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Sustainable Transport Planning: Economical and Morphological Thresholds

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Abstract. The aim to reach net-zero GHG emissions from human activities by 2050 in Europe is a priority and with the Recovery and Resilience Plan a large amount of funding will be devolved to new infrastructures and to new sustainable transport modality. In this framework the car-dominant model has to be transformed in a multimodal one. In this paper we analyse European urban transport policies and the widely spread tools used to evaluate infrastructure and mobility programmes. Our goal is to propose a complementary methodology, based on the threshold concept, to assess the mobility project in the initial phase. A step-by-step methodology that filters design options against territorial (morphological and social) and economic thresholds.

INTRODUCTION

The transition of urban mobility from a car-dominant to a multimodal and innovative model is one of the priorities set by the European Urban Agenda (2016). The aim of achieving net-zero GHG emissions from human activities in EU by 2050 was first envisaged in the EC Communication "A clean planet for all: strategic long-term vision for a prosperous, modern, competitive and climate-neutral economy by 2050' [1] and finally established as a pivot of the European Green Deal, launched in December 2019 by the Von der Layen Commission [2]. As far as transport is concerned, it implies a reduction of 90% emissions by 2050.

In this framework, on December 2020 the EC adopted the "Sustainable and Smart Mobility Strategy – putting European transport on track for the future" (SSMS), calling for an acceleration of the processes already underway, so far in a piecemeal fashion, for "the decarbonisation and modernisation of the entire transport and mobility system". Consistently, sustainable mobility is also one of the assets of the Next Generation Europe programme for the allocation of 'recovery and resilience' funding in response to the crisis caused by the Covid-19 pandemic. On June 2021, the European Commission has adopted a positive assessment of Italy's recovery and resilience plan, that includes measures to contribute to the sustainable mobility financing it with €32.1 billion.

Given the significant amount of funds that will be invested in Europe and in Italy on multimodal mobility models, it is crucial to develop a methodology to define their efficient allocation.

The Theory of thresholds may become a useful tool for that end. It gives a framework to optimize investment of available funds as they provide a set of general criteria on issues such as:

- morphology/geography thresholds of the area in which efficient projects could be developed
- economic thresholds to estimate additional costs to maintain service at the required level
- social thresholds

The combination of these thresholds provides a preliminary indication for further planning activities, saving time, costs and helping in focusing efforts. In the present paper we will focus mainly on the first two threshold mentioned above, i.e., the morphological/geographical and the economicGIS and BIM for asset management in infrastructure projects

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The impacts of transport on the environment– in terms of air pollution, noise, congestion, etc. - are both local and global, and essentially derive from its dependence to date from fossil fuels. The sector as a whole is responsible for 23% of global CO2 emissions from fuel combustion (source IEA, 2021), of which 74% is due to road transport (40% automobiles + 34% trucks – data 2018; source: Statista, 2021)

Given that

- the percentage of world population living in urban areas is a high and constantly growing (it was 46,5% of 6.1 billion people in 2000, and will be 66% of 9.2 billion in 2050 (source: UNO 2018); in the UE it is already roughly 75% (source: World Bank 2021),
- most passenger and freight travels are generated by cities or occur inside them,
- in most urban areas, especially in rich Western countries and in fast developing ones, transport and land use patterns favour a mobility mainly centred on the use of private motor vehicles,

urban transport policies aimed at reducing "car dependence" [3] [4], along with technical innovations in the field of alternative automobile engines and non-conventional fuels are expected to play in the next future a major role in delivering sustainability, both at local and global scale.

The transition to a low- or zero-emission transport is a prerequisite for achieving the objective set by the Paris Agreement (2015) to limit the global temperature increase in this century to 2 degrees Celsius while pursuing means to limit the increase even further to 1.5 degrees.

