

Article

Sustainable Mobility as a Service: Framework and Transport System Models

Antonino Vitetta

Dipartimento di Ingegneria dell'Informazione, delle Infrastrutture e dell'Energia Sostenibile,
Università degli Studi Mediterranea di Reggio Calabria, 89122 Reggio Calabria, Italy; vitetta@unirc.it

Abstract: Passenger mobility plays an important role in today's society and optimized transport services are a priority. In recent years, MaaS (Mobility as a Service) has been studied and tested as new integrated services for users. In this paper, MaaS is studied considering the sustainability objectives and goals to be achieved with particular reference to the consolidated methodologies adopted in the transport systems engineering for design, management, and monitoring of transport services; it is defined as Sustainable MaaS (S-MaaS). This paper considers the technological and communication platform essential and assumed to be a given considering that it has been proposed in many papers and it has been tested in some areas together with MaaS. Starting from the MaaS platform, the additional components and models necessary for the implementation of an S-MaaS are analyses in relation to: a Decision Support System (DSS) that supports MaaS public administrations and MaaS companies for the design of the service and demand management; a system for the evaluation of intervention policies; and also considers smart planning for a priori and a posteriori evaluation of sustainability objectives and targets.

Keywords: mobility as a service; sustainable mobility; transport system design



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1. Introduction

Passenger mobility plays an important role in today's society. Therefore, it is necessary to have more and more optimized transport services available for users.

(i) In recent decades transport services (individual and collective, private and public) have evolved, i.e.,: integration of the services offered in terms of fares and timetables; sharing of vehicles (bike sharing, car sharing, etc.) and services (transport flexibility, service on demand, etc.); information prior to travel (pre-trip) and during travel (en-route); technologies that characterize vehicles (type of traction, driving support systems, etc.) and infrastructures (control systems, smart road, etc.).

(ii) The evolution has also been driven by development of two strictly interconnected areas: Decision Support Systems (DSS), used mainly for the design of transport supply systems, for the management of user demand and for the decision support of operators adopting Transport System Models (TSMs); Intelligent and Communication Technologies (ICTs) mainly used for data collection in the transport system, information communication, construction of technology platforms and technologies on infrastructures and vehicles.

In recent years, a new sustainable transport for users has been proposed and tested in some real contexts [1,2], called Mobility as a Service (MaaS). A transport system with only one or more of the listed components, in terms of (i) evolution and/or (ii) areas is not a MaaS. MaaS requires user needs and components integrated in a system vision, as described in Section 2.

MaaS concerns transport services, starting from the existing services, and it can be implemented in a short time and can be immediately available to users. For this reason, in a few years, it will take on a high relevance and evolution.

In relation to the experience in Europe, in some cities, the service is active and in some other cities, a pilot experience has started. Some of these experiences are reported

in: [2] for Austria and Sweden, [3] for Finland, [4] for Germany, [5] for Italy, [6] for the Netherlands, [7] for Switzerland and [8] for the United Kingdom. At the end of 2021, the European Commission launched a call and cities can express their interest in joining the European Mission “100 Climate-Neutral and Smart Cities by 2030”. Further experiences are reported in [9] for Australia and [2] for Japan.

Referring to Italy:

- for the study of MaaS, a national research project involving universities and operators is supported, called “La Mobilità per i Passeggeri come Servizio–MyPasS” –“Mobility for Passengers as a Service-MyPasS”;
- a guideline is proposed for the development of MaaS in Italy [5];
- two calls were published, called “Maas for Italy”, for pilot MaaS in metropolitan cities (with the first call for proposals, three pilot projects were financed in the metropolitan cities of Milan, Naples and Rome; the second call is intended to finance a further three metropolitan cities).

Specific reference to transport models used for simulating and designing MaaS are reported in [10–14]. With reference to the bundle design and model calibration, some models and results are reported in [2,6].

Most of the papers related to MaaS focus on the MaaS platform and on the level of integration of the digital and ICT services available to users and operators. It has a rapid evolution considering it can be experienced with digital integration of real transport and ICT services.

On the other hand, the sustainable goals defined by the United Nations in the 2030 [15] agenda require the design of a user-oriented sustainable transport system; the goal is to move users in the best possible way instead of moving vehicles.

The innovations proposed in this paper are described below. Given the rapid evolution of MaaS and the need to achieve sustainability goals, a roadmap between now and 2030 is to be defined in terms of:

- A. definition of Sustainable MaaS (S-MaaS), starting from the current MaaS in order to achieve sustainable goals, without excluding all the present and indispensable digital and ICT evolutions;
- B. definition of Transport system models to enable the design of sustainable transport services for ex-ante and ex-post evaluations.

This paper aims to address the study of S-MaaS with particular reference to the consolidated methodologies used in the transport systems for the design, management and monitoring of the transport services. This work considers the technological and communication components indispensable for an S-MaaS and it starts from the assumption that the MaaS platform is given. In relation to the paper’s innovation, starting from the MaaS platform:

- A. the necessary developments for the construction of an S-MaaS are analyses within a general framework considering ICT, DSS and actors involved;
- B. the structure of a DSS that supports the MaaS public authorities and the MaaS companies for the design of the service and for the management of the demand (the specific insights are reported in [16,17]); an evaluation system of intervention policies for the a priori and a posteriori evaluation of sustainability objectives, targets and goals (the specific insights are reported in [18,19]).

The paper is divided into the following sections.

