes usage (e.g., bikes, scooters, walking etc.)
- Other ____

11. Which of the following key performance indicators should be used to measure the impact of the DIT4TraM solutions in your pilot(s) regarding Socio-Economic Impacts? (Choose all that apply)
    - Average travel cost per user per trip (Euros/trip/user)
    - Percentage of trips conducted by public transportation (%)
    - Percentage of trips conducted by soft modes (%)
    - Other ____

12. Please indicate which of the following goals are relevant for your organization regarding Cost. (Choose all that apply)
    - Investment and operational costs are of no interest to my organization
    - Reducing investment costs
    - Reducing operational costs of the deployed system
    - Other ____

13. Which of the following key performance indicators should be used to measure the impact of the DIT4TraM solutions in your pilot(s) regarding Cost? (Choose all that apply)
    - Investment cost (Euros)
    - Operating cost for the deployed system (Euros)
    - Other ____

14. Please indicate additional goals (if any) you may have that you believe are relevant to the pilot(s) of your interest.

____
____

15. Please indicate additional key performance indicators (if any) that you believe that should be measured within the pilot(s) of your interest.

____
____

Thank you for participating!

Appendix B

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Prioritizing objectives and Key Performance Indicators

Organization Info

Organization: ____

Name and Surname of Representative: ____________________________

Role inside the organization: _____________________________________

What is the type of the organization? (Please choose the option that best represents the entity)

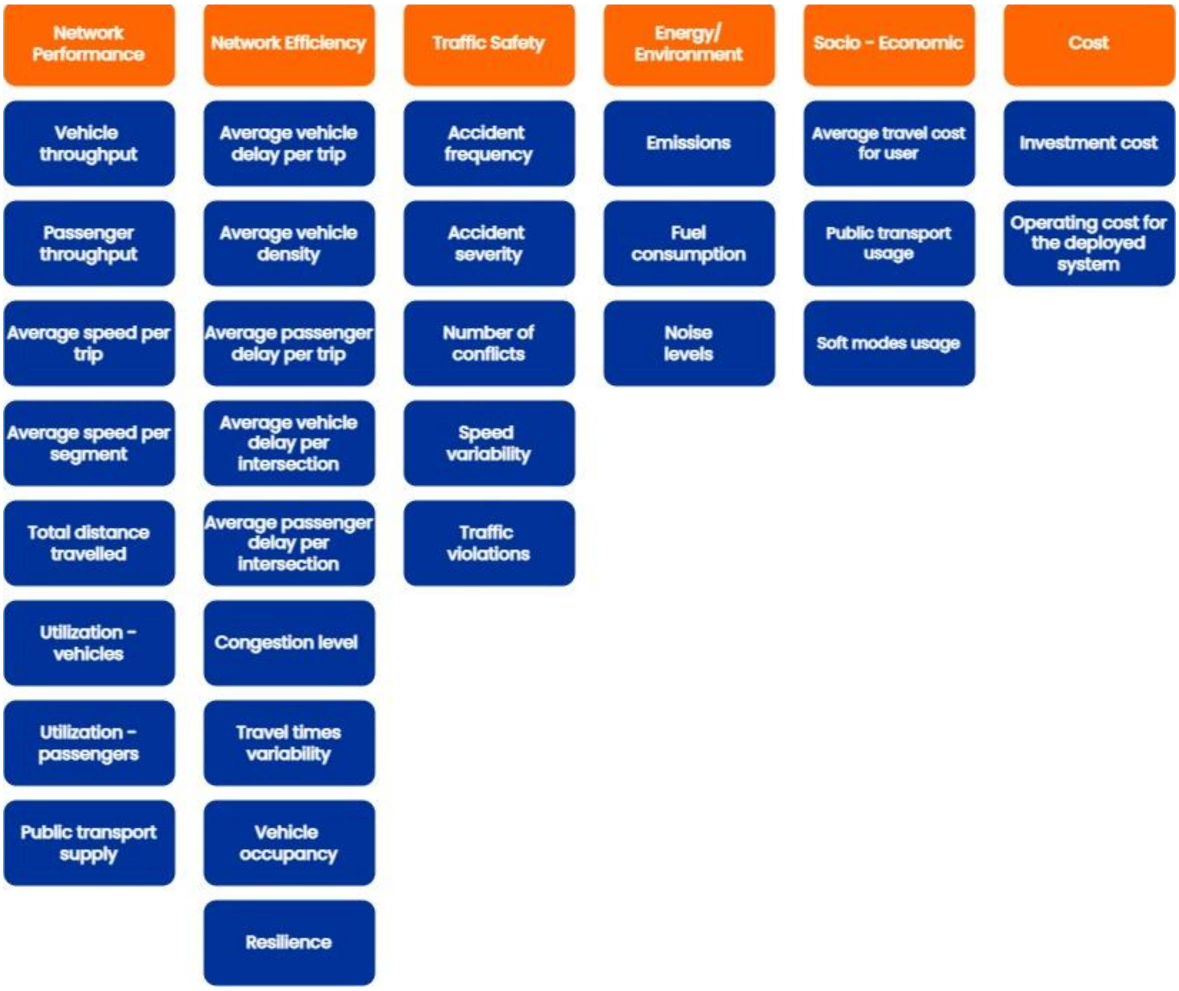
- Operators (TMCs, Public Transport)
- Transport network companies, MaaS platforms, service providers
- Authorities (Cities, Regions, Policy makers etc.)
- Industry
- Users
- Other ____

