Developing Indicators for Modeling and Monitoring Sustainable Transport

Sanna Ahvenharju, Gaia Group, Turku, Finland
Michal Arend, Econcept AG, Zürich, Switzerland
Roberto De Tommasi, Synergo, Zürich, Switzerland
Rik van Grol, RAND Europe, Leiden, the Netherlands
S. Adnan Rahman, RAND Europe, Leiden, the Netherlands
Wolfgang Röhling, Kessel + Partner, Freiburg, Germany
Warren E. Walker, RAND Europe, Leiden, the Netherlands

ABSTRACT

Sustainable development requires a balance between (1) the desire for a clean environment and the welfare of future generations and (2) the desire for economic growth and mobility, with concomitant increases in transport demand and use of fossil fuels. Policymakers have to accommodate these conflicting desires by balancing the positive and negative impacts of transport. This paper presents some of the results of the SUMMA (SUstainable Mobility, policy Measures and Assessment) project, which is a project sponsored by the Directorate-General for Energy and Transport (DG-TREN) of the European Commission (EC). Among the objectives of SUMMA are to define and operationalize the concept of sustainable transport, to define a set of outcomes from the transport system that can help policymakers monitor progress towards sustainable transport, and to assess policies designed to achieve this objective.

Most "outcomes of interest" to policymakers (e.g. the health effects of vehicle emissions or the accessibility of public transport) cannot be directly observed or are not defined clearly enough to be measured quantitatively. For purposes of monitoring or policy analysis, therefore, related outcome indicators are defined that can be measured or estimated (e.g. vehicle emissions or the distance to the closest bus stop). Determining the outcomes of interest and the associated outcome indicators is the subject of this paper.

In many projects focused on sustainability, the outcomes are limited to environmental impacts and the indicators are influenced by data availability. SUMMA covers all three dimensions of sustainable development (economic, environmental, and the often neglected social dimension) and the impact of the transport system on them. The result is a much more complete list of outcomes of interest and associated indicators, some of which might not be measurable (yet). The idea is that data for these indicators might be able to be collected in the future. In fact, the results of the project might stimulate the collection of some of these data. This paper describes how we related the EC's definition of sustainable transport to outcomes of interest, the principles that we used in developing the set of outcome indicators, the process we used in developing the indicators, and the resulting set of outcome indicators that we designed for each of the outcomes.

1. INTRODUCTION

1.1. Sustainability

Since the publication of the Brundtland report (WECD, 1987), the term sustainability has been associated with a myriad of topics. The term is also widely used by politicians, policymakers and academics and permeates a broad range of fields (e.g., agriculture, transport, economic development). The concept is multidisciplinary in nature. Inherent in the concept are economic, environmental, social, ecological, philosophical and ethical concerns. Given the range of disciplines concerned with, and concerns represented under this concept, it is inevitable that there are numerous interpretations and definitions of the concept. Almost everyone agrees about the need for sustainability and sustainable development, but few can agree on precisely what it means, or how to achieve it.

Related to the concept of sustainability is the concept of sustainable development. These two terms are often used interchangeably and it is worthwhile to clarify the relationship of these two terms. Although these two terms are obviously related they emphasize different things. Sustainable development refers to a long-term time path that results in a sustainable situation. Sustainability is a state that is capable of being sustained. There is agreement on the fact that the way the transport system is currently working (e.g., its dependence on fossil fuels) is unsustainable. The question is whether there is a path to a sustainable transport system.

Although the list of definitions for sustainability and sustainable development is long, the most widely used definition of sustainable development is the original definition given by the WECD (1987): "Sustainable development is development that meets the needs of the present without compromising the needs of future generations to meet their own needs". Even though this definition leaves much to argue about, it has become the basis for most work on sustainable development. The general principle in this definition – one of intergenerational equity – has received substantial international support, and led to the UN Conference on Environment and Development in 1992 (commonly known as the Rio Earth Summit), attended by Heads of State and Government. At this summit, several important agreements were reached, including the Climate Change Convention, and moves towards a Biodiversity Convention. On "sustainable development" the key outcome was the Rio Declaration on Environment and Development, which set out 27 general principles supported by 'Agenda 21', a comprehensive action plan for the pursuit of sustainable development into the next century, with 40 chapters providing detailed recommendations for international agencies, national and local governments, and non-governmental organizations covering environmental, social and economic issues. One of the initiatives included under Agenda 21 was the establishment of a new body called the Commission on Sustainable Development (CSD) within the UN, and to call on governments to prepare national strategies for sustainable development. Since the Rio Summit and the establishment of the CSD, several countries have developed and adopted sustainable development action plans.

Much of the work on sustainability has focused on the environmental-economy interaction. More recently, however, there have been attempts to broaden the concept of sustainable development by including the social dimension and considering the interactions between society and economy, and between society and environment (Munasinghe, 1993). We use this broader concept.

1.2. SUMMA

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 CO_2 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. Traditional solutions are unlikely to solve these problems. So far, policymakers have been unsuccessful in their efforts to reduce CO_2 emissions to below the Kyoto targets and building new transport infrastructure has generally led to only short-term reductions in congestion.

The need for new approaches in transport policy is now recognized. Sustainable transport and mobility has become an important 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, make it harder to achieve this 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 outcome indicators from the transport system that can help policymakers monitor progress towards sustainable transport and mobility. (For further information on the SUMMA project, see the SUMMA Website: www.summa-eu.org.)