- A. In Section 2: The main actors involved in the S-MaaS are described (Section 2.1); a scale is introduced that can be adopted for the different types of MaaS in relation to the use of ICTs, transport models and sustainable development goals (more details are reported in Section 3) and an overall architecture that can be adopted for the design and management of a MaaS is reported in relation to the actors involved and the methods introduced (Section 2.2).

- B. Section 3 reports a specification of the design model for MaaS (Section 3.1), the main methods that can be adopted within the DSS (Section 3.2), the main policies to be adopted and the main planning methods to be used for the definition of a S-MaaS (Section 3.3), with some results obtained from interviews from a sample of users (Section 3.4).

Finally:

- in Section 4, the main challenges and opportunities with S-MaaS are described;
- in Section 5, the main discussions, conclusions and possible developments of the research are reported.

2. S-MaaS

The main definition of MaaS is reported in [20] and a recent definition is proposed by [9]. The MaaS requires at minimum:

- an integrated mobility service (individual or collective in terms of sharing, private or public considering transport operators, urban or extra-urban service in relation to the space distribution) aimed at achieving sustainability objectives, targets, goals and policies;
- an integrated digital platform for users and operators with ICT services (information, reservations, payments, monitoring, feedback, etc.);
- users at the center of the system with the availability of integrated mobility services and the integrated digital platform.

Fare and timetable integration or (only) the sharing of the vehicle or (only) the information to users or (only) the existing joint services cannot be considered MaaS. MaaS requires all the reported components available and is designed to meet user needs and to achieve sustainable goals with different levels of integration.

2.1. MaaS actors

MaaS involves different actors (Figure 1) which can be grouped into three sets [14]: PEople (PE), Public Authorities (PAs) and COmpanies (COs). A dictionary for MaaS is reported in [21].

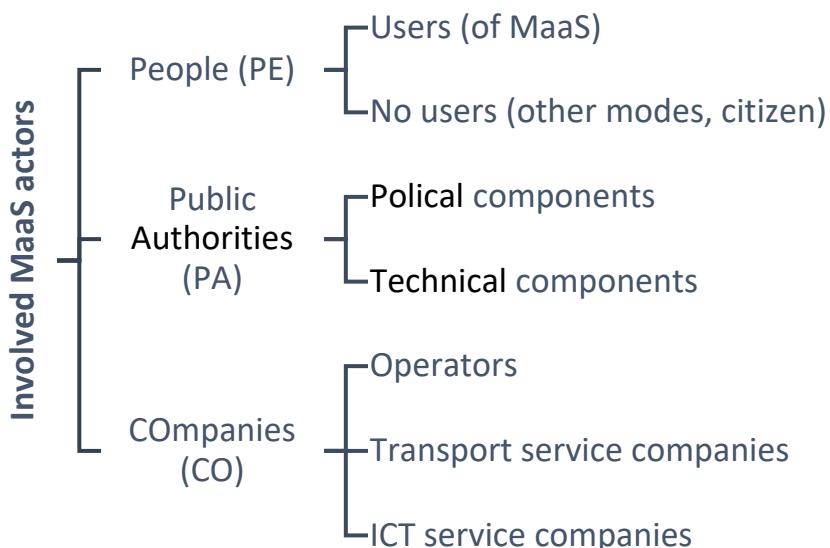


Figure 1. Involved MaaS actors.

PE can be users or non-users of the MaaS system. Non-users of the system can be users of services and modes of transport different than the MaaS system or citizens who do not use the transport system in the reference period of the analysis (i.e., residents who

do not travel for health reasons). It should be noted that the same person, based on the reference period, may belong to different categories (i.e., a person who moves through the MaaS system to go to the workplace and in the workplace plays a manager role in the MaaS system).

The PA is the public component that defines and verifies compliance with the overall operating rules of the system. The PA has two components: The *political component* that generally defines the objectives and goals (i.e., maximum level of pollutants, minimum level of services, minimum level of service, etc.); and the *technical component* that plans the system in the short, medium and long term, supports the political part in the decisions and connects the operators.

The COs can be composed of a large number of public and private companies and perform various functions: *operators* that integrate and provide the service to users, define the service contract and design and sell the transport product; *transport service companies* that perform transport services (individual and collective services, with private or public management) and design the specific service in accord to the operators; *ICT service companies* that provide ICT services (i.e., monitor and store data, provide information to users, etc.) in agreement with the operator and to the transport operators. Multiple services could be performed by the same operator.

2.2. From MaaS to S-MaaS

For the MaaS, some integration scales have been proposed by [22] considering the classification proposed in [23] and [24].

The scale proposed in [22], adapted from [23], considers the increasing level of integration:

- Level 0, No integration (single separate services);
- Level 1, Integration of information (multimodal travel planner, price info);
- Level 2, Integration of booking and payment (single trip-find, book and pay);
- Level 3, Integration of the service offer (bundling/subscription, contracts, ...);
- Level 4, Integration of societal goals (policies, incentives, ...).

Moreover, [22] propose a further scale starting from [24], which considers the decreasing level of cognitive efforts:

- Level 0, No integration (single separate services);
- Level 1, Basic integration (information integration across-some-modes);
- Level 2, Limited integration (as basic integration but also some operational and/or transactional integration);
- Level 3, Partial integration (some journeys offer fully integrated services);
- Level 4, Fully integration under certain circumstances (some journeys but not all modal options offer fully integrated service)
- Level 5, Fully integration under all circumstances (fully operational, transactional and informational integration across all modes for the journey).