My organization is interested in the pilot of:

- Bordeaux, France
- Utrecht, the Netherlands
- Amsterdam, the Netherlands
- Glyfada, Greece
- Athens, Greece
- Med. Highway, Spain
- Not related to a single DIT4TraM pilot - Interested in all pilots

Survey Structure

The figure below shows an overview of the criteria and KPIs identified during the first round of the survey. In the next sections, you will be asked, first, to prioritize the criteria (orange rectangles) through pairwise comparisons and then, to prioritize the KPIs (blue rectangles) of each criterion by assigning a score on a scale 0-100.



Pair-wise comparisons of criteria (1/15)

Which is more important for your organization? (If equally important, choose an arbitrary one and answer the next question accordingly)

- Network Performance
- Network Efficiency

What is the strength of your preference of the selected criterion over the other?

Equal importance of both ○ ○ ○ ○ ○ ○ ○ ○ ○ Absolut preference of the selected one

Pair-wise comparisons of criteria (2/15)

Which is more important for your organization? (If equally important, choose an arbitrary one and answer the next question accordingly)

- Network Performance
- Traffic Safety

What is the strength of your preference of the selected criterion over the other?

Equal importance of both	O	O	O	O	O	O	O	O	O	Absolut preference of the selected one

Pair-wise comparisons of criteria (3/15)

Which is more important for your organization? (If equally important, choose an arbitrary one and answer the next question accordingly)

- Network Performance
- Energy / Environment

What is the strength of your preference of the selected criterion over the other?

Equal importance of both	O	O	O	O	O	O	O	O	O	Absolut preference of the selected one

Pair-wise comparisons of criteria (4/15)

Which is more important for your organization? (If equally important, choose an arbitrary one and answer the next question accordingly)

- Network Performance
- Socio - Economic aspects

What is the strength of your preference of the selected criterion over the other?

Equal importance of both	O	O	O	O	O	O	O	O	O	Absolut preference of the selected one

Pair-wise comparisons of criteria (5/15)

Which is more important for your organization? (If equally important, choose an arbitrary one and answer the next question accordingly)

- Network Performance
- Cost

What is the strength of your preference of the selected criterion over the other?

Equal importance of both	O	O	O	O	O	O	O	O	O	Absolut preference of the selected one

Pair-wise comparisons of criteria (6/15)

Which is more important for your organization? (If equally important, choose an arbitrary one and answer the next question accordingly)

- Network Efficiency
- Traffic safety

What is the strength of your preference of the selected criterion over the other?

