the Swedish Life Cycle Center

Analysis tool for calculating environmental impact and efficiency of transport systems

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Preface

This report reports on a project that was run within the framework of the Swedish life-cycle centre, CPM at Chalmers University. The main part of the project work was done at IVL Swedish Environmental Research Institute and Northern Lead Logistics Centre, Chalmers. Participating industry was AB Volvo, SCA, ABB and AkzoNobel. The project was financed by VINNOVA - Swedish Governmental Agency for Innovation Systems through grant No 2009-04345.

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1. Introduction

Facing increasing volumes of freight transportation there is increasing pressure on monitoring and mitigating the negative impact on the environment and society that follows. This impact involves a number of areas where the climate gases are in focus but also comprises air pollutants, land use, accidents, congestion, pollution to water and soil, noise, the use of limited natural resources etc. Companies measuring the environmental impact from their products, e.g. the carbon footprint, often finds that transportation plays a key role. At the same time the deciding parameters when transportation services are purchased are typically related to logistics parameters, which means that the price, speed of delivery and reliability are what matters at the end of the day. In addition, there is of course the close connection between increase in transportation and economic growth that is an important background for policy decisions.

However, there are now methods being developed where the negative impact of a transport activity can be valued in economic terms and compared with direct costs for transport services. The impacts are then presented as external costs or externalities. There are a number of reasons why it is interesting to obtain explicit values for these external costs: following the polluter pays principle the magnitude of fees and taxes are often calculated from externalities; to be able to relate different types of impact making it possible to try to improve on the most important areas; as a way to obtain information about the total cost of an activity.

Since logistics factors are the most important for decisions on transport services there is a need for studying logistics and externalities together in order to improve a transport system. This report describes the result of the project ”Environmental impact and efficiency in freight transport systems” where a tool, named TrExTool, has been developed that is used to calculate externalities and logistics efficiency for freight transport systems. The tool has been used in a number of case studies with the industrial partners involved in the project. Chapter 2 contains a summary of the lessons learnt from the project and the benefits of the tool. Chapter 3 describes the project activities, Chapters 4, 5 and 6 explains the calculations of externalities, logistics efficiency and infrastructure effects, respectively, and in Chapter 7 the tool itself is described. The infrastructure model is described more extensively here since it has not been published elsewhere.

2. Lessons learnt from the use of the Tool

The TrExTool makes it possible to calculate a total cost, including direct logistics costs, service deficiency costs and external costs, for different logistics solutions or scenarios. It also facilitates comparisons between the different cost elements and the environmental effects can also be shown in physical terms. The tool gives a way to calculate the benefits and drawbacks of the different transport modes, which will give decision support when choosing between road, rail, sea and air transport and highlights, in cost terms, the benefits of e.g. choosing trucks with a higher emission class and using more environmentally benign fuels. The tool represents a way to calculate the benefits and drawbacks of the different transport solutions. By internalizing external effects it is possible to give a certain indication of the effect of different proposed logistics changes. The tool can be used to calculate a total transport cost for comparing different logistics solutions, but it is also possible to compare the magnitude of different types of costs and also physical measures of environmental impact. Thus, it is possible to prepare for future internalisation of external costs and by making forecasts of future costs.

The benefits of using the tool

The tool is useful when performing analyses of cost and environmental impact when making long term plans and designing new logistics structures and processes. It could involve scenarios where different solutions are explored, e.g. localisation of production units, warehouses, allocation of production capacity, transport modes and load units used. The tool can also be used for follow up and reporting on logistics costs, external costs and environmental performance and for analysis/benchmarking of the results when improvement areas can be highlighted and rules of thumb created.

The tool may be used by shippers, when purchasing transports on a larger scale, to find the most cost-efficient solution, or the most preferable transport provider. Initially there was a strong focus on purchasing of transport, and therefore purchasing processes have been mapped and analysed at a project partner company, and also at a number of other companies (see for instance the report by Wolf 2010 and the article by Rogerson et al., 2013). However, later in the project the idea of using the tool for supporting purchases of transport has been, if not dropped, at least reduced to strategic transport purchasing decisions. The use of the tool for more operational purposes has not been seen as a viable option.