In this perspective, during the 22nd Conference of Parties in Marrakech (2016), the Global Macro-Roadmap to Decarbonize the Transport Sector was launched by the international platform named Paris Process on Mobility and Climate (PPMC) [5]. The roadmap identifies a balanced package of actions according to the so-called A-S-I approach, which combines measures to "Avoid" or reduce unnecessary travel, through e.g., land use planning, logistics redesign, provision of remote services, "Shift" movement of goods and people to the most efficient and sustainable modes and "Improve" the environmental performance of fuels and powertrains, vehicle design, intramodality, and transport management.

Since its inception, the EU has identified urban mobility as one of the key issues for the sustainable redevelopment of cities. According to the Charter of European Cities & Towns Towards Sustainability, signed in 1994 at Aalborg (Denmark) by the representatives of 80 local authorities (which became around 3000 from 46 countries in the following years[1]),"it is imperative for a sustainable city to reduce enforced mobility and stop promoting and supporting the unnecessary use of motorised vehicles". Sustainable urban mobility patterns should therefore "give priority to ecologically sound means of transport (in particular walking, cycling, public transport)", while individual motor vehicles should only have "the subsidiary function of facilitating access to local services and maintaining the economic activity of the city".

Along this line, the issue of mobility as a main lever for urban sustainability has been addressed by the EU in a large number of documents, directives, funding programmes (like Horizon 2020 Work programme "Mobility for Growth"), and initiatives (like URBACT, CIVITAS, ELTIS, EPOMM, etc.).

In 2011, with the publication of the White Paper "Roadmap to a Single European Transport Area – Towards a competitive and resource-efficient transport system" [6], the European Commission set the goal for member countries to halve the use of conventionally-fuelled cars in cities by 2030 and phase them out by 2050, while city logistics should be fully carbon-free as early as 2030. Such commitments were consistent with the target to reduce at least 60% CO_2 emissions from transport sector by 2050 with respect to 1990, as a contribution to the 80-95% planned reduction of GHGs.

Two years later an "Urban Mobility Package" was adopted by the EC [7] in order to stimulate a shift in European cities towards cleaner and more sustainable transport modes, and new patterns for car use and ownership, through the set-up of Sustainable Urban Mobility Plans (SUMP).

"Guidelines for developing and implementing a SUMP" were first published in 2013 on the European online platform ELTIS and have been revised and updated in 2019 [8]. Differently from the traditional approach to traffic planning, which focused on the role and size of infrastructure in meeting the potentially ever-increasing demand for the transport of people and goods, the aim of SUMPs is defining a set of push-and-pull policies and actions, tailored on actual needs, local opportunities and physical conditions of any single urban context, to allow easy access - despite

1 Including five countries outside Europe: Australia, Israel, Lebanon, and Morocco.

some unavoidable restrictions - to places and activities, with minimal impact on the environment and optimising available spatial and economic resources. Sustainable mobility planning should involve citizens and local stakeholders by means of participatory processes, in order to promote in the most collaborative way an effective paradigm shift in the way people live and move inside the city. List of measures eligible to be part of place-based strategies for delivering sustainable mobility have been provided since the early 2000s both by scientific [9] [10] and institutional [11] [12] [13] literature.

In 2007-2009 a study on London by VIBAT (Visioning and Back casting for Transport Policy) reviewed about 150 policy interventions to decarbonize transport, grouped into policy packages to be adopted at different institutional levels, but mostly related to the local one. These include Avoid-Shift-Improve type measures, such as urban planning, the use of ICTs in the traffic management, pricing regimes, the promotion of public transport, walking and cycling, as well as of low-emission vehicles, alternative fuels, etc. [14].

The key message of both the SUMP and the A-S-I approach is that sustainable mobility, in being an essential ingredient of the sustainable city, can still be achieved by means of variable combinations of policy interventions. One of its distinguishing features is in any case multimodality, as an alternative to the pervasive use of the car

GIS relies on a simple notion of organizing data into discrete layers that are aligned (georeferenced) in relation to one another in geographic space and each dataset is managed as a layer and can be graphically combined[8]. GIS can function as a decision support system, assist in solving real-world problems in various fields such as urban planning, geology, hydrology, surveying and mapping, land and resource management, market analysis and others.

