A SYSTEMS APPROACH TO ANALYZING SUSTAINABLE TRANSPORT AND MOBILITY

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ABSTRACT

Sustainable development has become a central objective of policy in many places, including the European Union. There is a desire for a clean environment, preserving nature, and concern for the welfare of future generations. However, the desire for economic growth and freedom of movement, with their concomitant increases in transport demand and use of fossil fuels, run counter to this desire. Policymakers have to accommodate these conflicting desires by balancing the positive and negative impacts of transport. The European Commission, as part of its Thematic Programme on Competitive and Sustainable Growth, commissioned a study entitled SUMMA (SUstainable Mobility, policy Measures and Assessment). Among the objectives of SUMMA is to define and operationalize the concept of sustainable transport and mobility in terms of its environmental, economic, and social dimensions, and to define a set of outcomes from the transport system that can help policymakers monitor progress towards sustainable transport and mobility.

Studying something as complex as the impacts of external forces on the transport system, and the relationship between the forces and the outcomes from the system (e.g., emissions, congestion, economic benefits) requires a theoretical framework and a structured approach. The approach that we are using on SUMMA, which we call the systems approach, is particularly useful for analyzing problems involving complex systems that are characterized by uncertainty. The systems approach helps in understanding the interrelationships among the elements of the system and how policies might be designed to steer the system toward sustainability. This paper describes the systems approach and how we defined the transport system in terms of three markets – a movement market, transport market, and traffic market – in which choices are made that influence the final determination of traffic streams. The approach is illustrated with examples from the SUMMA project.

We conclude that the systems approach facilitates ways of anticipating systemic problems rather than merely reacting to them. By linking goals to outcomes of interest, and outcomes of interest to changes in the transport system, policymakers can become more systematic and methodical in identifying policies that are effective in helping them to achieve their goals.

BACKGROUND

Transport is the lifeblood of modern day economies. Simultaneously, however, transport is also the source of many social and environmental problems. One of the biggest problems is the level of emissions from the transport sector -- in particular road transport. Within the European Union (EU), the transport sector contributes 26% of all CO2 emissions, of which road transport alone is responsible for 84%. Another serious problem is congestion; by some estimates the costs of congestion amount to almost 0.5% of the EU's GDP. In addition, about 40,000 people are killed and 1,700,000 injured every year due to road accidents in the EU, at an estimated cost of 160 billion euros, or 2% of the EU's GDP. Building new transport infrastructure is unlikely to solve these problems.

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The need for new approaches in transport policy is now recognized. Sustainable development has become a central objective of European Union policy. There is a desire for a clean environment, preserving nature, and concern for the welfare of future generations. However, the desire for economic growth and freedom of movement, with their concomitant increases in transport demand and use of fossil fuels, run counter to the objective. Policymakers have to accommodate these conflicting desires by balancing the positive and negative impacts of transport. The European Commission, as part of its Thematic Programme on Competitive and Sustainable Growth, commissioned a study entitled SUMMA (Sustainable Mobility, policy Measures and Assessment). Among the objectives of SUMMA is to define and operationalize the concept of sustainable transport and mobility in terms of its environmental, economic, and social dimensions, and to define a set of outcomes from the transport system that can help policymakers monitor progress towards sustainable transport and mobility. Another objective is to understand how the transport system might respond to external forces, such as new technologies, economic, social, and political developments, and policy changes, so that policymakers can design policies that can be expected to lead to sustainability.

Studying something as complex as the impacts of external forces and policy changes on the transport system, and the relationships among the forces, the policies, the system, and the outcomes from the system (e.g., emissions, congestion, economic benefits) requires a theoretical framework and a structured approach. The approach that we are using in the SUMMA project, which we call the systems approach (see Findeisen and Quade, 1985), is particularly useful for analyzing problems involving complex systems about which there is insufficient knowledge and that are characterized by uncertainty. Although the transport system has been the subject of considerable study, there is still little known about how it might respond to policy changes and changes in other external factors, and how it can be changed in order to lead to more sustainable development. The systems approach is an ideal starting point for understanding the interrelationships among the elements of the system and how policies might be designed to steer the system toward sustainability. This paper describes the systems approach and how we defined the transport system in terms of three markets – a movement market, transport market, and traffic market – in which choices are made that influence the final determination of traffic streams. It illustrates the approach with examples from the SUMMA project.

THE SYSTEMS APPROACH

As shown on the right side of Figure 1, the systems approach is driven by a realization among policymakers and stakeholders that there is or will be a gap between the outcomes of interest from a system (e.g., the transport system) and the desired outcomes (based on a set of goals and objectives). Outcomes of interest are system outcomes related to the goals and objectives that policymakers are interested in either reducing (adverse effects) or increasing (positive effects). A goal is a generalized, non-quantitative policy objective (e.g., "reduce air pollution" or "ensure traffic safety"). In the systems approach, the outcomes of interest are related to measurable quantities called outcome indicators (e.g., "NOx emissions" or "traffic fatalities), which are used to measure progress toward the goals. Policy actions are intended to change what happens inside the system in order to change the outcomes of interest, closing the gap and bringing them closer to meeting the goals.

An outcome indicator is a proxy for an outcome of interest. The outcome indicators are 'proxies' for two reasons: (1) the outcome indicator is usually not the same as the outcome of interest but is related to it (e.g., NOx emissions are not the same as air pollution, but there is a relationship between the two), and (2) there are other factors (external to the system) that also contribute to the outcome of interest (e.g., CO_2 emissions are produced by transport, but also by industry). There are usually many possible proxies for any specific outcome of interest. The appropriate choice is seldom clear, but the choice of the indicator may have important implications for the policy decisions. For example, safety is usually one outcome of interest from the transport system. Two proxies for safety are fatalities per vehicle hour and fatalities per vehicle mile. The choice of fatalities per vehicle hour would lead the policy analysis to focus on urban accidents, while the choice of fatalities per vehicle mile would direct attention toward rural accidents.