1.3. Analytical Framework

By its very nature, the analysis of policies designed to lead to sustainable transport requires a holistic and systematic approach. Policies that reduce the environmental impacts of transport often have negative economic consequences; policies that improve economic development often have negative social impacts. The approach that we are using in the SUMMA project, which we call the systems approach (see Findeisen and Quade (1985)), takes into account all three dimensions of sustainability simultaneously and forces users of the approach to deal with tradeoffs among the three in evaluating the attractiveness of policies. It also tries to improve the performance of the entire system, not to optimize the performance of one subsystem (e.g., public transport) without considering the effects on the rest of the system.

Figure 1 presents the framework for the systems approach that we applied in the SUMMA project. As shown on the right side of the figure, the 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 (in this case, 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"). 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.

As shown in Figure 1, 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, which are under the control of policymakers and that are designed to help meet one or more of their policy objectives. 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.

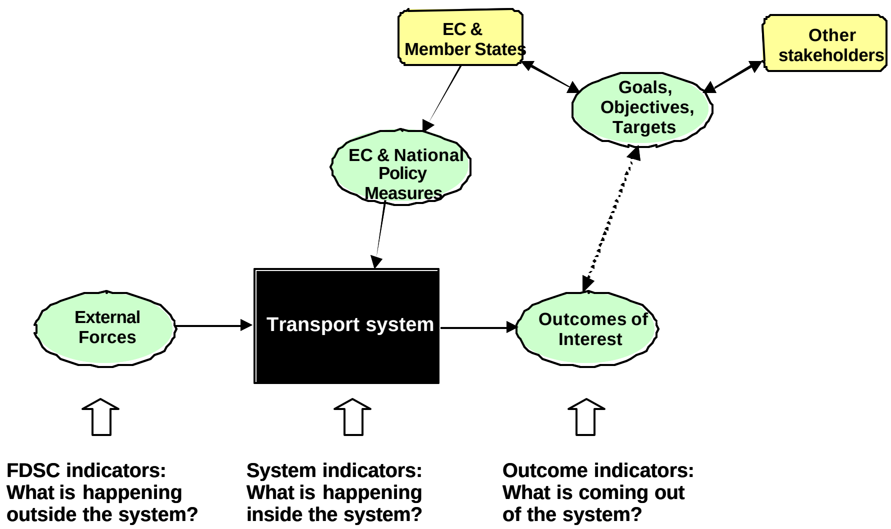

Figure 1 ¾ The policy assessment framework applied in SUMMA

Determining the degree to which a policy meets an objective involves measurement (either qualitative or quantitative). Such measurement is required both before a policy is implemented (in performing the policy analysis) and after (to make sure the policy is having the desired effect). Analysts require quantitative measures for representing the FDSCs, the transport system, and the outcomes of interest in order to build useful policy analysis models. Policymakers require quantitative measures for the outcomes of interest in order to monitor the results of policy changes and make sure that the policy is having the desired effect. These requirements led to a step in the SUMMA project in which we identified the quantitative measures (which we called indicators).

We defined the following three 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. The outcome indicators are the observable outputs of the system. They provide information about how sustainable the state of the present transport system is and (by comparing values of the indicators over time) whether it is moving toward a more sustainable state or not. (E.g., automobile emissions of NOx in the Netherlands in 2003.)
- **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 inside the system. (E.g., NOx emissions per kilometer driven, by type of vehicle.)
- **FDSC indicators:** An FDSC indicator can be used to describe or monitor changes in the Forces Driving System Change. (E.g., demographic changes, changes in GDP.)

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, and to help design policies, but have little importance in the policy assessment. They may, however, provide an understanding of the outcomes by providing information about the steps between the implementation of a policy measure and the resulting changes in the outputs of the system, and can provide insights into expected outcomes in situations when the outcomes themselves are unobservable. 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. The outcome indicators are of most importance to the SUMMA project. They identify the consequences of policy changes that can be estimated by models and monitored in the real world and that are directly related to the objectives (although we may not be able to specify the actual relationship).

2. SUSTAINABLE TRANSPORT: GOALS AND OBJECTIVES, OUTCOMES OF INTEREST, AND OUTCOME INDICATORS

2.1. Sustainable Transport and Outcomes of Interest

Given that there is little agreement on what the concept of sustainable transport and mobility 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 SUMMA, one of our objectives was to agree on a definition of sustainable transport and mobility and relate that definition to a set of outcomes of interest.

The literature includes many definitions of sustainable transport. An analysis of the diversity of definitions led us to conclude that no definition stands out as being significantly better than the others. Since our project was being conducted for the European Commission, we therefore 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.

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	Environmental
Impacts on land	• Resource use (incl. land take) • Direct ecological intrusion (incl. fragmentation)	Environmental
Noise	• Emission of noise	Environmental

2.2. Outcomes of Interest vs. Outcome Indicators

As described above, the outcomes of interest are linked to the policymakers' goals. A goal is a generalized, non-quantitative policy objective (e.g., "allow basic access"). Policy actions are intended to help meet the goals. Although outcomes of interest are the criteria that policymakers and other stakeholders would like to use in their evaluation of transport policies, there are two reasons why this is generally not possible and why we associate one or more outcome indicators with each of the outcomes of interest. First, an outcome of interest (e.g., accessibility) may not be a well-defined, directly observable, clearly measurable quantity. Second (as in the case of health effects or CO_2), there may be factors external to the transport system that also contribute to the outcome of interest.