In addition to being used by individual companies, the tool can also support discussions and collaborations between several actors in the transport system (both companies and authorities) regarding more fundamental changes in the transport system. In order to initiate changes there is a need for knowledge about what consequences different decisions and designs of the transport system will have. There is also a need for a common view on how to perform the total cost calculations and the tool can support a dialog regarding this between different actors.

Several of the industry partners tested the tool and in addition a company and some people not involved in the development of the tool tested it when analysing several different options to reduce cost and environmental impact. They perceived the tool as useful for this kind of strategic ex ante analysis and easy to understand and use. The possibilities to compare the results between different cases, as well as the graphic presentations of these were appreciated by those testing the tool. Another strength was the introduction of 'uncertainties', challenging the common view of KPIs as being accurate.

Challenges in using the tool

Lack of data

The major problem is the current lack of data to be used in the calculations. There are several reasons behind this, but many of them are related to the fact that the required data is distributed among several organisations - it could be the supplier/customer of the products being transported, the forwarder, the carrier, and also among different units at the shipper organisation. There is limited access to data necessary to calculate the external costs and a key informant for this is the transport provider. It could be information about the type of vehicle used and load factor (both crucial for the result but often lacking), type of Euro class used (it may be known on average, however, not which type of vehicle that was used for a specific shipment), weight/volume of the transported goods, and the length and route of the transport can also be problematic to obtain. In order to obtain necessary data for all transports, an information system where transport providers automatically can supply the information would be useful.

When the company making the calculations is not buying the transport itself, there is limited knowledge about the cost and other variables necessary for the calculations, and it may be problematic to obtain them. Another problem that may exist is if the transport is not produced in a dedicated system but in an open system, where the resources are shared with other transport buyers, which leads to an allocation problem. The accounting systems both at the services providers and the shippers may also cause problems which may be solved when there is a demand for certain data.

Valuation of external effects

The calculations of emissions are today fairly accurate; however, the valuation of external effects is uncertain. This especially applies to greenhouse gases, for which different approaches and methods can give significant variations in the results. Further, the costs for some categories will depend on the temporal and spatial distribution of the traffic, meaning that a high precision is needed in the input data. In reality this must lead to a compromise between accuracy and usefulness in the sense that the user will not be able to collect all details about their transport systems.

There are a number of challenges related to evaluation of service and turning this into a cost. The transport time and precision of delivery gives further challenges. It is highly relevant to include these parameters since they often are decisive in the design of a logistics system. As an example, this will capture the background to freight owners choosing air transportation over sea transportation in spite of the normally higher transportation costs and the higher external impact. It has not been possible to estimate all negative effects from deficient service levels, for instance delivering too late, which could lead to costs of lost sale in addition to inevitable bad-will. Costs that arise due to lack in meeting the target of service level may often be hidden in other functions than the transport function. One option could be to include expediting costs and other costs due to e.g. delays as a separate post in administrative and/or transport costs.

How to deal with the challenges?

It has been demonstrated that it is very difficult however not impossible to gain a ’total picture’ of costs and impact. There are not fully resolved issues regarding how to deal with value of ’time’ and cost of infrastructure. In both these cases it is a matter of availability of data but also how to evaluate the long-term impact, which of course also is an issue when to put a value on the environmental impact. What is being internalized?

The major challenge is how to handle limitation in the access of critical data. Using default values and stating the level of uncertainty in the values entered in the tool have solved this problem. There is a trade-off between obtaining a high precision is in the input data (which may require a substantial effort to achieve) and the practical usefulness of the tool. The ability of handling uncertainties is one of the strengths of the tool and it is important to present uncertainties of the results in the model.

It was found that it is important to present uncertainties of the results in the present model, not the least to show the uncertainties in the incoming data and to pinpoint how to narrow the uncertainties. For decision-making based on results from the model this means moving over to a more risk-based approach. Further, when doing cost-benefit analyses based on the calculated external costs the calculated uncertainties are of course essential to consider.

3. Project activities

Development of the tool

The processes of developing the tool started with communications with the industrial partners about the potential use of the tool, needs and requirements. This was done through regular project group meetings and also in meetings where the project team visited the industry partners in the project to discuss these issues. It was decided to produce the tool in Excel and that potential incorporation in logistics software etc. at the companies had to be done separately. The tool was then developed through interaction with the partners and by using experience from a number of case studies that were performed (see below).