The two scales can be considered jointly because the fully operational, transactional and informational integration in all travel modes has to be considered together with the design to achieve the goals and objectives of the sustainability policy.

The levels considered refer to: The integration of the services offered to users, as a minimum necessary condition for having a MaaS; the availability of ICT services; and to policies and incentives.

These classifications are valid but with reference to the purposes of this paper, a hypothesis on the evolution of MaaS is introduced that considers: The use of TSMs integrated with other models, the project and management according to sustainability objectives, targets and goals and the system acceptance by the users.

Before specifying the MaaS, with reference to the DSS, it can be noted that the PA and CO could make decisions even without the use of the DSS, based only on experience and skills. The decision without DSS cannot guarantee that it is the best one possible, even

considering that in some cases it could even be optimal. For this reason, a DSS is required to design an S-MaaS.

In this work, in relation to the methods adopted for the design of the management and monitoring of transport services in a sustainable context, a hypothesis on the evolution of MaaS is reported (Figure 2):

- (1) N-MaaS (No MaaS)
 - refers to single and separate systems, without transport integration;
- (2) MaaS 1.0 or I-MaaS (ICT MaaS)
 - (a) considers the integration of the service; (b) the availability of an ICT platform for operators and users;
 - (i) provides information and digital services in the integrated transport system;
 - different levels can be considered, according to levels 1–3 reported in [22,23] (i.e., MaaS 1.1 Integration of information, 1.2 Integration of booking and payment, etc.) or levels 1–5 reported in [22,24] (i.e., MaaS 1.1 Basic integration, MaaS 1.2 Limited integration, etc.);
 - in the future, the evolution of ICTs (i.e., 5G, 6G, see [25] and the references cited in the paper) will support the MaaS evolution also in T-MaaS and S-MaaS (defined in this list in the points 2 and 3) and new levels could be introduced;
- (3) MaaS 2.0 or T-MaaS (TSM and ICT MaaS) includes I-MaaS and in addition
 - (c) TSM adopted to design and manage the system with the DSS platform;
 - (ii) provides information and digital services in the integrated transport system and it has to be proactive in order to design the supply transport system and to manage travel demand; more details are reported in Section 3;
 - different levels can be considered (i.e., MaaS 2.1 Supply design, MaaS 2.2 Demand management, ...);
 - in the future, the evolution of ICTs and TSMs will support the MaaS evolution also in S-MaaS and new levels could be introduced;
- (4) MaaS 3.0 or S-MaaS (Sustainable, TSM and ICT MaaS) includes I-MaaS and T-MaaS and in addition
 - (d) the design and management of the system taking into account the sustainability objectives, targets and goals starting from the level 4 reported in [22,23] with Space Economic Transport Interaction (SETI) models [26] and Environmental Impact Functions (EIFs) [18];
 - (iii) controls the transport system in relation to the sustainable goal achievement; from the observed indicators obtained with ICT (MaaS 1.0) and a priori evaluation, the forecast indicators obtained with TSM (MaaS 2.0) can be adopted; more details are reported in Section 3;
 - different levels can be considered (i.e., MaaS 3.1 Policy evaluation; MaaS 3.2 Agenda 2030; MaaS 3.3 Smart planning);
 - in the future, the evolution of ICTs, TSMs, SETI and EIFs will support MaaS evolution and new levels could be introduced.

Considering the evolution over the centuries of collective transport services, it started in the sixteenth century with the introduction of the first regular service carried out by horse-drawn carriage with regular routes, fares and timetables. In the 19th century, new traction systems were introduced and the first rail transport services started. In the twentieth century, the integration of fares, services and vehicles was introduced and the first information was provided to users. Until the 20th century, there were non-integrated or lightly integrated transport services. A few years ago, MaaS was experimented and proposed to users (Figure 2). According to the sustainability development goals the S-MaaS could be completed by 2030.