ECONOMIC EVALUATIONS

At present, the most widely used tools for assessing infrastructure and mobility programmes are cost-benefit analysis (CBA) and multi-criteria analysis (MCA).

As stated in the European Commission's "Guide to cost-benefit analysis of investment projects", the CBA"...is an analytical tool to assess the change in social welfare resulting from an investment decision and, consequently, its contribution to cohesion policy objectives. The purpose of CBA is thus to facilitate a more efficient allocation of resources by demonstrating the social value of a particular intervention in comparison with possible alternatives"[15]. It is an evaluation tool for public investment that stemmed from the branch of economics that seeks to evaluate economic policies in terms of their effects on the well-being of the community (welfare economics). It has the advantage of being a generally accepted technique whose role is undisputed. Although its limitations are widely debated (monetarization of intangible assets, aspects of equity and income distribution, use of the social discount rate...) it is still universally used even if most of the time, following standard procedures, it seems to become an estimation exercise.[16]

In its ex-ante phase, it is used to decide how to allocate public expenditure and is mostly directed towards the evaluation of several alternatives for new infrastructure.

In its ex-post phase, it is used to determine whether the choices made were actually beneficial.

The analysis has two perspectives: financial - carried out from a business point of view and taking into account only costs and revenues, and economic – carried out from the public authorities' point of view and taking into account the social and risk aspects of the investment.

Theoretically the cost-benefit analysis uses the following economic/financial indicators:

- NPV (Net Present Value), the sum of all monetary amounts (costs and benefits) generated by the project along all its life, discounted at a certain defined point in time (discounting);
- IRR (Internal Rate of Return), the value of the discount rate making the NPV equal to zero, expressed as a percentage; it indicates the intrinsic profitability of the project;
- B/C, the ratio between discounted revenues/benefits and discounted costs, that must be greater than one

$$NPV = -IC + \sum_{t=1}^{t=n} (B_t - C_t) / (1+r)^t \tag{1}$$

$$NPV = -IC + \sum_{t=1}^{t=n} (B_t - C_t) / (1+IRR)^{-t} = 0 \tag{2}$$

where:

- IIC is the Initial Investment Cost (the minus highlights the nature of the cost)
- B_t C_t are the Benefits and Costs for the project year “t”
- t is the generic project year (takes values 1…, n)
- r is the discount rate.

Specifically for the goal of supporting decision making in the transport sector, the comparison of benefits and costs has to consider for each year t of the useful life of each project [option ????], issues such as:

- the difference between the construction costs of the Project and any extraordinary construction or maintenance costs of the non-Project, including, in the last year taken in account, a positive amount (therefore a benefit) representing the residual value of the work;
- the difference between the investment costs in vehicles or infrastructures costs of the Project and of the Non-Project;
- the difference between the management and maintenance costs of the Project and the Non-Project;
- the difference between the revenues from the sale of transport services in the Project and in the Non-Project
- the difference between the revenues from taxes and duties in the Project and in the Non-Project;
- the variation of surplus benefits perceived by the users of the transport system in the Project compared to the non-Project situation [17]
- changes in benefits not received by users between the Project and the Non-Project, this may include road accidents, vehicle consumption costs (lubricants, tyres, etc.);
- the variation of the effects on non-users between the Project and the Non-Project, including all the impacts on the environment (atmospheric pollution, noise pollution, etc., all appropriately monetized) and on the economic-territorial system

All the above quantities should be valued at shadow prices, taking care to avoid double counting.

Nevertheless, in most cases the main economic-financial indicators (such as NPV, IRR) are not sufficient to understand the trend of all the components related to the project that have a significant impact on the environment [18][19].Therefore, multicriteria analysis are considered as an appropriate tool to assess the heterogeneous impact of the project on the environment. For each selected criteria the impact due to the project is evaluated even if it is not expressed in monetary terms, as required by ACB requires. Such criteria could both be qualitative and quantitative, expressed in different measuring systems.