The systems approach, therefore, requires the capability of estimating how the outcome indicators will change as a result of changes to the system. This requires a deep understanding about the system and its structure. The way in which we document what we know about a system and its structure is by using a 'system diagram'. The system diagram clarifies the system by (1) defining its boundaries, and (2) defining its structure – the elements, and the links, flows, and relationships among them.

The boundary of the system is determined in large part by the outcomes of interest, which are, in turn, determined by the goals and objectives of the policymakers and other stakeholders and by the scope of the policy measures under the control of the policymakers. If we were assessing policy measures for reducing congestion on European highways our system boundary would be different from the boundary we have defined for assessing policy measures related to sustainable transport. For example, the system would not need to include non-road modes, nor would it need to include vehicle characteristics related to emissions.

In order to specify the system diagram, we need to specify three things: the outcomes from the system that are of interest, the system itself, and the inputs to the system (which change the system, and thereby lead to changes in the outcomes). Defining the transport system includes describing the physical elements of the system, the actors, their behavior (i.e., the choices they make), and their mutual relationships. For example, the physical elements of the transport system include the locations of residences, offices, distribution centers, retail stores, the transport vehicles, and the transportation infrastructure. The actors include governments, people, and transport companies. The behavior of the actors consists of describing how the actors make choices within the system, while their mutual relationships provide information on the interactions among the actors. Businesses, governments, households, and individuals make choices that are relevant for and have impacts on the demand and supply of transport. Within the system, we identified the choices that the various actors make.

Two sets of external forces act on the transport system: external forces outside the control of the actors in the policy domain (which we call Forces Driving System Change, or FDSCs), and policy changes. Both sets of forces are developments outside the transport system that can affect what happens inside the system (and, hence, the outcomes of interest to the policymakers and other stakeholders). An FDSC can be a technological, political, regulatory, economic, or societal development. In the case of transport, an example of an FDSC might be changing consumer behavior reflected, for example, in a 50% increase in e-shopping and a decline in the number of grocery stores. It can also be a policy outside the transport policy domain (e.g., tax policy). The impact of an FDSC can be to change the physical elements of the system (e.g., new infrastructure), the behavior of the actors within the system (e.g., more use of public transport), and/or their mutual relationships. For example, increasing affluence could change the tastes of individuals in terms of wanting more space, resulting in changes to the spatial structure of cities. Important FDSCs are those that are likely to have the largest and most significant impacts on the outcomes of interest. In Figure 1, EU and national policy measures are shown separately from other external forces (which are not under the control of EU and national policymakers). This is due to the focus of the SUMMA project, which intends to help EU and national policymakers to design appropriate policy measures.

In order to be useful for policy analysis and monitoring purposes, the descriptions of the outcomes of interest, the FDSCs, and relevant elements of the system need to be related to measurable indicators. We therefore define the following types of indicators:

- Outcome indicators: An outcome indicator can be used to describe or monitor changes in an outcome of interest. Each outcome of interest is associated with a set of outcome indicators.
- System indicators: System indicators are sometimes outcomes of interest in themselves, but they are usually intermediate variables that are used to estimate the values of the outcome indicators. A system indicator can also be used to monitor changes and developments in the system.
- FDSC indicators: An FDSC indicator can be used to describe or monitor changes in the Forces Driving System Change.

There are some fundamental differences among the three types of indicators. The system and FDSC indicators are mainly needed to understand and analyze the functioning of the system, but have little importance in policy assessment. They may, however, provide important information about the steps between the implementation of a policy measure and the resulting changes in the outputs of the system. For example, there may be an assumption that CO2 emissions will decrease if there is an increase in vehicle taxes. Understanding the resulting changes in the system will help to explain why this might or might not happen. In SUMMA, we were not interested in defining indicators for all external forces or all system data. We were interested in defining indicators for those forces and system characteristics that, if they were to change significantly, would lead to significant changes in one or more of the outcomes of interest.

In the remainder of the paper we show how we applied the systems approach described to the specific problem of sustainable transport and mobility in the SUMMA project. Although passenger transport and freight transport overlap in some aspects (e.g., they use much of the same infrastructure), the actors, their behavior, and their relationships are quite different. We, therefore, developed different system diagrams for the passenger and freight transport systems. In what follows, we present the system diagram associated with passenger transport.

RELATING SUSTAINABLE TRANSPORT GOALS TO OUTCOMES OF INTEREST

Although sustainable transport and mobility is one of the overarching goals of European transport policy, there is little agreement on what the concept means. One of the first activities on the SUMMA project was to define the concept and operationalize it in terms of outcomes of interest. In the literature on sustainability, it is common to distinguish three dimensions of sustainability: economic sustainability, environmental sustainability, and social sustainability. Economic sustainability refers to strong and durable economic growth (quantity and quality) – e.g. preserving financial stability, low and stable inflationary environment, capacities for investment and innovation. Environmental sustainability comprises maintaining the integrity, productivity, and resilience of biological and physical systems, and preserving access to a healthy environment. Social sustainability includes the importance of high employment, of safety nets capable of adapting to major demographic and structural changes, of equity, and of democratic participation in decisionmaking. In the case of sustainable transport and mobility, our job was to agree on a definition and relate that definition to a set of outcomes of interest. Those outcomes would then help to define the boundaries and elements of the system diagram.