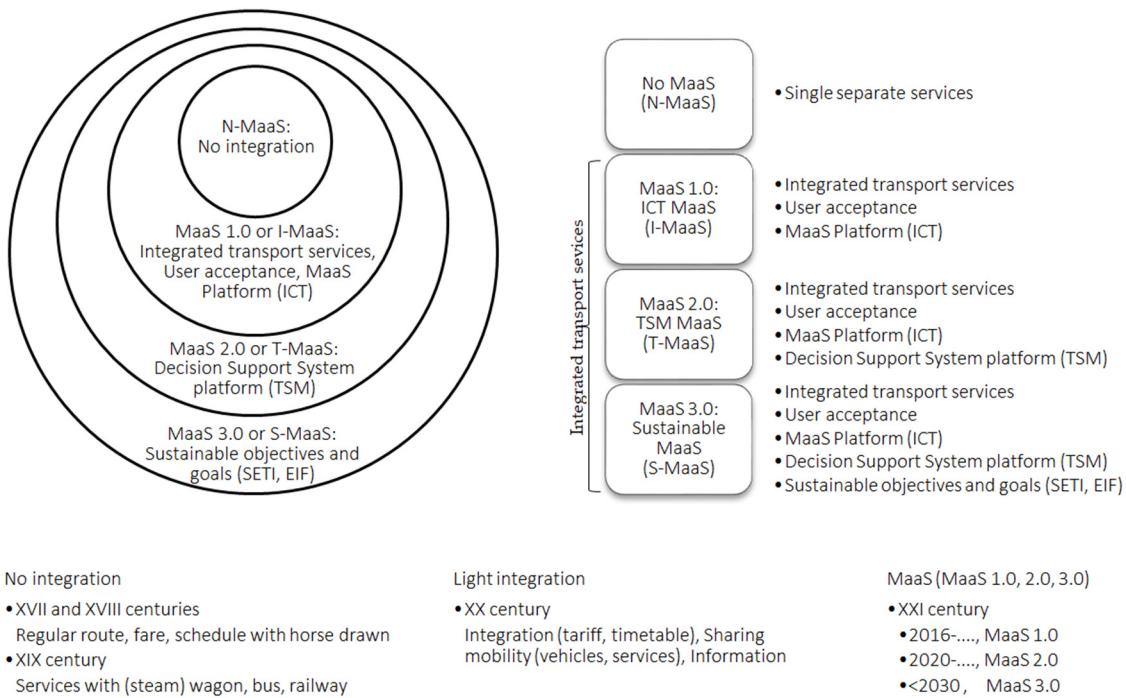


Figure 2. MaaS in relation to the integration, methods adopted for design, management and monitoring of the transport services.

3. Methods for MaaS

The contribution in this paper focuses on the methodologies applied in the transport systems engineering sector for the design and management of MaaS systems [14] described in [27] and also considers the evolution in transport models (i.e., sentiment [28] and quantum [29] models). The other components are also relevant for the proper functioning of a MaaS system; for these components, it can refer to numerous published papers (i.e., refs. [9,21,22,24]).

The MaaS is not a union of existing services and for this reason it must be designed, managed and monitored considering all the integrated transport services and taking into account the sustainability objectives and goals considering the users at the center.

The MaaS platform is defined by the information and technological structure used by the PAs and COs [21] to provide the final mobility service to end users (MaaS 1.0 or I-MaaS in Figure 2).

Analogous to the MaaS platform, a MaaS DSS is required. A MaaS DSS contains the TSMs used by PAs and COs to provide the supply design, demand management and system monitoring to achieve sustainability goals and targets. TSMs are needed to support PAs and COs in the processes of design (pre), management (during) and monitoring (post) of the transport system (T-MaaS and S-MaaS or MaaS 2.0 and 3.0).

Figure 3 reports an architecture of the whole method for MaaS 1.0, 2.0 and 3.0 considering the actors involved.

MaaS 1.0, 2.0 and 3.0 require transport services integration. MaaS 1.0 requires the availability of a digital MaaS platform. MaaS 2.0 requires the availability of a MaaS DSS, integrated with the MaaS platform; the MaaS DSS platform provides different methods available for PAs and COs (simulation and design methods; supply design and demand management, etc.). MaaS 3.0 requires the design of the entire system and considers the sustainable objectives and goals.

Each level of MaaS includes the previous levels: i.e., the technologies and methods adopted in the I-MaaS are included in the T-MaaS and in the S-MaaS. The technologies and techniques deriving from the ICT sector (artificial intelligence, digital twin, big data,

internet of things, block chain, etc.) are also relevant in the development of DSS considering that they can be applied together with TSMs for modelling user choice behavior.

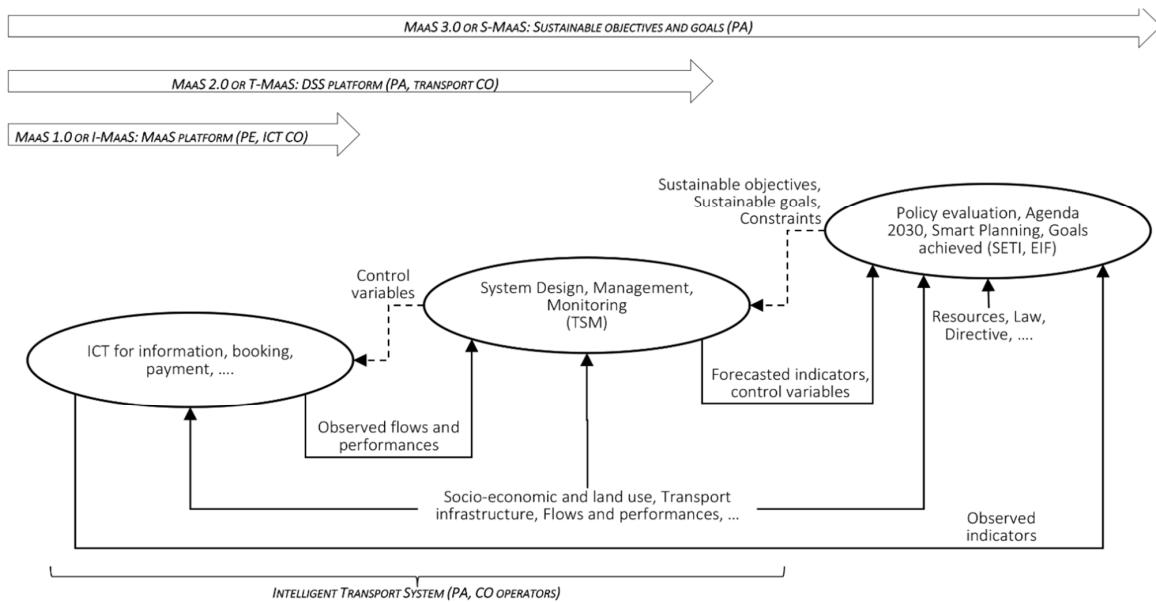


Figure 3. Architecture of MaaS 1.0, 2.0 and 3.0 and actors involved.