Some of the requirements on the tool that came up during the discussions are listed below.

- Calculation of explicit emissions of climate gases and air pollutants
- Inclusion of the costs for use of limited natural resources
- Calculation of external costs for emissions and for noise; congestion; accidents; up and down stream costs; impact on soil and water
- All calculations to be done with uncertainty analysis
- A wide range of logistics costs including direct transport costs; customs; administration;
- Inclusion of XX cost calculated from value of goods, transport time and an interest rate
- The possibility to rate the transport time
- The possibility to rate the uncertainty in delivery time
- The inclusion of costs and time for warehousing
- All four transport modes
- A wide range of different vehicles and vessels
- A range of different emission classes
- Different fuels
- Calculation of external costs at different geographical locations manifested as different population densities
- Calculation of externalities that depend on the time of day (congestion and noise)
- Costs and externalities for infrastructure
- Subtraction of internalised costs

These requirements have been implemented when designing the tool. Several versions of the tool were made and tested by the project group.

Publications

Within the project the following reports and publications have been produced:

- Jerksjö, M., Fridell, E., Andersson, D., 2013. Manual TrExTool 2.0
- Fridell, E., Andersson, D., Jerksjö, M., 2013. A tool for calculating external costs and efficiency of freight transport systems. Paper for the 6th International Conference on Life Cycle Management – LCM 2013
- Andersson, D., Fridell, E., Halldorsson, A. 2013. A total cost tool for internalizing logistics and environmental externalities. Paper for The 18th Annual Logistics Research Network (LRN)
- Wolf C., Analysis tool for calculating environmental impact and efficiency of transport systems CASE STUDY on SCA Personal Care. CPM report 2010.
- Westerdahl, J. and Santén, V., 2011. Case study at ABB
- Wolf, C., 2011 Effect measurement of (goods) transport noise
- Santén, V., Andersson, D., 2011, The total logistics cost concept, CPM report
- Karlsson, I., 2010, Development of an operational indicator framework for monitoring and controlling environmental impact from freight transport at ABB, Master thesis. E - Department of Technology Management and Economics, Chalmers University of Technology, Gothenburg, Sweden; E2010:075, 2010
- Rogerson, S., Andersson, D., Johansson, M., I. (2013/14), "Influence of context on the purchasing process for freight transport services", International Journal of Logistics Research and Applications, forthcoming, published on-line.

In addition a large amount of case study documentation has been compiled to be used for future publications.

4. Description of the Tool

With the model a certain goods transport system can be studied. Exactly how to use the tool is explained in detail in the manual. The user needs to provide certain information about the goods (weight, volume, value) and the distance travelled. Further, the transport during rush hour and night time needs to be specified, the reason being that this influences driving patterns and external costs for congestion and noise. Additionally, some information about the fraction of the distance that is in urban respective rural areas should be given, the reason being that some impacts, notably emissions of particulate matter and noise, have more severe effects in highly populated areas. The tool associates externalities and costs to transport work rather than traffic and therefore load utilization factors are also needed.

The user further needs to choose mode of transport (air, road, sea or rail) and the specific vehicle/vessel from a list together with the type of fuel used. The list of vessels contains different sizes, types and emission classes. Normally there are several legs in a transport chain and these can have different modes and/or vehicles/vessels.

The logistics costs also need to be specified split into cost for transport, packaging, warehousing (costs for the warehouse itself, the warehouse personnel and their equipment, handling and storage), inventory carrying (cost of capital accumulation, risk costs, and inventory service costs) cost of loss (costs that arise due to loss of goods, e.g. insurance fees, loss of sales, additional administration and additional transport costs), delay costs (e.g. loss of sales, stand still cost, additional administration costs and extra transportation costs), value of early delivery (costs associated with waiting for e.g. spare parts), administration. The ability to deliver fast and/or with a high precision is normally difficult to capture but are included since they may explain the mode selection.