For the purposes of the SUMMA project, we adopted the definition of the Council of the European Union for a sustainable transport system (Council of the EU, 2001.). According to that definition, a sustainable transport system is one that:

- Allows the basic access and development needs of individuals, companies and societies to be met safely and in a manner consistent with human and ecosystem health, and promises equity within and between successive generations;
- Is affordable, operates fairly and efficiently, offers choice of transport mode, and supports a competitive economy, as well as balanced regional development;
- Limits emissions and waste within the planet's ability to absorb them, uses renewable resources at or below their rates of generation, and, uses non-renewable resources at or below the rates of development of renewable substitutes while minimizing the impact on land and the generation of noise.

Although this definition talks about sustainable "transport system", the transport system is not an end in itself, but rather a means to other ends. Thus, we saw our interest not in sustaining the transport system, but in making sure the outputs from the system contribute to the sustainable development of society (in terms of its economic, social, and environmental dimensions). Our next step, therefore, was to relate the definition to a set of economic, social, and environmental goals:

- Economic goals: Basic access, development needs, fairness, efficiency, competitive economy, balanced regional development, use of renewable and non-renewable resources
- Social goals: Basic access, development needs, safety, health, equity, affordability, fairness, choice of mode
- Environmental goals: Ecosystem health, emissions, waste, use of renewable and non-renewable resources, impacts on land, noise

This set of goals led us to define the outcomes of interest presented in the middle column of Table 1. Since some of the outcomes of interest relate to several of the goals, these are mentioned twice or more in the table.

DEFINING THE PASSENGER TRANSPORT SYSTEM

The description of the transport system used in SUMMA is based on a representation that assumes that the process of generating traffic streams can be divided into three steps. The three markets on which choices are made that influence the final determination of traffic streams are: the movement market, the transport market and the traffic market (see Figure 2). A market represents an action space where demand meets supply and choices are made. Therefore it consists of three elements: demand, supply and output. The result of the dynamic interaction of the three elements is: a realized supply, a realized demand and an allocation of the realized demand to the realized supply. This representation of the transport system results in seven elements, which are directly related to the elements of each market (supply, demand and output). The elements are described in Table 2.

Different actors interact within each of the markets. These actors make trade-offs and choices that produce the output of the market. In addition to the different sets of actors within each market, some actors are external to the market but influence it, such as the government and interest groups. Of course there are also relationships among the actors within the different markets, and some actors might act in more than one market. Table 3 shows the sets of major actors by market.

The choices that are made in the course of generating traffic streams, and which determine the outcomes of interest from the system, are therefore:

- Activity choice
- Settlement choice
- Destination choice
- Time-of-day choice
- Mode choice
- Route choice

One aspect that also has to be taken into consideration in understanding these markets is that the choices have different time horizons and are not independent. Let us look for example at two different choices in the transport market: the decision to acquire a train ticket has a short time horizon while the purchase of a car has a relatively long time horizon. There are feed-forwards and feedbacks among the markets. People making a choice in one market will, for example, anticipate what might happen in a later market. On the other hand, an improvement in the infrastructure connecting a residential area with a shopping mall might, for example, lead to a higher demand by people who want to go to the mall.

The three elements of each of the three markets are described in detail in the following subsections.

The Movement Market

In the movement market, the demand side consists of the activities to be performed. This means the individual decisions taken after making trade-offs among different activity needs. The time and the location for these activities are at this stage unknown. For example the demand side includes the individual deciding to go shopping without having fixed a time or a location where this shall happen. The supply side represents the spatial and temporal structure of society as well as the perception of these elements. It contains the distribution of the locations where these activities could be performed, defining for example operating hours and location of shops. The output of this market is the set of movement patterns – a complete description of all required transport in terms of its origins, destinations, and time of travel.

Demand -- activities to be performed

The need for transport comes from the need to perform different activities that are not co-located. Not too long ago the demand picture might have been quite simple. The man would go to work, the wife would take care of the small children and go to the shop to get groceries, and the older children would walk or cycle to school by themselves. Each of these activities would be associated with a simple journey from home to some destination and back. Over the years this picture has changed considerably. Not only the man works these days, but often both partners work (often part-time). Both partners take care of the household and/or hired help is available. Small children need to be taken to the nursery or day-care-center and older children are taken to school (because of safety and security problems). Shopping is done during or after work, in the evening, or during weekends. An increasing amount of time-off leads to more time for hobbies and leisure time (and leisure trips). Journeys have also evolved from simple home-destination-home journeys to transport chains, e.g. home-nursery-work-shop-work-nursery-home.

To capture the full complexity of the demand side of the market, it is essential to have a good understanding of (1) the activity choices, and (2) the potential traveler. We begin with the potential traveler. The potential traveler decides what activities to perform. Some of these choices are short-term; others are long-term. On a specific day, the potential traveler may choose to stay at home and relax (no travel), to hike in nature, to visit friends, to shop, etc. This is clearly a short-term choice. On the days that the traveler works, there is not much choice (except perhaps to decide whether to telework or not). However, at some stage the traveler made a long-term choice for the current employer. In principle the activity choice should capture the full range of activity choices.

The traveler will base his choices on personal preferences, but also on the circumstances in which he or she lives. In other words, choices are strongly influenced by the household in which the traveler participates. The activities from which the potential traveler has to choose are basically all activities a human being performs. A non-exhaustive list of activities is:

- Relaxing at home -- sleeping, relaxing, staying at home
- Working (office, business trip, teleworking)
- Learning
- Shopping
- Visiting family and friends
- Sports
- Tourism

The choices that the potential traveler makes daily, amongst the listed activities, depend on his/her characteristics. E.g. an unemployed person will not go to work, and retired people will not work nor go to school. Each activity has a preferred time of execution, where the preference is strongly correlated with what is considered “normal”.

Supply -- spatial and time structure

On the supply-side of the movement market are the locations where the activities can take place and the time frame within which they can take place. The activities are the same as those identified in the demand side of the movement market. Here we will talk about the issues that determine the locations and the times.