MaaS 1.0, 2.0 and 3.0 require a priori and a posteriori evaluation system to achieve the targets and goals; feedback on the goals, target and indicators relating to efficiency (MaaS 1.0 or I-MaaS), effectiveness (MaaS 2.0 or T-MaaS) and sustainable (MaaS 3.0 or S-MaaS) is required.

Considering the actors (PE, PA, CO):

- PE are involved in MaaS 1.0, 2.0 and 3.0; MaaS users are mainly interested in MaaS services (MaaS 1.0 and 2.0) and sustainable effects (MaaS 3.0); PE, not users of the MaaS system, are mainly interested in sustainable effects (MaaS 3.0);
- PAs are involved in MaaS 1.0, 2.0 and 3.0; the political components are mainly involved in MaaS 3.0; the technical components are mainly involved in the other levels;
- COs are involved in MaaS 1.0, 2.0 and 3.0; operators are involved in MaaS 1.0, 2.0, 3.0, considering that they manage the whole system; the COs of transport service are mainly involved in MaaS 2.0 and 3.0 as they produce and manage the transport services; ICT COs are mainly involved in MaaS 1.0 and 3.0 as they produce and manage individual ICT services.

3.1. Models

The design model is the core of the DSS and can be used in all activities (design, management, indicators evaluation, monitoring) in MaaS 2.0 and 3.0 (or T-MaaS and S-MaaS). More details related to the general formulation of the design models are reported in [14]. It can be specified as:

$$\left\{ \begin{array}{l} \text{Minimum}_{y,f}(\text{orMaximum}) \Phi(y, f) \\ (\text{y* is the value of y in the minimum point}) \\ \text{SUBJECT TO} \\ y \in \Psi_{ETy} & (\text{external and technical feasible sets for y}) \\ f \in \Psi_{ETf} & (\text{external and technical feasible sets for f}) \\ f \in \Psi_Bf & (\text{behavioural feasible set for f}) \\ f = \xi(f, y) & (\text{behavioural feasible constraints}) \end{array} \right. \quad (1)$$

with

- $\varphi(\bullet)$: The objective function to be minimized (or maximized) and defined with mono or multi-criteria specification (i.e., minimum travel time, minimum monetary cost for users, maximum accessibility, minimum pollutants); it is not a linear function;
- f : the vector of traffic flow in the links related to each service and mode; in each link, it has many components because it is multi-service and multi-modal with respect to the transport supply and the demand segmentation respectively;
- y : the vector of transport design (or control) variables, defined in term of system topology (i.e., network layout, transit routes), capacity (i.e., number and size of vehicles, junction regulation, parking space) and price (i.e., bundle, tickets) for each system element;
- Ψ_{ETy} : The feasible external and technical sets for y ; an example of an external constraint for the variable y is the maximum number of vehicles with a specific engine in relation to the environmental laws; an example of a technical constraint for the variable y is the maximum capacity of each vehicle; very often these constraints are specified with linear inequalities;
- Ψ_{ETf} : The external and technical feasible sets for f ; an example of an external constraint for the variable f is the maximum traffic flow in the links for each specific vehicles category and in relation to environmental laws; an example of a technical constraint for the variable f is the maximum capacity in each link; very often these constraints are specified with linear inequalities;
- Ψ_{ETf} the behavioral feasible sets for f ; it contains the conservation flow at junctions level, paths level, origin-destination level for all users' categories and all services and modes; very often these constraints are specified with linear inequalities;
- $\xi(\bullet)$: The loading flow function; it models the circular dependency of the flow vector f on the design variables y (cost and demand), cost and on the flow vector f [27]; in the system static evolution and in the stationary flow, it is modelled in terms of user equilibrium flows; in the day-to-day dynamic evolution (considering the evolution between stationary or non-stationary states or periods) and within-day evolution (considering the evolution inside a periods with macro, meso or micro approach), it is modelled with dynamic deterministic or stochastic processes; in congested transport systems, these constraints are specified with non-linear functions and/or inequalities.

The design output is the vector y^* . It is the value of the vector y at the minimum (or maximum) point of the objective function $\varphi(\bullet)$.

The same objective can have a different sign in relation to the actors involved (i.e., the increase in services improves the utility for the users and increases the costs for operators). For this reason, the problem must be solved by adopting a multi-criteria approach.

It should be noted that in an optimum model, some objectives and constraints can also be interchanged; i.e., a financial budget constraint can be transformed by considering the criterion that minimizes the financial resources and vice versa. The same can be done for constraints concerning the pollutant emissions.

3.2. Decision Support System Platform

The DSS platform refers to models, algorithms and methods to support PAs and COs for (Figure 4A):

- the a priori design of the service in relation to the sustainable objectives and goals, taking into account external, technical and behavioural constraints, using historical and observed data in real time (socio-economic and land use, transport infrastructures, expected flows and performance); the output of the design model is the expected control variables;
- the management of the system in real time by adopting the design models and available data; the outputs of the management model are the control variables in real time and

- the forecast indicators to be associated with the observed indicators obtained by the ICT;
- the system monitoring (efficiency, effectiveness and sustainability indicators); the output of the system monitoring are the observed and forecasted indicators.