In the first case, if an outcome of interest is not directly measurable, we need to identify related outcomes that are measurable. These are the outcome indicators. An outcome indicator is a proxy for a goal or an outcome of interest, since it is not the same as goal or outcome of interest, but is directly related to it. For example, reducing air pollution is one of the goals of the policymakers. For this goal, an outcome of interest from the system might be vehicle emissions. Vehicle emissions are measurable. We can, therefore, define outcome indicators, such as the number of kilotons of NO_x emissions from vehicles in Europe in 2003. However, NO_x emissions are not the same as air pollution. There is a direct relationship, but air pollution is caused not only by NO_x emissions. The relation is even less straightforward realizing that air pollution in a region depends on the specific geographic and climatic aspects of the region. Nevertheless, one can safely say that, all other things being equal, a policy that reduces NO_x emissions will reduce air pollution (although it is not possible to say by how much).

The second case, in which factors external to the transport system contribute to an outcome of interest, is illustrated in Figure 2. For instance, suppose the outcome of interest was CO_2 emissions. The transport system is not the only source of CO_2 emissions. Industry also produces CO_2 emissions (e.g., in generating electricity). So, the outcome indicator "CO_2 emissions from transport" is not the same as the policymakers' outcome of interest "CO_2 emissions from all human activity". For policymaking, it is important to understand the relative contributions of the various sectors to any specific outcome of interest. Such an understanding would suggest where policy should be focused in order to be most effective in achieving the policy goals. For example, in Germany, the transport sector contributes only 22% of the of the CO_2 emissions, while the service sector and households contribute 24% and the energy sector contributes 30%. Looking at the outome of interest "waste", we see that scrapped cars contribute less than 1% of the waste generated in Europe, while building construction and demolition contribute 26% and manufacturing contributes 27%. This suggests that, in order to achieve a sustainable society, policymakers need to have a broad focus, which includes all sectors of the economy.

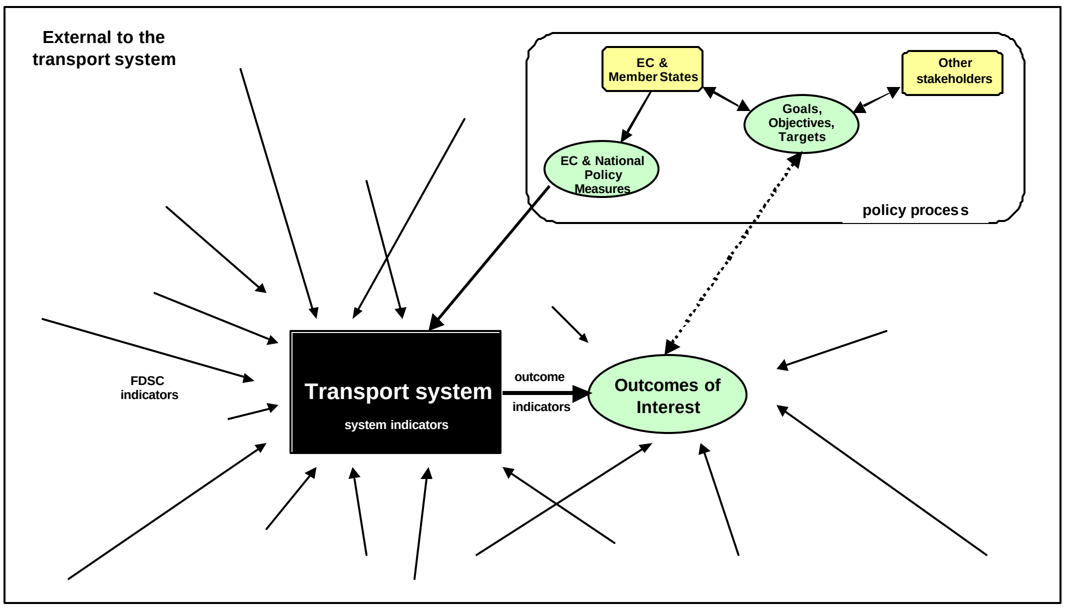

Figure 2 ¾ Relationship between the outcome indicators and the outcomes of interest

3. DEVELOPING OUTCOME INDICATORS FOR SUSTAINABLE TRANSPORT

3.1. Principles of Indicator Development

There are many existing sets of indicators that have been developed to monitor sustainability and sustainable transport. Most of them, however, focus on the environment (e.g., the outcomes of the OECD project "Environmentally Sustainable Transport" (OECD, 1996)), or are based on data that are easily collectable (e.g., indicators for which data are being collected by Eurostat through the Transport and Environment Reporting Mechanism (TERM) – see EEA, 2002). The main criteria that we used in creating the set of outcome indicators were their importance, relevance, and completeness in measuring and monitoring the outcomes of interest. We tried to make sure that the indicators covered all of the economic, environmental, and social outcomes of interest, had a clear relationship to sustainable transport, and were measurable outcomes of the transport system. Availability of data or methods to calculate these indicators was not taken as a decisive factor, although it certainly had an impact on the indicators we selected. The set of indicators presented in this paper is, therefore, a 'wish list' of indicators that are needed in both modeling and monitoring the performance of the transport system in the light of its impacts on sustainability. The specification of some of the indicators is incomplete (especially in the social dimension), suggesting directions for future research.

3.2. Process of Indicator Development

Indicators were developed by the SUMMA team for each outcome of interest:

- Based on existing work whenever available;
- Identifying several possible indicators for each outcome of interest.