A major part of the process on the supply side of the market is the process of settlement. Where do the activities choose to locate themselves? For some of the activities listed on the demand side of the market, Table 4 provides examples that indicate the types of sectors that need to choose locations at which to settle, and the factors that play a role in the settlement process. The relevance of this process for the traffic system that we are describing is twofold:

- The distance between locations determines the need for transport in society;
- The locations at which activities settle dictate the required infrastructure and the available infrastructure dictates the settlement process.

A second major part of the process on the supply side of the market is the process of determining the period of activity. The opening times are a trade-off between supply and demand. Sectors that "sell " something need to be active when the buyers desire to do their shopping. This used to be the housewife during normal working hours. However, this picture is undergoing considerable changes. Now, both partners often work and there is a move toward a 24-hour society in which shops are increasingly open outside working hours, such as in the evening and on Sundays. Sectors that are producing something need to be as cost-effective as possible. With expensive production machinery, it is necessary to keep the machinery working, which has led to working in three 8-hour shifts per day, in order to keep the production process active around the clock. For some activities (e.g., at city hall) the opening hours are not sensitive to the needs of the market. These are services that are not produced to make profits. Table 5 shows the factors influencing the activity period for some sectors.

Outcomes of the movement market

This is the actual market. On the demand side, we have the need for activities with a desired time-window. On the supply side, we have the locations where these activities can be performed and the time frame within which this is possible. The only ingredient missing to determine the movement pattern is the cost to travel between the locations. Because the cost is mode dependent and the choice of mode is still to be made, the cost used at this stage is the expected generalized cost, which includes the prices and travel times, and perceptions about these, for all modes with which the destination can be reached. The minimum generalized cost mode should have a high weight, but also the modes that are reasonable alternatives.

The outcomes of the movement market are movement patterns – trips to be made from specific origins to specific destinations at specified times – which is an origin-destination matrix (OD-matrix) by time of day.

The Transport Market

In the transport market, the demand side is the output from the movement market -- the movement patterns. These patterns define the need for vehicles to transport passengers and freight, and are specified by an origin-destination matrix by time. On the supply side, the available vehicles and services to accommodate these movement demands and the perception of these vehicles and services are given. The elements to be found here comprise travel time, convenience, price, etc. The main decision in this market is the choice of mode. Modes are characterized by differences in many aspects, such as local accessibility, travel time, costs, reliability, comfort, and security. These differences force the individual to make trade-offs in choosing a means of transport to satisfy a particular transport need. The output of the transport market is the set of transport patterns (origin/destination matrix by time and mode).

The demand side of this market (the movement patterns) were discussed above as the output of the movement market. The other two elements of the transport market are described below.

Supply – transport means and services

The different transport means and services are found on the supply side of the transport market. In the last century, the variety of transport means has expanded enormously. Today, the biggest share of transportation (at least in the industrialized countries) is accomplished by using some form of artificially generated power. With the changes in transport means, locations seem to have moved “closer”; a trip from Europe to the U.S. takes no longer than a day.

But, given the variety of options from which one can choose, which transport means should one choose for realizing his transport demand? To take an example, a man who has to do his shopping on a Saturday and has chosen to do so in a shop in the city center while his residence from where he has to depart is located in a suburb of the city has to consider the different ways to get there. His decision will mainly be based on the so called “service characteristics” of the alternative modes. He might go by foot, but this will take him some time and could be very inconvenient if he will have to carry back his purchases. Going by car, in case he has one at his disposal and has also a driving license, will perhaps be quite convenient regarding the shopping bags, but might take some time due to congestion and problems finding a parking space. By using public transportation he might face only a short travel time, but it could take him some time to reach the bus stop from his home and to wait for the bus to arrive.

As a separate mode, the alternative of combining different modes to perform a trip has to be considered. This mode (which we call intermodal transport) has some of its own unique characteristics, since it not only assumes the characteristics of each of the modes being used, but also is defined by the characteristics of the interfaces between the modes. For example, for a trip that includes both bus and train, one must take into account not only the walk to the bus, the travel time by bus to the train, and the duration of the train trip, but the time of waiting for the train; this time relates the interconnectivity of different modes.

Including intermodality as a mode, we can identify the (non-exhaustive) set of transport modes and their associated means listed in Table 6.

So given the many different modes, the question arising is: what are the factors influencing the choice of mode for a specific trip? Each of the modes has particular features that make it attractive for a certain traveler for a given trip at a given time. Those characteristics are what we call the mode's service characteristics (which include the vehicle characteristics). Some examples of these characteristics are provided in Table 7.

Other characteristics, not related to the vehicle and the service, that will influence the decision, are the network characteristics, which describe the infrastructure used by the transport means. Of course, since these have an impact on the characteristics of the means, they have to be taken into consideration when looking at the mode choice. But, since they have an even more direct and stronger effect on the route choice, we will deal with the network characteristics when analyzing the traffic market. To give only one example, the fact that the roads in a certain area are of very bad quality might lead to a high number of accidents, which will lead to the judgment that the use of a car to do a certain trip is too dangerous and unsafe, which will result in the choice of a different mode.

Besides all of these characteristics, one has to be aware of the fact that the mode choice decision is influenced by the perception of these characteristics. It is not the actual travel time that makes us rule out the possibility of using a certain mode, but our individual perception, often based on our own experiences or on second hand information, that drives us. This perception can of course be influenced by measures taken to improve information on the real characteristics, such as better visibility of timetables or better information centers, as well as by campaigns promoting the use of a certain mode.

Output of the transport market -- Transport patterns "mode choice by OD and time of day"
Given the need to travel from A to B at a certain time, a traveler is faced with many alternative mode options. As we described above, those modes will be described by certain characteristics that influence the choice. The traveler will select the mode that satisfies his personal needs and preferences best. This will require trade-offs among the many aspects. The output of the traffic market is the set of transport patterns for trips, each of which has a chosen mode with a defined origin, destination, and a time of day.