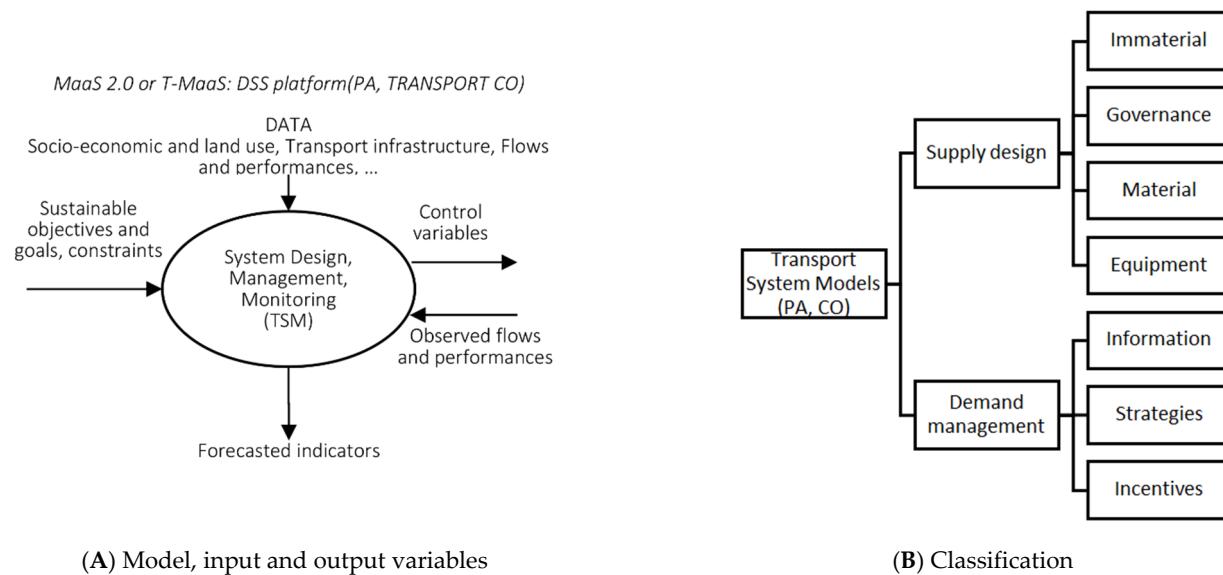


Figure 4. MaaS Transportation System Model platform (level 2, Intelligent MaaS).

Figure 4B, right side, shows a list of possible problems that can be addressed within a DSS. They are divided into problems mainly related to the supply design or to the demand management classes. The supply design is divided into immaterial, governance, material and equipment actions. The demand management is divided in information, strategies and incentives actions.

Problems mainly related to the supply design are explored in [16]. Problems mainly related to the demand management are explored in [17]. Other problems are related to vehicles energies consumption ([30,31]) and transit and dynamic optimal travel strategies simulation (i.e., ref. [32–35]). Starting from the passenger demand distribution (i.e., ref. [36]), a possible extension can also consider freight distribution (i.e., ref. [37,38]) in order to evaluate the effect of mixed passengers and freight flows on the roads.

3.3. Sustainable Objectives and Goals

The policy evaluation, Agenda 2030 (signed in 2015 by the governments of the 193 member countries of the United Nations) and smart planning refer to models, procedures and methods to support PAs and COs for the definition of (Figure 5A):

- sustainable objectives and targets in relation to public and private policies, taking into account external (i.e., law, directive, guidelines, etc.) and technical (i.e., budget, resources, etc.) constraints;
- target to be achieved and milestones with a different time horizon as well (i.e., short, medium, long term);
- activities and procedures to manage, verify and modify the activities in relation to the expected and observed indicators and the control variables.

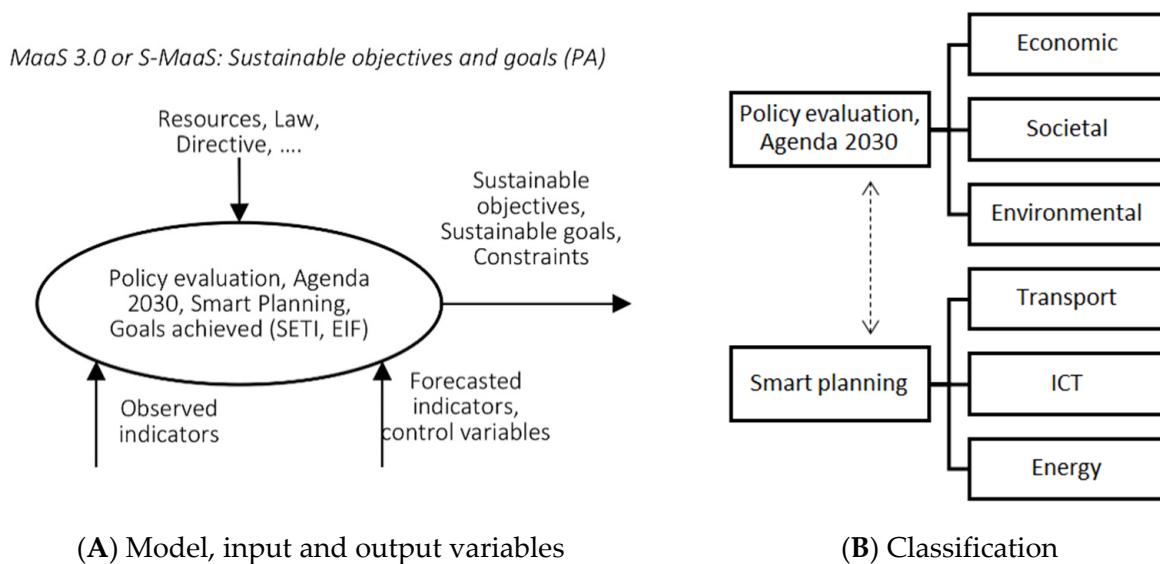


Figure 5. Sustainable objectives and goals and users acceptance (level 3, Sustainable MaaS; level 4, MaaS for Users).