Equal importance of both ○ ○ ○ ○ ○ ○ ○ ○ ○ Absolut preference of the selected one

Pair-wise comparisons of criteria (7/15)

Which is more important for your organization? (If equally important, choose an arbitrary one and answer the next question accordingly)

- Network Efficiency
- Energy / Environment

What is the strength of your preference of the selected criterion over the other?

Equal importance of both ○ ○ ○ ○ ○ ○ ○ ○ ○ Absolut preference of the selected one

Pair-wise comparisons of criteria (8/15)

Which is more important for your organization? (If equally important, choose an arbitrary one and answer the next question accordingly)

- Network Efficiency
- Socio - Economic aspects

What is the strength of your preference of the selected criterion over the other?

Equal importance of both ○ ○ ○ ○ ○ ○ ○ ○ ○ Absolut preference of the selected one

Pair-wise comparisons of criteria (9/15)

Which is more important for your organization? (If equally important, choose an arbitrary one and answer the next question accordingly)

- Network Efficiency
- Cost

What is the strength of your preference of the selected criterion over the other?

Equal importance of both	○	○	○	○	○	○	○	○	○	Absolut preference of the selected one

Pair-wise comparisons of criteria (10/15)

Which is more important for your organization? (If equally important, choose an arbitrary one and answer the next question accordingly)

- Traffic Safety
- Energy / Environment

What is the strength of your preference of the selected criterion over the other?

Equal importance of both	○	○	○	○	○	○	○	○	○	Absolut preference of the selected one

Pair-wise comparisons of criteria (11/15)

Which is more important for your organization? (If equally important, choose an arbitrary one and answer the next question accordingly)

- Traffic Safety
- Socio-Economic aspects

What is the strength of your preference of the selected criterion over the other?

Equal importance of both	○	○	○	○	○	○	○	○	○	Absolut preference of the selected one

Pair-wise comparisons of criteria (12/15)

Which is more important for your organization? (If equally important, choose an arbitrary one and answer the next question accordingly)

- Traffic Safety
- Cost

What is the strength of your preference of the selected criterion over the other?

Equal importance of both	○	○	○	○	○	○	○	○	○	Absolut preference of the selected one

Pair-wise comparisons of criteria (13/15)

Which is more important for your organization? (If equally important, choose an arbitrary one and answer the next question accordingly)

- Energy / Environment
- Socio - Economic aspects

What is the strength of your preference of the selected criterion over the other?

Equal importance of both	○	○	○	○	○	○	○	○	○	Absolut preference of the selected one

Pair-wise comparisons of criteria (14/15)

Which is more important for your organization? (If equally important, choose an arbitrary one and answer the next question accordingly)

- Energy / Environment
- Cost

What is the strength of your preference of the selected criterion over the other?

Equal importance of both	○	○	○	○	○	○	○	○	○	Absolut preference of the selected one

Pair-wise comparisons of criteria (15/15)

Which is more important for your organization? (If equally important, choose an arbitrary one and answer the next question accordingly)

- Socio - Economic aspects
- Cost

What is the strength of your preference of the selected criterion over the other?

Equal importance of both	○	○	○	○	○	○	○	○	○	Absolut preference of the selected one

Network Performance - KPIs prioritization (1/6)

For each of the below Key Performance Indicators, please assign a score ranging from 0 to 10 indicating the importance of this specific KPI for your organization.

- Passenger throughput (number of passengers ending their trips per hour)

○	○	○	○	○	○	○	○	○	○	○
0	1	2	3	4	5	6	7	8	9	10

- Vehicle throughput (number of vehicles ending their trip per hour)

○	○	○	○	○	○	○	○	○	○	○
0	1	2	3	4	5	6	7	8	9	10

- Average speed per trip (km/h)

○	○	○	○	○	○	○	○	○	○	○
0	1	2	3	4	5	6	7	8	9	10

- Average speed per segment (km/h)

○	○	○	○	○	○	○	○	○	○	○
0	1	2	3	4	5	6	7	8	9	10

- Total Distance Travelled (km)

○	○	○	○	○	○	○	○	○	○	○
0	1	2	3	4	5	6	7	8	9	10

- Utilization - vehicles (vehiclekm travelled)

○	○	○	○	○	○	○	○	○	○	○
0	1	2	3	4	5	6	7	8	9	10

- Utilization - passengers (passengerkm travelled)

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

- Public Transport supply (vehiclekm travelled)

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

Network Efficiency - KPIs prioritization (2/6)

For each of the below Key Performance Indicators, please assign a score ranging from 0 to 10 indicating the importance of this specific KPI for your organization.