The Traffic Market
In the traffic market, the choice of route is made. The demand side contains the aggregated output of the transport market: the transport patterns. These patterns (origin/destination matrix by time and mode) define the need for infrastructure to accommodate the vehicles and services. The supply side consists of the available infrastructure, their attributes and how the infrastructure is perceived. The output of this market is the allocation of the transport vehicles and services to the infrastructure: the set of realized traffic patterns or the traffic streams. These traffic streams lead to the ultimate outcomes of interest from the transport system, such as congestion, emissions, etc.

The demand side of this market (the transport patterns) were discussed above as the output of the movement market. The other two elements of the traffic market are described below.

Supply -- Infrastructure
The supply side of the traffic market consists of the alternative sets of infrastructure by mode for a particular OD matrix at a given time. One infrastructure option is of course defined by certain attributes that distinguish it from other infrastructure options.

The expansion in the range of transport means has, naturally, led to an expansion in infrastructure components. These components include: roads (highways, normal streets, bicycle lanes, etc.), railways, bridges, waterways, tunnels, seaports, airports, stations, bus stops, and intermodal transfer terminals.

Even if a traveller has already decided where to go, when to go, and what transport means to take, the choice of the route is still open. A couple might have decided to go on vacation on a Friday evening after having finished work, might have chosen a tiny village at the seaside, and might have already agreed to go by car because of the costly train and plane trips to the location, without having defined the route. They will have to take a look at a road map or consult a "route planner" to find out what the different options are. In selecting the route, not only the distance but also the expected congestion, the fact that tolls have to be paid, that it is a scenic route, or that the route is known for its high safety risk are going to play a role.

The characteristics describing the infrastructure alternatives are generally called network characteristics. Some examples of these characteristics are provided in Table 8. All of these characteristics might be decisive for the route choice of the individual traveler. Of course, as mentioned above, these characteristics might already have influenced the mode choice or even the choice of activity.

Output of the traffic market -- Traffic patterns "mode choice by OD, time of day and route"
The output of the traffic market is the assignment of transport demand to the infrastructure: the set of realized traffic patterns or traffic streams. These are also the main drivers of the outcomes of interest that transport policies want to affect, since the outcomes like congestion, emissions, and injuries in accidents, are directly linked to the traffic streams. But there are also outcomes of interest that come from earlier stages of the traffic generation process. An example of such an outcome is the land-take by transport, which is a direct result of building the infrastructure and not of the traffic streams.

THE SYSTEM BOUNDARY AND FORCES DRIVING SYSTEM CHANGE

So far we have described the transport system without defining the system boundary. The boundary of the transport system divides what is considered to be inside the system from what is considered to be outside. What is inside the system can be described as a 'snapshot' of the system at a given point in time. In other words, the transport system is defined by the activities that people perform, the places at which they perform them, the places at which they live, the times at which they perform their activities, the modes of transport, the vehicles used (including vehicle technologies), the transport infrastructure, the choices concerning departure time, mode of transport, etc. Everything that is not encompassed by the above description we placed outside of the transport system.

An important part of the SUMMA project was to identify FDSCs that should be monitored. To determine the FDSCs that need to be monitored we first needed to revisit the way the policy assessment framework was presented. The purpose of the framework is, as the name suggests, assessing policies. The problem with the definition of the transport system as given above is that it does not allow us to assess all issues related to sustainability that are of concern to policymakers. For instance, a successful policy to promote the use of hydrogen cars would have a significant impact on the emissions coming from the transport system. Although this is correct, it is not the full picture required to assess the policy. To assess the policy, it should be taken into account that the process of producing the hydrogen that is used within the system may also produce pollutants. Ignoring these pollutants will give an overoptimistic assessment of the pollutant reduction from this structural change in the system.

To correctly determine which processes outside the transport system need to be included in the policy assessment, one needs to look at the policies and the outcomes of interest. Those external processes that can be affected by transport policies and that affect the outcomes of interest should be included in the assessment. This requires an extension of the policy assessment framework that was described above. We explained that outcomes of interest may get contributions from outside the transport system, and that if they have significant effects on the outcomes of interest they should be taken into account in the assessment of policies. We now need to clarify the relationship between the external processes (forces) and the outcomes of interest to explain which of them should be included in the policy assessment framework.

Consider CO2 emissions -- an important outcome of interest. CO2 emissions are generated by the transport system, but also by the heating systems in houses, and by power stations generating electricity (there are other sources, but we will not discuss these here). The heating systems and the power stations are outside the boundaries of the transport system. It is clear that heating systems should not be included in the assessment of transport policies. But it is equally clear that the total direct contribution from the transport system in terms of CO2 emissions should be included in the assessment of transport policies. This direct contribution is generally estimated from the number of vehicle kilometers driven combined with the emission rates of the vehicles. What is missing from this calculation is the contribution to CO2 emissions by power stations. Although electricity is used for lighting in houses, it is also used to light streets and highways. It is also used to power electric vehicles, trams and trains. Clearly the contribution to CO2 emissions from power stations is at least partly related to the transport system. A correct policy assessment framework would have to reflect the fact that power stations are needed to deliver electricity for transport.

As a result of the need to involve factors outside the boundaries of the transport system in the assessment of transport policies, we add a new boundary around the transport system that includes those external forces that contribute to the outcomes of interest and (partly) substitute for the contributions to those outcomes of interest from the transport system. We call this new boundary the policy domain. The production of electricity to power transport vehicles and streetlights lies within the transport policy domain.