Figure 5B, right side, shows a list of possible problems that can be addressed in the context of policy evaluation, the Agenda 2030, smart planning and the sustainable goal achieved. The policy evaluation and Agenda 2030 is divided into the three sustainable subsets: economic, environmental and social. The smart city is divided in three subsets: transport, ICT and energy.

Problems mainly related to the policy evaluation and Agenda 2030 are explored in the paper [18]. Problems mainly related to smart planning are explored in [19]. Models need to be extended by considering sequential models (i.e., ref. [39]) in TSMs and extending them to SETI and EIFs and urban planning of a smart city (i.e., ref. [40–42]).

3.4. A Case Study

The case study used to highlight the need to review transport services in MaaS logic refers to the area of the Strait of Messina (Figure 6).

Two metropolitan cities, Reggio Calabria and Messina are divided by a sea called the Strait of Messina, just over 3 km away at the closest point. Although close in the area, the transport systems of the two cities are different for many reasons. Some of these reasons derive from the following structure:

- there are seven PAs (Messina municipality and metropolitan city and Sicily Region for local mobility on Messina side; Reggio Calabria municipality and metropolitan city and Calabria Region for local mobility on the Reggio Calabria side; Central National Authority for long distance mobility on the sea);
- there are several transport service companies that carry out the service with separate management on road and rail, on the Calabria side and on the Sicily side, at urban, extra-urban and national levels; some of these companies perform the service with partial public financial support; some companies use a public business model and other companies use a private business model;
- there is a barrier between the two areas considering that there are only low frequency short sea transport services [43];
- in the area immediately behind the Strait of Messina, there are about 350,000 inhabitants and between the two mainlands there are about 20,000 journeys/day, in addition to the journeys that take place on each mainland (about half a million journeys/day).

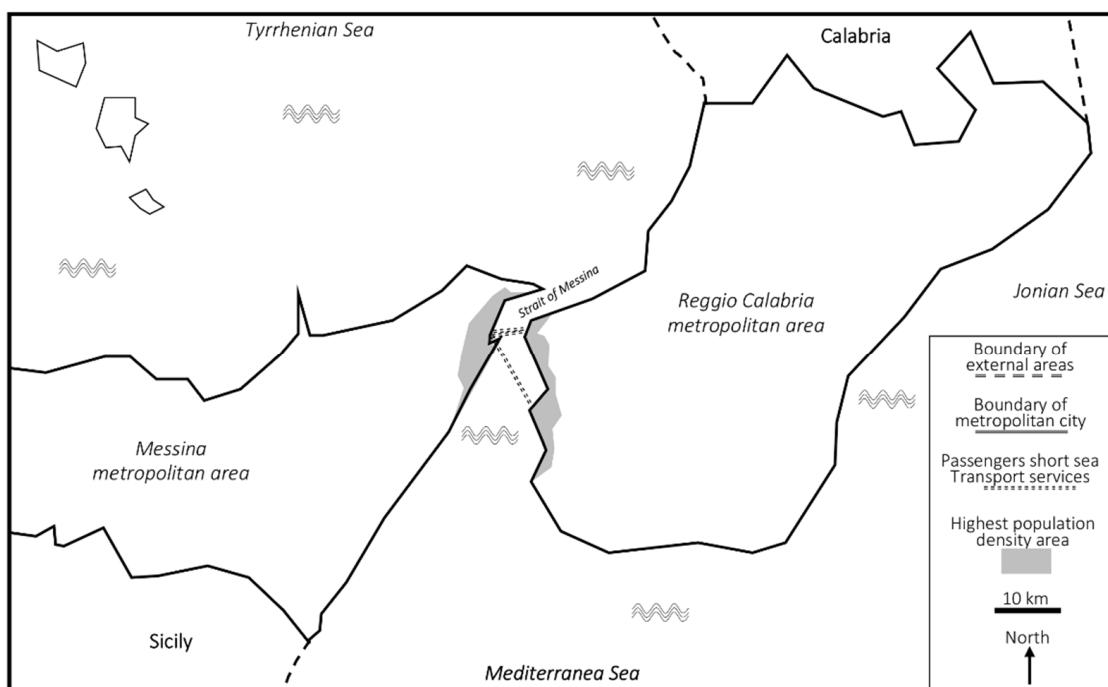


Figure 6. Strait of Messina: study area.

In this scenario, in the past, the attempts to integrate fares, timetables and services have not produced the desired results; for obtaining sustainable results, in the future, it should probably evolve from an integration of services towards a S-MaaS.

A pilot survey was carried out to test the satisfaction of a MaaS service in the strait area [44] within revealed preferences and stated MaaS preferences. The questions to users contained requests related to: user characteristics; the most frequent journey in the last week; preferences with respect to proposed scenarios and bundles in each proposed scenario. Four scenarios were proposed that represent hypothetical journeys that the user should make. For each scenario, three different levels of quantity of transport services and fares (bundle) were proposed to the user. The user had to express his/her preference for any proposed services.

The main information relating to the pilot survey are:

- 47 users were interviewed;
- Four scenarios were proposed, two concerning journeys only by land (inside the same metropolitan city) with increasing use of the transport system in the revealed preference (Ground 1, Ground 2), and two concerning journeys that cross the sea (between metropolitan cities). The increasing use of the transport system in the MaaS revealed a preference (Sea 1, Sea 2);
- for each scenario, three bundles (A, B, C) were proposed with increasing quantity of available transport services and increasing price in the revealed preferences.