The emission calculations for road take use of emission factors from HBEFA (Hausberger, 2009) and uncertainties from COPERT (Kouridis, 2010). For rail the methods in ECOTRANSIT (EcoTransIT, 2011) are followed with the addition of uncertainty estimates, while the air calculations are done with emission factors for a large number of planes. The emissions for shipping are calculated using a recently developed model (www.ntmcalc.org) with the addition of uncertainties (Cooper, 2004). The external cost values for emissions are from a number of sources (Maibach, 2008, Steen, 2000). The values for congestion, accidents, noise, up/down stream, ecosystems, soil and water are from Maibach (2008).

As mentioned the uncertainties are calculated using the Monte Carlo method. This means that uncertainty estimates (shape and size) are needed for all ingoing parameters and that random numbers are used to make the calculations a large number of times giving the uncertainties in the resulting parameters from statistical analyses.

The calculations result in large amounts of data. For the total freight transport system, as well as for each leg, fuel consumption, emissions of climate gases (CO_2, N_2O, CH_4 as well as CO_2-equivalents), and air pollutants (NO_X, PM, CO and HC) are calculated. External costs for these are given together with external costs for the other categories listed above. The logistics costs are given together with valuation of transport time and precision.

There are a number of reasons why it is of interest to calculate the values of external costs for goods transports. One is to compare the different impact categories. Today most of the concern about external effects is about the impact on climate change. The values for external costs give a way to relate different impacts to each other. This opens up for focusing on reducing the most severe factors and to leave the less important ones. It also shows that there are other issues with transport systems than climate problems. Further, the model shows the total costs for goods transportation which is important for many stakeholders. For the freight owners this gives an idea of the future costs for transportations and for policy makers it shows the burden put on society and others from our transport systems. There is an on-going trend in internalizing external costs which will mean that in the future there is a high likelihood that this will give higher transport costs. An example of this is the Eurovignette tax which is calculated from external cost values.

The tool also offers a way to calculate the benefits and drawbacks of the four transport modes and of different vehicles and vessels. This will give decision support when choosing, e.g., between rail, road and sea in a transport system. It also highlights and valuates the benefits of choosing trucks of higher emission class and more environmentally benign fuels, and relates this to the potentially higher transportation costs.

There are a number of challenges in obtaining one single cost for a transport system, a cost that include the direct costs, the external costs as well as valuation of the logistics efficiency. The calculations of emissions are today fairly accurate due to, for example, the modelling needed for the Kyoto protocol and the European Ceilings Directive. However, the valuation of external effects is often uncertain. This especially applies to greenhouse gases for which different approaches and methods can give significant variations in the results. For example the valuation can be based on future impacts due to draught, flooding, deceases etc., and then the number obtained per kg of CO_2 emitted will be highly dependent on the discounting used; or it can be based on costs for replacing fossil fuels with biofuels. Further, the costs for some categories will depend on the temporal and spatial distribution of the traffic, meaning that a high precision is needed in the input data. In reality this must lead to a compromise between accuracy (e.g., in dividing up the scale from megacities to rural in many steps) and usefulness in the sense that the user will not be able to collect all details about their transport systems.

The transport time and precision of delivery present further challenges. It is highly relevant to include these parameters since they often are decisive in the design of a logistics system. As an example, this will capture the background to freight owners choosing air transportation over sea transportation in spite of the normally higher transportation costs and the (normally) higher external impact (due to high emissions of CO_2 per tonne-km).

The tool is intended to be used for a number of purposes including procurements, design of logistics systems and strategically in e.g. the location of units and warehouses. So far a number of case studies have shown the usefulness of the tool.

5. Calculating environmental impact

External costs from the transport sector are estimated in different ways (see e.g. Maibach 2008). Whilst the existence of externalities is conditioned by a polluter and a contaminated (human, environment) they are also case specific, location specific and specific to the mode of transport in question. However, the most used method today to assess transport externalities as well as their external costs is the impact pathway approach including the following steps:

-inventories of the disturbance

-dispersion of the disturbance

-exposure to humans and ecosystems of the disturbance

-impact of the exposure on humans and ecosystem

-damage, i.e., actual types of costs and their values

The damage costs are dependent on several variables such as:

-The damage or the degree of harm implied by the externality including the size of this harm, e.g., number of deaths and/or cases of illness as well as exceedance of certain ecosystem thresholds below which the harm may be assumed to be insignificant.