For each indicator, we developed a detailed description

- Using the same template to describe each indicator
- Including the definition (with units of measure), references, applicable disaggregations (e.g., geographic, demographic, temporal)

The set of indicators was screened and revised at expert and policymaker workshops, where we:

- Received detailed comments and suggested changes for the indicator descriptions;
- Ranked the importance of the outcomes of interest (which fed into an assessment of the relevance of the identified indicators; some were dropped).

4. THE OUTCOME INDICATORS

4.1. Environmental Indicators

Environmental impacts of transport are the most studied of the three kinds of impacts -- economic, social and environmental. Even so, finding a systematic framework for classification is not simple: there are many of them around, but not one that would be widely used and accepted.

In order to ensure completeness of the outcome indicators, an input-output framework was used for the classification of the environmental outcomes of interest. This framework, presented in the Figure 2, is a modification of one developed by Gudmundsson (2002). Important in this framework is the differentiation between (1) the inputs needed *from* the environment to the transport system (the resources used), and (2) direct outputs from the transport system *into* the environment (the outcomes of interest). Note that the direct outputs from the system (e.g., noise and emissions to air) are indirectly related to the ultimate outcomes defining a sustainable society (e.g., climate and ecosystems).

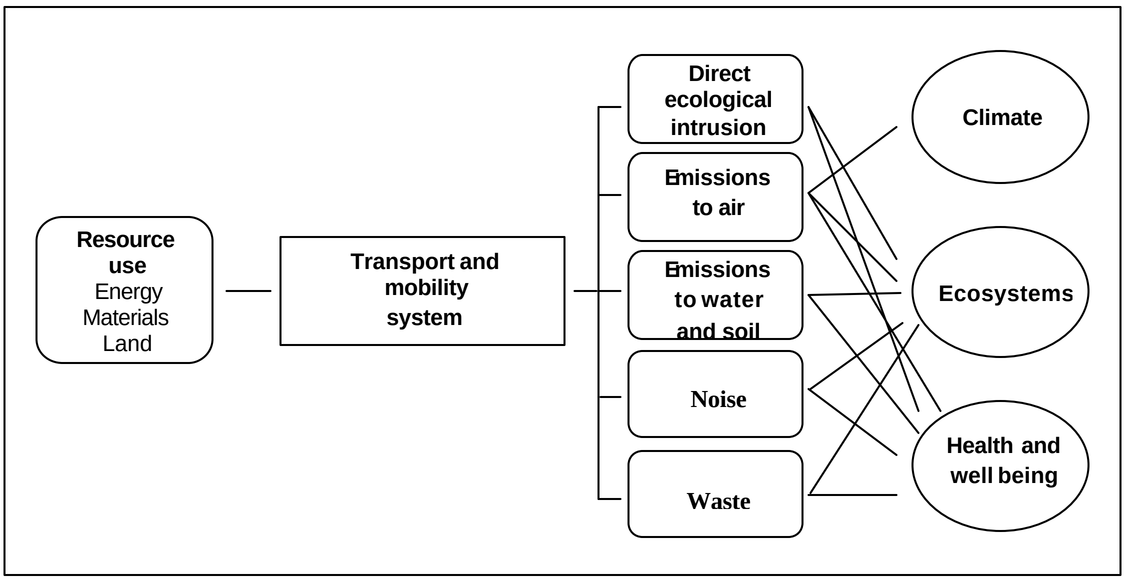

Figure 2 — Input–output framework of the environmental outcomes of interest (adapted from Gudmundsson, 2002)

Thus, we limited our selection of outcomes of interest and outcome indicators to the outputs from the transport system. The ultimate impacts (e.g. on health) are not included. (The importance of the ultimate impacts is taken into account in a later stage of the project in which we will be monetizing the outcomes.)

An important concept that has been used in the selection of the indicators to represent the outcomes of interest is the life-cycle approach. Rather than looking at only the impacts of transport activity, such as vehicle emissions and infrastructure land-take, we attempted to include impacts caused at all stages of the vehicle/vessel/aircraft life-cycle as well as infrastructure manufacture and production. A simple example of the contribution of transport to environmental problems is the life cycle of vehicle production and use presented in the Figure 3. The manufacturing stage depletes resources, consumes energy, and produces wastes; the service stage produces emissions, noise and accidents; and the end of life stage involves waste, recycling, and disposal.

Some may argue that looking at the whole life cycle is not relevant, since many of these issues belong to other policy sectors. However, in most cases they can also be influenced through transport policy, even though these connections are indirect. A better argument for applying the life-cycle approach is the fact that our aim was to identify the most important environmental impacts of transport, regardless of their policy domain. If these happen to be outside the traditional transport policy sector, this is also an important piece of information.