One of the main results deriving from the survey is the high level of satisfaction with the MaaS scenarios, in particular with the movements across the Strait of Messina. The confidence interval with significance of 95% of users willing to choose at least one MaaS bundle (A, B or C) is as follows:

- 50–77% for the Ground 1 scenario;
- 74–95% for the Ground 2 scenario;
- 93–100% for the Sea 1 scenario;
- 100% for the Sea 2 scenario.

From the results, it is evident that the preference towards the MaaS grows with the quantity of transport services used and with the complexity (multi-mode, multi-service, multi-city, with barrier) of the type of journey.

4. Challenges and Opportunities with S-MaaS

The sustainable objectives, targets and goals defined by the United Nations in the 2030 agenda involve transport systems and the users have to be considered at the center. Transport services have to be sustainable and user-oriented. These concepts have to be considered in the MaaS by moving from advanced technologies to available advanced transport services integrated with technologies. The MaaS is expected to evolve in the next year from the I-MaaS, to T-MaaS, and then to S-MaaS.

For some years, the MaaS has been proposed in the I-MaaS class. The S-MaaS is expected to be completed probably by 2030 according to the 17 sustainability goals defined by the United Nations. The T-MaaS is expected to be completed predictably in the next few years as an intermediate step between I-MaaS and S-MaaS.

The development, even in the future of I-MaaS, is crucial for T-MaaS and S-MaaS and it requires further improvements. In this paper, the ICT development is not analyzed considering that the objective is focused on the development of TSMs in MaaS assuming that ICTs are developed in other research areas.

For I-MaaS, T-MaaS and S-MaaS, the sets of decision variables (or control variables), objectives and indicators are reported in Table 1, considering the evolution from MaaS 1.0 to MaaS 3.0.

Table 1. Main sets of components of objective function and decision variable in MaaS.

| MaaS ¹ | Design Variables Y | Objective Maximum $\varphi(y, f)$ | Indicators Main Components of φ |
|-------------------|---------------------------------------|--------------------------------------|--|
| 1.0, I-MaaS | Technology and App | Efficiency | 'MaaS Services Offered'/Resources |
| 2.0, T-MaaS | Transport service and infrastructures | Effectiveness | 'MaaS Users'/Resources |
| 3.0, S-MaaS | External services and infrastructures | Sustainability | Economic, Societal, Environmental |

¹ each raw includes the objectives, indicators and variables of previous raw.

I-MaaS generally pursues mainly efficiency objectives, i.e., to maximize the service offered by reducing resources; the control variables are of the ICT type in an existing and integrated transport service. In T-MaaS and S-MaaS, the transport service is optimized by achieving: in T-MaaS, efficiency objectives, i.e., to maximize the users served by reducing resources; and in S-MaaS, sustainability objectives in the three economic, social and environmental components (i.e., accessibility, energy pollutants).

In T-MaaS and S-MaaS, a DSS supports PAs and COs for the design and management of the transport system. In a multimodal, multiservice and multiclass transport system, the decision cannot be based only on the experience alone. The DSS is required for the supply design and for the demand management, adopting users' behavior models in order to evaluate, in advance, the optimal strategies for achieving sustainability objectives.

In S-MaaS, the transport system switches to an efficient and effectiveness system, also from a financial point of view, which integrates ICTs (with digital platform) and TSMs (with DSS), to a sustainable system that integrates the economic, social and environmental components of sustainability.

To model this new mode of transport, it is necessary to specify traditional and new TSMs, SETI and FEI. In S-MaaS, it is also necessary to integrate the sustainable transport system into a broader vision of territorial and planning of a smart city in the three main components: ICT, transport and energy.

5. Discussion and Conclusions

In this work the MaaS is described in relation to the actors involved, to the current and the expected evolutions in the coming years. MaaS cannot be considered just an

integration of existing transport services with or without an app. MaaS is a new modality for passengers and therefore it requires new methods for supporting decision makers.

Considering that MaaS can be built starting from current services with management actions, it has been growing in the past few years with particular reference to the high support of ICT. This evolution is ongoing and is defined I-MaaS. In the future, considering the sustainable development goals, defined by the United Nations in the 2030 agenda and smart cities, they require a new evolution defined S-MaaS. It will be reached with an intermediate step defined T-MaaS.

The paper defines an overall architecture of the MaaS, considering the evolution dived in MaaS 1.0 or I-MaaS, MaaS 2.0 or T-MaaS and MaaS 3.0 or S-MaaS and the actors involved. The classes of problems to be addressed and the subclasses of activities to be undertaken are identified. For T-MaaS, the network design and the demand management classes are considered; for S-MaaS, the policy evaluation, Agenda 2030 and smart planning classes are considered. The problems relating to each class identified are detailed in the respective papers cited.

MaaS is evolving and the proposals in this paper must be seen as a work in progress. Considering that MaaS is a new transport service, the TSMs to be used cannot be those currently existing without further extensions, specifications, calibrations and validations. In the coming years, the TSMs must be tested within the MaaS and necessary changes must be proposed so that they can be used for transport system modelling and for supporting decision makers. Furthermore, for this reason, the T-MaaS and S-MaaS require intense research works in the TSM area. The existing MaaS, even in prototype form, are a good research laboratory to test the new class of transport models and to improve the methods adopted in order to achieve sustainability goals and target.

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