-The cost of the harm, e.g., medical costs in the case of illness or the cost of remediation in the case of ecosystems, such as the cost of liming related to acidification.

This method thus considers the impact of the disturbance and calculates the costs from that. Other means to estimate the external costs are:

- The willingness to pay to reduce or to avoid the externality as discussed above.

- The avoidance or mitigation cost to prevent the negative harms. The definition of avoidance cost is not straightforward. At the consumer level this cost is related to the costs devoted to prevent from negative externalities such as expenditure on air cleaners by those receiving the pollutant. At the polluter level these costs are sometimes related to abatement costs to reduce the externalities.

The external costs do in general depend on a number of parameters such as location and time. However, depending on lack of resources, it is sometimes not possible to estimate specific (to location and mode) external costs, and therefore the most used method to adapt estimation is the so called benefit transfer method. Using this method implies adapting for example external costs estimated for a certain region to another one.

The categories of external costs associated with the transportation of goods considered in this report are: congestion, accidents, noise, air pollution, climate change, up and downstream processes, nature and landscape, soil and water pollution. Here follows a brief description of how these different categories usually are treated for the different modes of goods transportation - road, rail, air and sea.

External costs for air pollution are usually obtained following the impact pathway method outlined above. The most important substances normally considered are NO_X, SO_2, PM, VOC, CO and the secondary pollutant O_3. Typically health risks are the most important but also impact on ecosystems (acidification, eutrophication etc.) and by corrosion are important. However, there are a number of other substances that may be considered in the future. The treatment is similar for the different transport modes although the location of the emission is of course very different which must be considered. For electrical carriers (mostly rail) one usually considers the emissions occurring during the production of electricity. Regarding mitigation costs there are a number of technical measures such as exhaust converters, cleaner fuels, electrical vehicles etc. to consider.

For noise there is annoyance and health related costs. The different modes have rather different noise characteristics. Air and sea noise is usually confined to areas around airports and harbours. Rail noise can be a severe disturbance, especially at night with sudden noise in an otherwise silent surrounding. Road traffic is of course a major noise source in most urban areas.

The emission of CO_2 and other climate gases is of course a major concern and traffic is a large and growing source.

Estimating damage cost is often based on integrated assessment models such as the PAGE model used to estimate the Stern results. These models are used to estimate the social costs of carbon using different discounting rates (Brännlund 2009).

Up and downstream costs are indirect costs for the production of vehicles, fuels, infrastructure etc. A large fraction is usually associated with energy conversion.

Congestion costs stem from different sources. There is a travel time increase that can be evaluated. This is normally the largest part of external congestion costs although there are also costs for increased wear and fuel consumption, for loss in reliability and for scarcity of slots (railway and air freight). There is also a positive externality (the Mohring effect) where congestion leads to better service, e.g., more frequently running public transportation.

Soil and Water external costs can be calculated as repair costs or from impact on human health and crops from e.g. heavy metals.

Costs on nature and landscape can be calculated as repair costs or by methods to quantify habitat loss and loss of biodiversity.

Abiotic resources are derived from the non-living world (e.g., land, water, and air). Mineral and power resources can be abiotic natural resources. Abiotic resources in this study are about non-renewable resources such as fossil fuels.

In the tool it is possible to create different lists of costs that can be used. The present list is based mainly on impact costs, e.g. costs for health effects when it comes to air pollution and noise. The values used for air pollution are from Steen (2000) while most of the other costs are from Maibach (2008). Estimates of uncertainties in the unit costs are done using data in Maibach (2008). The costs are divided into different area-types depending on the population density since many categories (PM-emissions, congestion...) have unit costs related to the number of people being affected. Further, for some categories (noise, congestion) there are different unit costs for different times of the day.