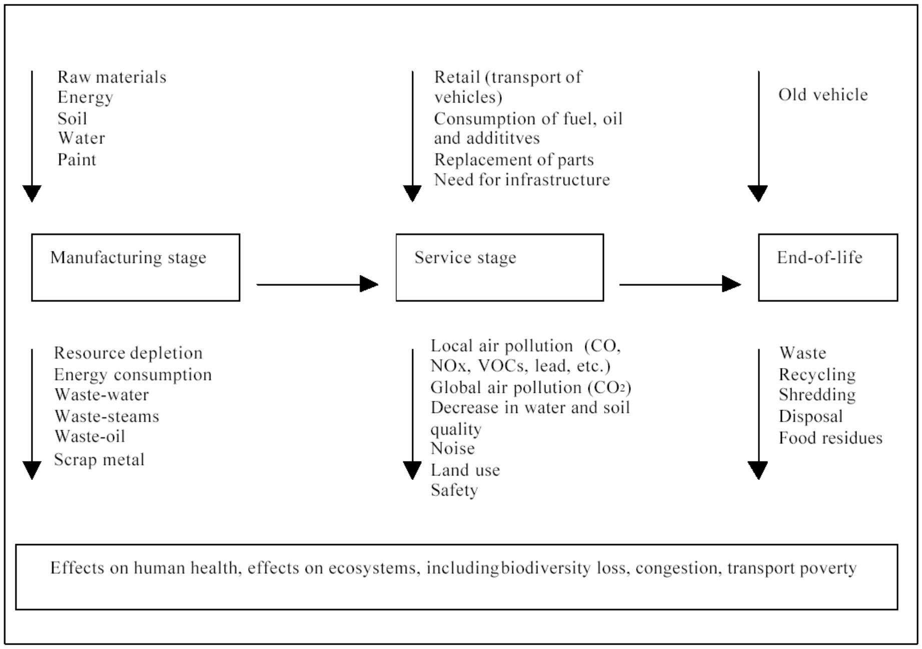

Figure 3 — Life cycle of vehicle production and use (UNEP, 2001)

In developing indicators for monitoring environmental impacts of transport, the U.S. Environmental Protection Agency (US EPA, 1999) identified the following stages of a transport system life-cycle:

- **Infrastructure construction** - Construction and development of transportation facilities, such as roadways, railways, airports, and navigation channels;
- **Vehicle manufacture** - Production of vehicles and parts (including motor vehicles, railcars and locomotives, aircraft, and ships and boats);
- **Travel** - Vehicle operations to transport people and goods;
- **Operations, maintenance, and support** - Activities to support travel, such as application of de-icing chemicals, and operation of facilities to support travel, such as gas stations, airport terminals, and marinas;
- **Disposal** - Disposal or recycling of vehicles, parts, and facilities.

However, introducing the life-cycle approach to the indicator selection entered into a complex field of interrelations, and in many cases finding suitable indicators for all aspects would have simply caused an endless list of indicators. Thus a coarse selection based on the present understanding of the relative importance of the impacts was necessary.

The list of selected environmental outcome indicators is presented in Table 2. The arrows in the table indicate the desired direction of development in the indicator values. In the case of some indicators, the desirable direction may not be clear, due to the fact that within the indicator there may be counteracting changes. For example, for indicator EN42, the amount of pollutants released in transport accidents should of course be decreasing. However, it depends on the type of pollutant released. For example, even when the overall amount of polluting substances has decreased, the share of more harmful substances may have increased, resulting in no change or an increase in the net negative effect. Indicators that need a closer look using detailed data before an interpretation can be made are marked with an asterisk (*). The indicators are divided into categories according to the six environmental outcomes of interest (resource use, direct ecological intrusion, emissions to air, emissions to soil and water, noise, waste).

Table 2 — Environmental Outcomes of Interest and Related Outcome Indicators

Outcome of Interest	Indicator Name	Indicator Definition	Units and relation to the environmental aspect of sustainability	
EN1 Resource Use	**EN11 Energy consumption**	A. Final energy consumption in transport by mode and by energy source	Million tonnes of oil equivalents	↓
		B. Share of final energy consumption in transport produced from renewable energy sources	Million tonnes of oil equivalents	↑
	EN12 Consumption of solid raw materials	A. Raw materials used in building transport infrastructure by type of material	Tonnes	↓*
		B. Raw materials used in vehicles manufacture by type of material	Tonnes	↓*
	EN13 Land take	A. Land take by transport infrastructure by mode	Km^2	↓
		B. Land take by transport infrastructure by mode percentage of country surfaces	Percentage of surface area	↓
EN2 Direct Ecological Intrusion	**EN21 Fragmentation of land**	Effective mesh size (m_{eff})	Km^2	↑
	EN22 Damage of underwater habitats	Amount of dredging at ports, waterways, etc. by type of dredged area	M^3	↓*
	EN23 Losses of nature areas	Losses of natureareas due to construction of transport infrastructure by mode, and as % of total nature area losses	Km^2 and percentage of total nature area losses	↓
	EN24 Proximity of transport infrastructure to designated nature areas	Designated nature areas in the proximity (unit has to be defined) of transport infrastructure in total and by mode	Km^2 and percentage of designated nature areas	↓
	EN25 Light emissions	Area of lighted transport infrastructure	Km^2	↓
	EN26 Collisions with wildlife	Annual number of collisions with animals by mode	Number of collisions per year	↓*
	EN27 Introduction of non-native species	Number of non-native species introduced by marine transport and in transport infrastructure construction	Number of species	↓*
EN3 Emissions to Air	**EN31 Transport emissions of greenhouse gases**	Transport emissions of greenhouse gas by mode and by type of gas	Tonnes of CO_2 equivalent	↓
	EN32 Greenhouse gas emissions from manufacture and maintenance	Greenhouse gas emissions from vehicle and parts manufacture, and transport maintenance by mode and by gas	Tonnes of CO_2 equivalent	↓