There is another type of external force that should be included within the policy domain. This is an external force that is controllable by policy but does not directly contribute to any of the outcomes of interest. An example of such an external force is research and development. A transport policy might subsidize the development of new technologies. Although vehicles with new technologies are in the system, the new technologies themselves and the process to develop them are not. Therefore, research and development of new vehicle technologies lies within the transport policy domain. It can be described as a system itself, with its own external forces, policies acting on it (e.g., subsidies), and outcomes of interest (the vehicle technologies).

Figure 3 illustrates the difference between the policy domain and the transport system. Assume that system 1 in Figure 3 is research and development. Research and development itself is influenced by FDSCs, including transport policies. This system produces new vehicle technologies that form an FDSC for the transport system (not all new technologies are used; this depends on many factors). System 2 in Figure 3 might represent the electricity production subsystem or a hydrogen production subsystem. System 2 is also influenced by FDSCs, but not necessarily by transport policies. The outcomes of System 2 need to be taken into account, because these outcomes partly substitute for outcomes from the transport system.

Important FDSCs are those for which changes will lead to significant changes in the outcomes of interest. These are FDSCs that should be monitored. Another reason for identifying important FDSCs is to identify leverage points for policy measures in cases in which the FDSCs belong to the group that policymakers can influence by their decisions. Some of the FDSCs will be inside the policy domain (e.g. research and development, as discussed in the above example). Contributions to an outcome of interest coming from outside the policy domain will not be taken into account.

Figure 4 shows how FDSCs act on the transport and mobility system. They generally act on one of the markets and influence one or more outcomes of interest. To understand the factors influencing the outcomes of interest, one has to understand the linkages and interactions among all the involved elements, including the FDSCs. Figure 4 gives only a few examples of FDSCs. A more complete listing of FDSCs is given in Table 9. This table relates an FDSC to the box within the transport system that it influences.

CONCLUSIONS

The three-market representation of the transport system described above and illustrated in Figures 2 and 3 provides a useful framework for understanding the full spectrum of the transport policy domain (beyond the traditional narrow focus on infrastructure planning). The system diagram and system approach provide new tools for policy analysts and policymakers at a time when systems are growing in complexity, in uncertainty, and in their interactions with each other. These tools facilitate ways of anticipating systemic problems rather than merely reacting to them. For example, in the past, policymakers reacted to increased demand for transport by increasing the infrastructure supply. In this case, the policymakers were focusing only on the third market, the traffic market. Gradually, they have expanded their interest to the second market, where the mode choice is made. However, recent steps have added the movement market, where demand for transportation from a certain origin to a certain destination is generated, to their policy domain. By linking goals to outcomes of interest, and outcomes of interest to changes in the transport system, policymakers can become more systematic and methodical in identifying policies that are effective in helping them to achieve their goals.