6. Evaluation of efficiency in logistics

The area of logistics measurements has been investigated by a number of authors (e.g. Andersson & Aronsson, 1989 a, b, Caplice and Sheffi, 1994, 1995, Ljungberg, 1998, Näslund, 1996, Holmberg, 2000, Keebler et. al. 1999). In general it has been considered difficult to design a measurement system, partly because the complexity in the underlying logistics structures and the need to measure several dimensions (Andersson and Aronsson, 2002). The total logistics cost concept has been discussed and different models suggested by several authors (e.g. Stock and Lambert (2001)). In the total cost model developed by Stock and Lambert (2001) the idea is to minimize the total cost and not only the cost of a single cost category. The logic behind this is that reduction in one category may lead to increases of costs in another. One example is that a reduction of warehousing and inventory carrying costs can lead to substantially higher transport costs or reduced service levels to customers, which will have an intangible cost effect. Another type of total cost analysis was developed in the purchasing context where Ellram (1995) developed the total cost of ownership model (TCO). From the total cost of ownership (TCO) perspective, the aim is to reduce the total logistics cost while achieving a defined service level and TCO helps to show logistics performance (Lambert and Burduroglu, 2000). However, cost related to the service performance deficiencies are very hard to evaluate. Having various lead times, being on time or not, being able to deliver a complete order will have direct and indirect effect on business performance and will for instance influence mode selections. It is not only a matter of transport lead time but also the frequency and the cost of delay is in many cases not a continuous function but rather a step function.

There are different content in the cost categories in the different models, some of them overlap when comparing the models. It is also a question of system boundaries of logistics, what to include in the logistics system. Our approach is to identify a number of activities that are generally relevant for a variety of companies in the supply chain dealing with logistics. This means that cost elements that are related to the flow and storage of goods are included, but costs connected to production and manufacturing of products are not. The model takes its starting point in the mission costing approach suggested by Christopher (2005) but here we regard a mission as a process to be carried out, e. g. move a shipment from a to b, which requires the performance of a number of logistical activities (such as transport, warehousing, inventory). The importance of the total logistics cost model is not to see each activity cost, but to see the total cost of activities in different material flows.

The following cost items are included as input to the total logistics cost module in the analysis tool developed: direct transport cost (as invoiced from transport company or specified in invoice from product supplier); goods value; packaging cost (material used and processing of packaging and marking goods charges for disposal or handling reusable packages); warehousing costs related to storing and handling (costs related to the building, equipment, personnel, and this may be time and/or activity dependent); risk costs; inventory service costs which are expressed as an inventory interest (the tool will calculate this cost as the value*time*interest rate); costs that arise due to loss of goods, caused by to transport damages, theft etc. (insurance fees, loss of sales, administration costs and additional transportation costs); value of early delivery (cost/h associated with waiting for e.g. spare parts); delay costs (e.g. loss of sales, penalties, stand still cost, additional administration costs and extra transport costs); administration costs (administration of logistical activities, planning, processing orders, procurement, reporting); customs (clearance fee, brokerage fee, and allocation fee).

Since there is a large variation among companies of what to include in some of these items, there may be an overlap in between those. For instance, transport costs can (for some) also include packaging costs, thus packaging costs are not possible to be separated into one single cost activity. In that case transport costs are filled in, and packaging costs can be ignored.

7. Environmental aspects of traffic infrastructures on transports

A transport is a complex activity involving many parts of the society. It is thus not sufficient to consider only the transport vehicle and its fuel consumption and the vehicle emissions. A transport needs for example production of the vehicle, production of the fuel, and infrastructure (roads, railroads, airport, harbors etc.) for its operation. All these activities need to include construction, operation and maintenance. Several environmental aspects need to be covered such as primary energy use, material resource use, emissions to air including greenhouse gases, emission to water, waste handling etc. In addition to these aspects, there are theoretical aspects so consider such as the time aspects which are different for different transport types which makes the function and the functional unit of the different transports different. Establishment of the infrastructure also provides various problems when the function can be fundamentally different, e.g. roads can take the transport all the way to its destination while railways, air transports and ship transports needs complementary transport to take the transport all the way to its destination. This means that roads are almost always required and the other transport types are optional and used for its specific advantages. All these different aspects require to be addressed in an assessment of a transport. Some of these theoretical aspects have been covered in the report "Miljödeklarerad infrastruktur" (Uppenberg 2003). To be able to handle all these aspects, a system perspective has to be used. The most frequent and probably the best tool for such analyses is Life Cycle Assessment (LCA).