	EN33 Transport emissions of air pollutants	Transport emissions of air pollutants by mode and by type of pollutant	Ktonnes	↓*
	EN34 Air pollutant emissions from manufacture and maintenance	Emissions of air pollutants from vehicle and parts manufacture, and transport maintenance by mode and by type of pollutant	Ktonnes	↓*
EN4 **Emissions to Soil and Water**	**EN41 Hardening of surfaces**	Hardened surfaces in transport use by mode and as % of total land take by transport infrastructure	Km^2 and percentage of total land take	↓
	EN42 Polluting transport accidents	Amount of pollutants released in transport accidents by type of pollutant and by mode	Litres or tonnes	↓*
	EN43 Runoff pollution from transport infrastructure	Amount of pollutants released by run-offs by type of pollutant and by mode	To be defined	↓*
	EN44 Wastewater from manufacture and maintenance of transport infrastructure	Amount of wastewater produced from manufacture and maintenance of transport infrastructure not treated in wastewater treatment plants	M^3 or litres or tonnes	↓
	EN45 Discharges of oil at sea	Illegal discharges of oil by ships at sea	Number of observed oil slicks	↓
	EN46 Discharges of wastewater and waste at sea	A. Amount of wastewater discharged into sea from ships	Litres or tonnes	↓
		B. Amount of waste discharged into sea from ships	Tonnes or m^3	↓
EN5 **Noise**	**EN51 Exposure to transport noise**	A. Amount of population exposed to traffic noise levels detrimental to health (>65 dBA) by mode	Number and percentage of population	↓
		B. Amount of population exposed to traffic noise levels affecting well-being (between 40 and 65 dBA) by mode	Number and percentage of population	↓
EN6 **Waste**	**EN61 Generation of non-recycled waste**	Total amount of non-recycled waste generated by transport by mode and by type of waste	Tonnes	↓*

4.2. Economic Indicators

The transport sector is not an end in itself. It has a service function, supporting the mobility needs of people and goods. For example, it can increase the economic efficiency of production processes by spatially separating the processing. On the other hand a great amount of resources are needed, which produce costs for the society, individuals, and firms. The transport sector does not, by itself, provide any capital build up. On the contrary, it consumes large amounts of capital (in the form of energy consumption and physical outputs, such as pollution, noise, damaged land, etc.). The sector itself, therefore, will never be able to satisfy strong sustainability criteria. It can be justified on sustainability grounds only in terms of its relationship with other sectors.

Therefore, looking at the economic dimension of sustainability, the main questions are:

- How efficiently does the transport system work?
- What are the costs and the benefits of transport for individuals and for society?

Our objectives in defining economic outcome indicators were to be able to:

- monitor the economic impacts of transport
- evaluate the economic impacts of alternative transport policies and other external changes to the transport system

There is less common agreement on economic indicators for sustainable transport than there is for the environmental indicators. Our specification of economic outcome indicators, therefore, was based primarily on the definition of the Council of European Union for a sustainable transport system (Council of the EU 2001). The main economic objectives of the definition are basic access, affordability, fairness, competitive economy and efficiency. As a result, we identified the following five categories of economic outcomes of interest:

- Accessibility
- Transport operation costs
- Productivity/ efficiency
- Costs to economy
- Benefits to economy

We used the Driving force-State-Response model (DSR) model of the United Nations Commission for Sustainable Development (UN CSD, 1996) as the basis for the identification of the economic indicators. The DSR model extends the OECD's Pressure-State-Response (PSR) model (OECD, 1998) to facilitate the inclusion of non-environmental variables. The replacement of the term "pressure" in the PSR framework by the term "driving force" was motivated by the desire to include economic, social, and institutional aspects of sustainable development. Another aspect of the DSR framework that separates it from its predecessor is that there is no assumption of causality between indicators in each of the categories.

In the framework, driving forces represent human activities, processes, and patterns that have an impact on sustainable development. Driving force indicators are mainly found in the outcomes of interest "accessibility" (e.g. "accessibility of origins/ destinations (EC12)" and "access to basic services (EC13/ SO11)"), and "transport operation costs" (e.g. "transport related expenditures of households (EC22)" and "transport prices (EC23)").

State indicators provide an indication of sustainability at a given point in time. In the economic dimension, state indicators are provided in the outcome of interest "productivity/ efficiency" (e.g. "energy efficiency (EC 34)").

Response indicators indicate policy options and other responses to the state of sustainability. These indicators provide a measure of the willingness and effectiveness of a society in providing responses. Some responses to the state of sustainability can be legislation, regulation, economic instruments, and information activities. Examples of response indicators for the economic dimension of the SUMMA framework include the outcome indicators "costs to economy" and "benefits to economy" (e.g. "public revenues from taxes and traffic system charging (EC52)" and "benefits of transport (EC53)") (Mortensen 1997).

The list of selected economic outcome indicators is presented in Table 3. The arrows in the table indicate the desired direction of development in the indicator values. In summary, the indicators can be grouped into five outcome of interest categories:

- Accessibility as an important function of the transport system.
    - Accessibility of regions for goods and people as a driver for regional economic development
    - Accessibility to important national and international destinations
- Transport operation costs
    - Market prices for transport services
    - Individual costs for private households and for companies
    - Coverage of external costs
- Productivity/efficiency
    - The general impacts for the whole economy
    - Disaggregated impacts
- Costs to the economy
    - Investment in the transport system
    - Maintenance cost
- Benefits for the economy