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Figures and Tables

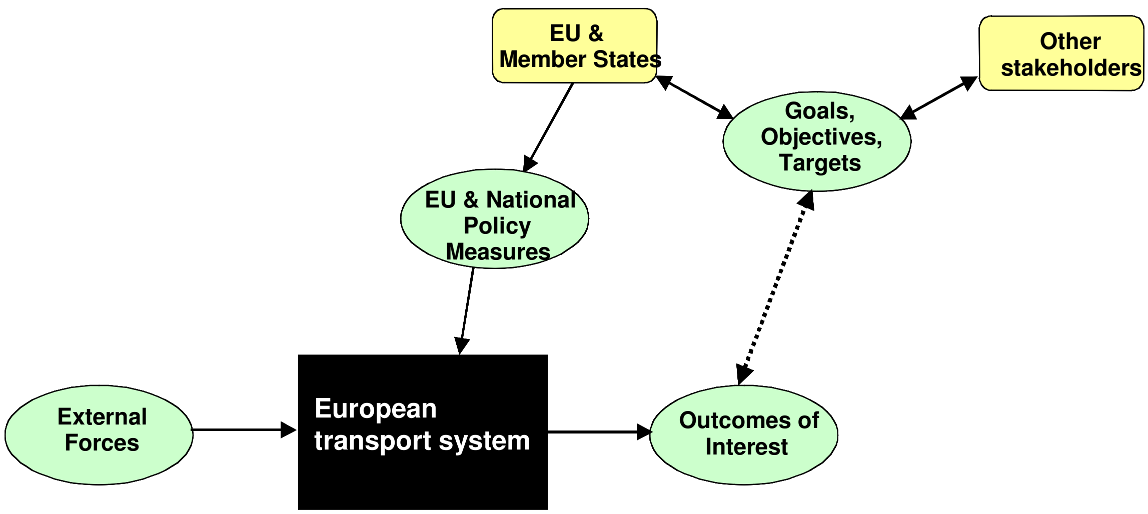

Figure 1 *— The policy assessment framework applied in SUMMA*

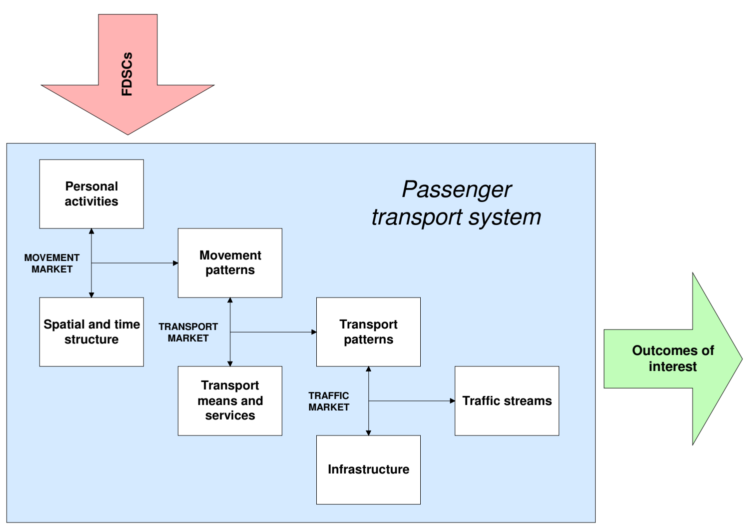

Figure 2 *— The passenger transport system*

Table 1 — Links between sustainability goals and SUMMA outcomes of interest

Element from the definition of sustainability	Related Outcome of Interest (OoI)	Dimension
Basic access	• Accessibility	Economic, social
Development needs	• Accessibility • Cost / benefits to economy • Productivity / Efficiency • Transport operation costs • Social cohesion	Economic, social
Safety	• Safety and security	Social
Human health	• Safety and security • Fitness and health • Liveability, amenity • Emissions to air, soil and water	Social, environmental
Ecosystem health	• Direct ecological intrusion • Emissions to air, soil and water • Waste	Environmental
Equity	• Equity	Social
Affordable	• Accessibility (incl. affordability)	Social
Fairness	• Accessibility (by mode) • Equity • Transport operation costs	Economic, social
Efficiency	• Productivity / efficiency • Transport operation costs	Economic
Transport modes	• Accessibility	Economic, social
Competitive economy	• Accessibility • Transport operation costs • Costs and benefits to the economy • Productivity / efficiency	Economic
Emissions	• Emissions to air, soil, water • Emissions of noise	Environmental
Waste	• Waste	Environmental
Renewable and non-renewable resource use	• Resource use	Economic, environmental
Impacts on land	• Resource use (incl. land take) • Direct ecological intrusion (incl. fragmentation)	Environmental
Noise	• Emission of noise	Environmental

Table 2 *—Elements of the passenger transport system*

System element	Description
Activities to be performed	Number of activities per type and duration
Spatial and time structure	Places, in terms of location and time, where activities can be performed
Movement patterns	Number of movements per type, location and time unit (person kilometers assigned to origins and destinations)
Transport means and services	Available supply of transport means and services in terms of type, location and time
Transport patterns	Use of transport means in terms of type, location and time (person kilometers assigned to transport means and services)
Infrastructure and its attributes	Available supply of infrastructure elements in terms of type, location and time
Traffic patterns	Use of infrastructure in terms of type, location and time (person and ton kilometers assigned to infrastructure)

Table 3 *—Actors in the passenger transport system*

Market	Actors on the demand side	Actors on the supply side
Movement	Potential travelers	Suppliers of activity facilities (schools, shops, etc.)
Transport	Travelers	Suppliers of transport means and services, and transport facilities (transporters, providers of logistical services, etc.)
Traffic	Operators of manned or unmanned transport means	Infrastructure providers (managers of rail, road and other modes of transport)
All three	Governments Interest groups	Governments Interest groups

Table 4 *—Examples of activities and factors influencing the settlement process*

Activity	Sector	Factors influencing settlement
All activities		• Cost of land • Legislation
Relaxing at home	Home	• Employment • Accessibility to all other activities • Landscape • Neighborhood • Cost of living
Working	All sectors	• Labor market • Accessibility – to raw materials – to intermediate products – to finished products – skilled laborers
Learning	Nurseries	• Accessibility • Neighborhood
Shopping	Shops, markets	• Population of catchment area • Income of residents in catchment area • Location of competing shops

Table 5 *— Factors influencing personal activity times*

Sector	Factors influencing the activity time
Home	Employment and education situation of household members
Agriculture	Daylight
Industry	Round-the-clock production
Service sector	Availability of employees; demand from clients
Retail sector	Availability of employees; demand from shoppers
Nurseries	Work hours

Table 6 *—Passenger transport modes and means*

Transport mode	Transport means
Road	Car, bus, motorbike, bicycle, walking, horse, wagon etc.
Rail	Train, tram, metro
Short-sea Inland waterways Maritime sea	Ship, ferry
Air	Airplane, hot-air balloon, zeppelin etc.
Intermodal	Combination of the given means

Table 7 *—Service characteristics of passenger modes*

Characteristic	Description
Fuel consumption	Amount of fuel consumed per unit distance
Travel price	Fixed cost (e.g. car price and insurance for the private transport; ticket price for public transport) Variable cost (e.g. fuel cost)
Time consumption	Travel time (e.g. network speed, congestion) Transfer time by time of day Waiting time (frequency, reliability)
Availability (time and place)	Access/Egress time
Accessibility for deficiency groups	Availability of special provisions for handicapped or elderly (e.g., access for handicapped; seats reserved for handicapped and elderly)
Reliability	Delays in services
Potential load factor	Maximum load in tons Maximum number of passengers
Environmental friendliness	Emission rates of pollutants
Security	Crimes Economic losses by crimes (e.g. stolen suitcases on airports) Patrol by security guards Investment in security Video cameras in train stations
Safety	Accidents Injuries Fatalities Economic losses in accidents
Comfort	Crowding Quality of equipment Toilets (e.g. on trains and train stations) Services (e.g., availability of food on trains) Age of equipment Cleanliness of equipment

Table 8 *—Network characteristics by mode*

Network Characteristic	Description
Coverage	Length of network
Capacity	Height, depth, width Numbers of vehicles that can be operated per per day (or numbers of passengers)
Speed	Average network speed
Price of infrastructure usage	Tolls, parking etc.
Reliability	Time that infrastructure cannot be used (e.g. road is closed due to ice or accidents)
Maintenance	Frequency of maintenance Investment in maintenance of network
Security	Crimes (e.g., hold-ups of vehicles) Security patrols
Safety	Accidents Injuries Fatalities Damages to vehicles
Accessibility	Access/egress locations in network
Congestion	Amount of time and hours of congestion
Interoperability	Harmonisation of standards between modes
Interconnectivity	Density of locations where transfer form one mode to the other is possible
Quality of network	Investment in infrastructure