- Average vehicle delay per trip (minutes/trip)

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

- Average vehicle density (vehicles/km)

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

- Average passenger delay per trip (minutes/trip)

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

- Average vehicle delay per intersection (seconds/vehicle)

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

- Average passenger delay per intersection (seconds/passenger)

O	O	O	O	O	O	O	O	O	O	O
0	1	2	3	4	5	6	7	8	9	10

- Congestion level

O	O	O	O	O	O	O	O	O	O	O
0	1	2	3	4	5	6	7	8	9	10

- Travel times variability (%)

O	O	O	O	O	O	O	O	O	O	O
0	1	2	3	4	5	6	7	8	9	10

- Vehicle occupancy (%)

O	O	O	O	O	O	O	O	O	O	O
0	1	2	3	4	5	6	7	8	9	10

- Resilience - response time to event (minutes)

O	O	O	O	O	O	O	O	O	O	O
0	1	2	3	4	5	6	7	8	9	10

Traffic safety - KPIs prioritization (3/6)

For each of the below Key Performance Indicators, please assign a score ranging from 0 to 10 indicating the importance of this specific KPI for your organization.

- Accident frequency (number of accidents/vehiclekm)

O	O	O	O	O	O	O	O	O	O	O
0	1	2	3	4	5	6	7	8	9	10

- Accident severity (number of injuries and fatalities/vehiclekm)

○	○	○	○	○	○	○	○	○	○	○
0	1	2	3	4	5	6	7	8	9	10

- Number of conflicts (conflicts/vehiclekm)

○	○	○	○	○	○	○	○	○	○	○
0	1	2	3	4	5	6	7	8	9	10

- Speed variability (km/h)

○	○	○	○	○	○	○	○	○	○	○
0	1	2	3	4	5	6	7	8	9	10

- Traffic violations (events/vehiclekm)

○	○	○	○	○	○	○	○	○	○	○
0	1	2	3	4	5	6	7	8	9	10

Energy/Environment - KPIs prioritization (4/6)

For each of the below Key Performance Indicators, please assign a score ranging from 0 to 10 indicating the importance of this specific KPI for your organization.

- Emissions (g/vehicle)

○	○	○	○	○	○	○	○	○	○	○
0	1	2	3	4	5	6	7	8	9	10

- Fuel consumption (lit/100km)

○	○	○	○	○	○	○	○	○	○	○
0	1	2	3	4	5	6	7	8	9	10

- Noise levels (dB)

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

Socio-Economic - KPIs prioritization (5/6)

For each of the below Key Performance Indicators, please assign a score ranging from 0 to 10 indicating the importance of this specific KPI for your organization.

- Average travel cost per user per trip (Euros/trip/user)

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

- Public transport usage (%)

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

- Soft modes usage (%)

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

- Jain's fairness index (variation of throughput) - suitable for intersections

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

- Overall system fairness (%)

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

Cost - KPIs prioritization (6/6)

For each of the below Key Performance Indicators, please assign a score ranging from 0 to 10 indicating the importance of this specific KPI for your organization.

- Investment cost (monetary value)

○	○	○	○	○	○	○	○	○	○	○
0	1	2	3	4	5	6	7	8	9	10

- Operating cost for the deployed system (monetary value/month)

○	○	○	○	○	○	○	○	○	○	○
0	1	2	3	4	5	6	7	8	9	10

Thank you for participating!

DIT4TraM

Distributed Intelligence & Technology
for Traffic & Mobility Management

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