Revenues from the transport sector

Table 3 — Economic Outcomes of Interest and Related Outcome Indicators

Outcome of Interest	Indicator Name	Indicator Definition	Units and relation to the economic aspect of sustainability	
EC1 Accessibility	**EC11 Intermodal Terminal facilities**	Terminal facilities with access by intermodal traffic system (road, rail, waterway)	Percentage of terminals with access by more than one mode	↑
	EC12 Accessibility of origins/ destinations	Accessibility Index between important economical centres and regions by mode	Index value (Aij)	↑
	EC13 Access to basic services (SO11)	Average travel time for households to reach "basic" purposes	Minutes	↓
	EC14 Access to public transport (SO12)	Percentage of households living within walking distance of 5 minutes from the next stop of public transport	Percentage of households	↑
EC2 Transport Operation Costs	**EC21 Supplier operating costs**	Monetary costs of transport operators (fixed and variable components)	Euro per year	↓
	EC22 Transport-related expenditures of households (SO14)	Average transport - related share of household expenditures by type of household	Percentage of expenditures	↓
	EC23 Transport prices	Transport prices for passenger transport by mode	Euro per passenger- km (public transport)	↓
			Euro per vehicle- km (private transport)	↓
		Transport prices for freight transport by mode	Euro per tonne - km	↓
EC3 Productivity/Efficiency	**EC31 Freight haulage-related costs on product costs**	Average share of freight haulage costs on product cost by sector	Percentage of product costs	↓
	EC32 Utilisation rates	Average occupancy rate in passenger vehicles	Number of passengers per car trip (private transport)	↑
			Percentage of capacity (public transport)	↑
		Average loading rate of freight vehicles	Percentage of capacity	↑
		Average utilisation rate of transhipment terminals	Percentage of capacity	↑
	EC33 Energy consumption efficiency of transport sector	Energy consumption per unit of GVA generated by transport sector	Joule/ Euro GVA	↓
	EC34 Energy efficiency	Energy consumption intensities for passenger transport by mode	toe/ passenger-km	↓
		Energy consumption intensities for freight transport by mode	toe/ tonnes-km	↓

EC4 Costs to Economy	**EC41 Infrastructure costs**	Traffic system- related public and private construction costs by mode	Euro/ km per year (traffic network)	↓
			Euro/ tonne per year (transhipment terminals)	↓
		Traffic system- related public and private; improvement and maintenance costs by mode	Euro/ km per year (traffic network)	↓
			Euro/ tonne per year (transhipment terminals)	↓
	EC42 Public subsidies	Public expenditures/ investments in transport and mobility-related sector e.g. for development of vehicles, transhipment technologies, mobility-related information and communication technology, research and transport operation	Euro per year	↓
	EC43 External transport costs	Accident costs by mode	Euro per year	↓
		Delay costs due to congestion by mode	Euro per year	↓
		Environmental costs by mode	Euro per year	↓
	EC44 Energy consumption (EN11)	Final energy consumption in transport by mode and by energy source	Million tonnes of oil equivalents	↓
		Share of final energy consumption in transport produced from renewable energy sources	Percentage	↑
EC5 Benefits to Economy	**EC51 Gross value added**	Share of an economy's gross value added (GVA) generated by transport	Percentage of GVA	↑
	EC52 Public revenues from taxes and traffic system charging	Public revenues from traffic system charging (tolls and user charges)	Euro per year	↓
		Public revenues from transport sector related taxes (petroleum, vehicle and emission taxes)	Euro per year	↓
	EC53 Benefits of transport	Indirect positive growth and structure effects realised by the transport sector	Euro per year	↑

4.3. Social Indicators

Up until now, most approaches to sustainability have emphasized the environment and economy dimensions, sometimes exclusively. This is primarily due to the fact that it is quite difficult to integrate social factors into the concept of sustainable development. One of the most thorough and up-to-date analyses can be found in the work of the Institute for Socio-ecological Research (ISOE) in Frankfurt (see http: //www.isoe.de/). They identify four core elements of social sustainability:

- The provision of basic needs for all members of society
- The maintenance and development of social resources
- Equal opportunities concerning access to resources
- Participation within social decision processes

What is true for sustainability in general is even truer for the social dimension of sustainable transport. One of the few papers to deal with this topic is a thematic paper from the European Commission’s EXTRA project (EXTRA, 2001) that synthesizes research results on the social aspects of sustainable mobility. It covers the following main topic areas:

- Accessibility to transport services, such as affordable public transport, and access to destinations from different parts of the European Union;
- Effects of the transport network on social cohesion;
- Care for marginal/disadvantaged/vulnerable groups -- e.g., ensuring physical access to transport services for people with mobility difficulties;
- Social equity of transport policy changes and the implications for public acceptability – depending, for example, on the effects on income distribution, regional development, and employment;
- Working conditions for operatives, who may for instance be affected by policies towards safety, new technologies, and deregulation of services.

The list of selected social outcome indicators is presented in Table 4. The arrows in the table indicate the desired direction of development in the indicator values. They are divided into categories according to the six outcomes of interest (accessibility and affordability, safety and security, fitness and health, livability and amenity, equity and social cohesion).