Multi-criteria analysis is mostly used to assess plans and programs, and, through the use of indicators, aim to evaluate the effect of the planned actions by means of appropriate indicators, clearly showing when and how much they differ from the goals [20]. The elements common to all models for multi-criteria evaluation, are:

- **Agents** i.e., the decision makers. They can be both individuals and groups with their own internal dynamics as in any large organization, where goals and decisions must be explained against objective criteria;
- **Goals** i.e., the objectives to be achieved;
- **Criteria** i.e., rules for testing the desirability of alternatives that meet the chosen goals; they might be measured qualitatively and / or quantitatively through evaluated attributes;
- **Weights,** assigned to the evaluation criteria to express the preferences of decision makers;
- **Alternatives** among which choice is to be made;
- **Scores i.e.,** the values reached by each Alternative against a criterion; they become elements of an assessment matrix (the score can be also imposed from outside).

Based on the performance of alternatives against the selected criteria, the alternatives are evaluated and ordered.

Multicriteria methodologies require an in-depth analysis of the various projects, as well as the selection of appropriate criteria and scoring methods, which makes them time consuming and particularly fit to be employed on projects that basically respond to the requirements.

Thus, especially when a large number of projects are to be analysed unbiasedly and when the decision has significant economic/social impacts, it is advisable to narrow down the number of the projects on which multicriteria analysis will be carried out. Thresholds are a tool that can deliver this pre-selection phase, as will be explained in the following paragraphs.

THRESHOLDS THEORIES

Thresholds is a fascinating concept. We can define them as the values that a certain agent or a certain quantity must reach in order for a certain phenomenon to occur. Thresholds are invisible but (sometimes) measurable points, beyond which a certain phenomenon takes place.

If we look at them as territorial items, the concept of threshold or border is deeply changing in a very short time: human cultures are in a constant flux, as aggregations and divisions follow one another, even though they fail to counteract and in tendency towards unity [21]. This change is profoundly altering the economic, political and cultural interdependencies of the contemporary world.

Already in the early 1900s the concept of threshold was analyzed under various approaches: geographic, urban and economic. Walter Christaller in 1933 introduced the "*central place theory"* [22], a geographical theory establishing a relationship between size and location of human settlements, in order to optimize services delivery to the surrounding areas.

August Lösch gave a great contribution to regional and urban economics and in in 1940 published "Spatial Organization of the Economy" analysing how locations interact with each other in terms of the movement of people, freight, services, energy, or information. More specifically he analysed the issue of transferability among different locations and the effort in terms of distance, time, and cost needed for that, defining a theory of general economic equilibrium among regions. From the urban point of view, the threshold-analysis was originated in Poland by Malisz in the early sixties.[23] By observing towns' structures, he showed that they encounter physical limitations to their expansion called development thresholds. They are not irremediable but can be overcome only at 'additional' cost, i.e., at threshold costs which must either be spent before the land is opened up for development, or have to be spread over the period of time subsequent to the moment in which the land is used and are normally higher from various points of view (economic, social, management etc.)

Analysis of costs based on thresholds makes possible a number of insights into the efficiency of investment planning also in relation to mobility demand but, perhaps more important, it accommodates the economists' methodology of comparing alternatives [24].

The driver for the definition of economic thresholds is the additional cost per user that has to be met in order to improve the service and satisfy the demand of that user.

A threshold may be designed as a line on a planning map or an inflexion point on a cost or efficiency curve.

Definition of Threshold Looking at Urban Morphology in Relation to Mobility Infrastructure and Patterns

As far as urban analysis is concerned, the demographic size and composition, the geographical extension, and the spatial distribution of urban functions and weights are significant but not the only factors affecting mobility demand.