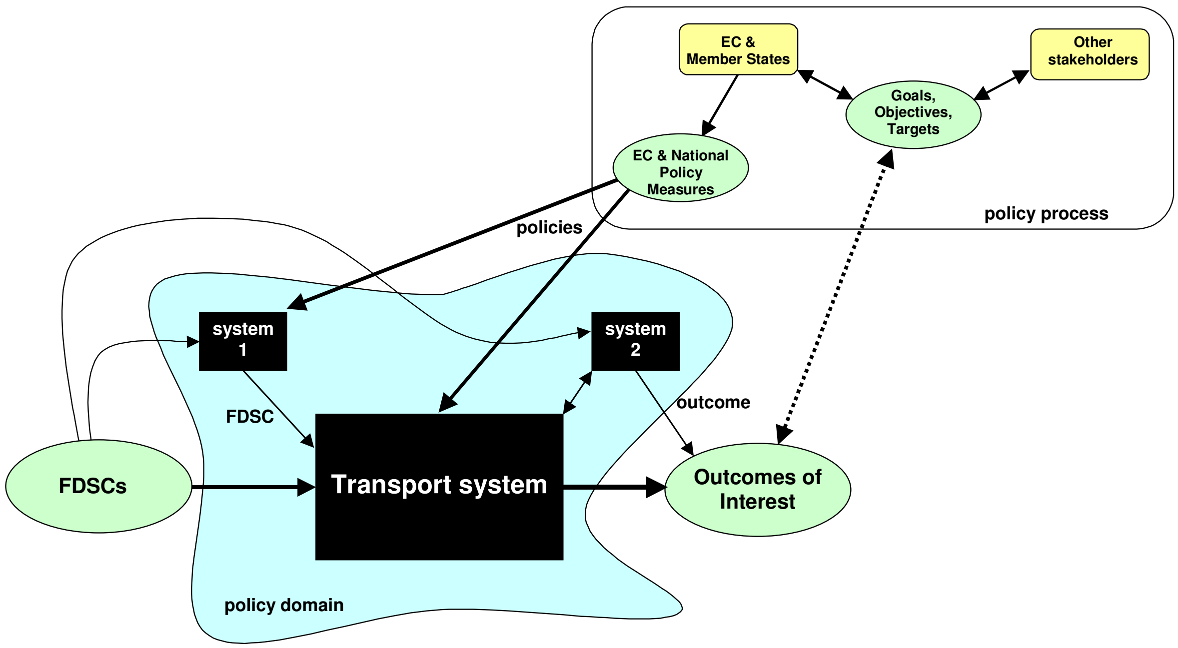

Figure 3 *— Policy assessment framework including the policy domain*

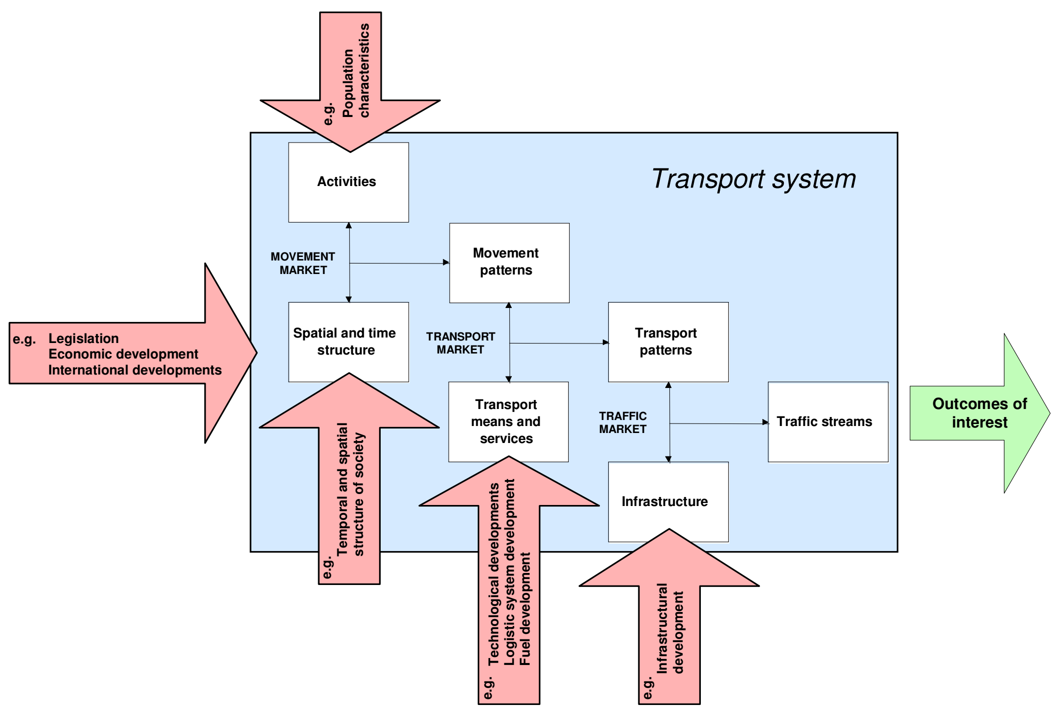

Figure 4 *— Forces Driving System Change*

Table 9 *— Forces Driving System Change (FDSC) and the location of their influence on the transport system*

Force Driving System Change	Influenced box in the transport system
Demographic development	Activities
Income development	
Labor force development	
Labor force participating	
Job market development	
Changes in economic structure	
Changes in the cultural characteristics of society	
Land market development	Spatial and time structure
Time routine development	
Changes in logistics systems	
Changes in location of activities	
Fuel and energy development	Transport means and services
Development of vehicle technologies	
Infrastructure development	Infrastructure
Consumer demand development	General - several boxes
Legislation	
International developments	
Climate changes	
Changes in GDP	
Innovations in vehicle and fuel technologies	
Political changes	