Table 4 — Social Outcomes of Interest and Related Outcome Indicators

Outcomes of interest	Indicator name	Indicator definition	Units and relation to the social aspect of sustainability	
SO1 ACCESSIBILITY AND AFFORDABILITY (users)	**SO11 Access to basic services**	Average travel time for households to reach "basic" purposes	Minutes	↓
	SO12 Access to public transport	Percentage of households living within walking distance of 5 minutes from the next stop of public transport	Percentage of households	↑
	SO13 Car independence	Percentage of households without cars	Percentage of households	↑
	SO14 Affordability	Average percent age. of household expenditures related to transport	Percentage of expenditures	↓
	SO15 Trip length	Percentage of short trips from all trips	Percentage of trips	↑
SO2 SAFETY AND SECURITY (users, drivers, the affected)	**SO21 Accident related fatalities and serious injuries**	SO21a Number of transport accident related fatalities and serious injuries per year and 1'000 inhabitants	Number of persons per year, per 1'000 inhabitants	↓
		SO21b (based on SO21a) Number of children below 18 years seriously hurt or killed per 1'000 children in the same age group	Number of children per year, per 1'000 children	↓
		SO21c (base SO21a): Number of adults from 18 to 65 years seriously hurt or killed per 1'000 persons in the same age group	Number of adults per year, per 1'000 adults	↓
		SO21d (base SO21a): Number of persons older than 65 years seriously hurt or killed per 1'000 persons in the same age group	Number of elderly per year, per 1'000 elderly	↓
	SO22 Vehicle thefts & other vehicle crimes	Recorded crimes against private vehicles per year and 1'000 inhabitants	Number of crimes per year, per 1'000 inhabitants	↓
	SO23 Security on public transport	Number of incidents (property offences + offences against passengers + offences against staff) per year and 1'000 km	Number of incidents, per year, per 1'000 km	↓
SO3 FITNESS AND HEALTH (users)	**SO31 Walking and cycling as transport means for short distance trips**	Percentage of short trips/journeys done by walking or cycling	Percentage of trips/journeys	↑

Outcomes of interest	Indicator name	Indicator definition	Units and relation to the social aspect of sustainability	
SO4 LIVABILITY AND AMENITY **(inhabitants, society, the affected)**	**SO41 Walkability, pedestrian friendliness**	Total length of separate walking paths and/or special pedestrian areas in % of the length of the whole transport net	Percentage of length of the whole transport network	↑
	SO42 Traffic calming	Total length of city streets with speed limits of maximum 30 km per hour in % of the length of the whole city street network	Percentage of length of the city street network	↑
	SO43 Children's journey to school	Percentage of children driven to school by car	Percentage of children	↓
	SO44 Open space availability and accessibility	Percentage of inhabitants/households living within maximally 15 minutes walking distance from urban green areas	Percentage of inhabitants/-households	↑
SO5 EQUITY **(users and the affected)**	**SO51 Horizontal equity (fairness)**	Percentage of "self-financing" of transport costs by the users, differentiated by mode	Percentage of costs	↑
	SO52 Vertical equity (income)	SO52a Ratio between richest/poorest 20% (quintile) for transport related household expenditures (based on SO14)	Number	↓
		SO52b Ratio between richest/poorest 20% (quintile) households for access to basic services (based on SO11)	Number	↓
		SO52c Ratio between richest/poorest 20% (quintile) households for public transport reliance (based on SO13)	Number	?
	SO53 Vertical equity (mobility needs and ability)	SO53a Explicitly earmarked public transport expenditures for the disabled and elderly in % of total public transport expenditures	Percentage of expenditures	↑
		SO53b Percentage of easy accessible low-floor vehicles in % of the total urban transport fleet	Percentage of vehicles	↑
	SO54 Intergenerational equity	Important outcomes of interest, but no indicators can be suggested here		
	SO55 Interregional (spatial) equity			
SO6 SOCIAL COHESION **(inhabitants, society and the affected)**	**SO61 Transport individualism, "traffic loneliness"**	Average car occupancy	Number of persons per car	↑
	SO62 Public opinion profile on transport and transport policy issues	Percentage of adults supporting radical pro- and anti-car positions in the transport policy discourse	Percentage of adults	↓
	SO63 Violation of traffic rules	Percentage of drivers violating traffic rules and regulations	Percentage of drivers	↓
	SO64 Long distance commuting	Percentage of commuters commuting daily over distances of more than 10 km	Percentage of commuters	↓

5 DISCUSSION

5.1. Reflections on Indicator Development

The set of outcome indicators presented above should be seen as the basis for further development. Although the basis on which this set has been produced is much broader than previous attempts to define a set of outcome indicators, it should not be viewed as the ideal list. Our selection has inevitably been influenced by notions of data availability, or at least on notions concerning the possibility to produce the indicator (even though this was not one of the criteria), and by our desire to keep the list reasonably short. Certainly, there are many other possible indicators of sustainable mobility and transport. But endless numbers of indicators are not a good idea — neither for collecting purposes nor for their interpretation. It would be useful to develop criteria for adding indicators to the set presented above, and then to identify new indicators that satisfied these criteria.

5.2. Next Steps in Monitoring and Modeling

The list of indicators presented above was produced for two reasons: monitoring and modeling. It is clear that some of the indicators will be easy to monitor but difficult to model, while others will be easy to model but difficult to monitor. SUMMA's main concern is for modeling, but we will briefly touch upon both purposes.

5.2.1. Monitoring

For monitoring purposes, it is important to consistently obtain data over a long period of time. Some data can be measured directly, other data need to be determined by surveys, etc. The next step on the monitoring side would be to implement the collection of these data. In some cases, this would require extending existing collection systems (e.g., the new environmental indicators could be added to those already being collected by the Transport and Environment Reporting Mechanism (TERM)). In other cases (e.g., for the social indicators) a new reporting mechanism would need to be established.

5.2.2. Modeling

If a model is being built from scratch, it would be possible, in principle, to incorporate the estimation of all of the outcome indicators. Of course, the estimation of some indicators (e.g., traffic safety) might require an unreasonably high level of detail. The problem is different when an existing model system is used. In that case, if the necessary information is not already part of the system model, the outcome indicator will not be able to be determined. SUMMA is using existing models. Our next step will be to identify which of the indicators can be produced as outcomes from our models, and how. We are already aware that many of the outcome indicators presented above will not be able to be produced by our models.

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