The possibility of orienting mobility supply towards alternative mobility options (including all carbon-free solutions) while defining consistent traffic patterns, is strongly conditioned - even more so in heterogeneous and stratified contexts such as Italian cities - by morphological aspects concerning both geography and urban fabric, such as gradients, slopes, road widths, position and characteristics of physical barriers crossing points, etc.

By developing GIS-based analysis techniques, usually used for calculating configurative spatial relationships in built environments, with special regard to the assessment of the performance of road networks in terms of accessibility (following a line of research that refers to the Space Syntax method – Hillier B 1996) [25] ad hoc applications should be developed to measure and map the variations, even punctual, of the main physical parameters that condition the use of the urban mobility infrastructure, with reference to specific thresholds (e.g.: variations in the width of the roads that allow or do not allow to host different paths for different road users; slopes, which limit walking and biking, etc.). This is in order to orient the scenario building towards plausible combinations of policy packages with respect to the structural characteristics of the place. To define significant threshold values to be used for the construction of urban mobility strategies, by means of a step-by-step procedure for evaluating alternative mobility options, with regard to four different disciplinary points of view: urban analysis, mobility and transport, cost estimates and social behaviors.

Using Thresholds to Narrow Down Choices Among Multimodal Mobility Projects

Given the stress lately put also at European level on the issue of green multimodal mobility, the significant funds that in Europe and outside of it are expected to be invested in this sector, and the strong theoretical analysis – briefly summarized above – on multicriteria analysis and thresholds, the aim is here to outline a methodology that relies on the concept of threshold to narrow down the number of multimodal projects to be then chosen with a multicriteria.

It is a step-by-step methodology that puts the following thresholds in sequence, filtering projects that have to pass the analysis of the threshold higher in the sequence in order to get to the subsequent one.

The proposed sequence of thresholds is the following:

1. Morphology
2. Social
3. Economics

At the initial stage, the morphology of the city under examination should be studied in depth, collecting information not only on the territory (slopes, extension etc.) but also on the current infrastructures (cycle pathways, dimension of the streets etc.), on constraints in building new infrastructures or modifying the existing ones (due to cultural heritage preservation, to urban fabric etc.).

Each project should first pass this threshold for two main reasons: first of all, certain constraints that morphology dictates are virtually impossible or extremely expensive to overcome; secondly, because due to the multimodal essence of the project, it is possible to modify it at this stage in order to adapt it according to the morphological requirements.

Projects that pass level a), have then to meet certain social general criteria, which relate to data widely available but that need to be analysed. We refer for example to the age of the population, which may or may not be open to accept certain innovations, or are or are less able to use different solutions, as well as their use of certain routes and their capacity/openness to change for others.

It should be noted that such thresholds are less burdensome to overcome than level a), but still require a significant deal of time and investment and in some cases are impossible to be moved

Projects that pass level b) have then to show a general level of economic viability, drawn on market standards and assessments that do not require an in-depth analysis but rather rely on sound experience.

Elements such as the supposed overall costs of the project (vehicles, infrastructures physical and digital, communication etc.), the supposed capacity of the users to meet their share in those costs, the contribution of non-residents to such a project, the expected funding that the project may be entitled to, should be collected. Looking at them, project may fail to pass this final stage of the initial examination and do not get to the later stage of multicriteria analysis.

CONCLUSION

The concept of threshold can be extremely useful to assess project ideas in an initial phase, when plans have still to be defined and various options – only outlined - are on the table. From this point of view, we may consider this approach as complementary to the classic evaluation methods that require that the object of the analysis – the plan – would be fairly well defined in all its components. On the contrary, it happens especially in the present historical phase, that resources are available and public administrations and private entities are to decide on which sector/area to invest them. We have outlined here a step-by-step methodology, putting thresholds in a sequence according to which projects can be roughly examined, and only those passing an initial step/threshold can be examined according to the other. Most of the data collection activity required requires a fairly short amount of time, given the vast quantity of data available, and is based on the use of internationally accepted approaches and standards.

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