General aspects

From a methodological point of view, a road differs significantly from other types of products that are produced, used and wasted with a more or less defined lifetime. Roads or other infrastructures can be seen more as an on-going activity even if individual components in the system have a defined lifetime. A road construction process differs noticeably also from other manufacturing processes through its great variation with regard to manufacturing conditions. Large and important variations exist between different sites, but even within the same strip of road the conditions can vary substantially.

The methodology used to overcome these problems is based on a simple strategy namely to break down the infrastructure in smaller process units. An analytic LCA model of the infrastructure can then be built up of the different processing units. As already has been pointed out different infrastructures vary significantly in terms of their design and other production conditions. The LCA results are thus more or less individual for a specific infrastructure. This situation can be handled in the model by varying the model-input data. However, based on the accuracy needed for the analysis, general base figures for a typical infrastructure can be calculated. These are valid only as background data for general overview analyses.

Relative to an ordinary product, a road is considered as more or less permanent, beginning with the start of construction. In maintenance procedures the pavement is constantly upgraded. It is thus more useful to analyse a particular time period than to work with a "cradle to grave" concept. The time period used in the IVL studies has been 40 or 60 years. With a longer time period, the initial construction phase will be less dominant and the maintenance and operation processes will be more and more important. Another significant time aspect is the residual value of the road or other infrastructure. An ordinary product is usually worn out at the end of its life cycle. Such a product has a very low residual value and is therefore disposed of. A road can however, due to the maintenance procedures, have a very high residual value. After a time period of 40 years the road can be in almost the same design condition as a new road.

System boundaries for infrastructures

The system boundaries used for infrastructures follows in principle the same pattern as for other LCA studies according to the ISO standard. A useful principle for infrastructure analyses has been to divide the activities in three groups: Construction, Maintenance and Operation. In a full transport LCA there are two parts, which have to be combined; the LCA of the infrastructure and the LCA of the actual transport vehicle. The overall layout must be designed in such a way that the two parts can be added. This requires a uniform way of handling the functional unit and the used parameters. The main structure of a full transport LCA is shown in Table 1. The End of Life procedures are normally included in the maintenance procedures for infrastructures while for the traffic the End of Life Vehicle (ELV) processes have to be included, e.g. in the operation of the traffic module or added separately. Sometimes it can be difficult to distinguish if a parameter should be assigned to the infrastructure or the traffic. An example of this is the allocation of noise or particle emissions resulting from the interaction (friction wear) between vehicle tires and the road surface .

Table 1 Main structure of a full transport LCA.

	Construction	**Maintenance**	**Operation**
Infrastructure			
Traffic			

Environmental parameters and limitations

A goal for an environmental evaluation is of course to include as many environmental aspects as possible to create an as complete picture as possible. However, some parameters can easily be represented as a number such as the NO_X emission and therefore also easily be included in an LCA model. Other parameters such as biodiversity or biological barrier effects are much more difficult to handle and very difficult to quantify and therefore not possible to include in an LCA model. A suggestion to handle this problem can be to include the difficult parameters in a checklist. The list can then be handled separately. A simple yes/no form can be used in environmental impact assessment or some kind of index or point system can be used in the final evaluation.

Functional units for infrastructures

The functional unit utilised for a justified comparison in LCA is always very important when comparing different systems. To compare two LCA model results in a correct way the LCA models used must have the same functional unit, i.e. deliver a minimal setup functions or performance requirements. This generates some difficulties to define a common functional unit for different transport alternative and the facilitated infrastructures. A schematic picture of a transport and its infrastructure is shown in figure 1. The figure shows the main part of the transport and as can be concluded from the figure there is a fundamental difference between road and railroads on one hand and air and ship transport on the other. The traffic can usually be represented with the transport distance as the functional unit (per km and tonnage). The infrastructure of roads and railroads can also be represented by the transport distance and tonnage as the functional unit. This is however not the case for air and ship infrastructures. The infrastructures for an aircraft transport is almost entirely related to the airports and thus independent of transport distance. This means that a generic representative transport and distance have to be chosen when comparing those transports, when specific information is not available.

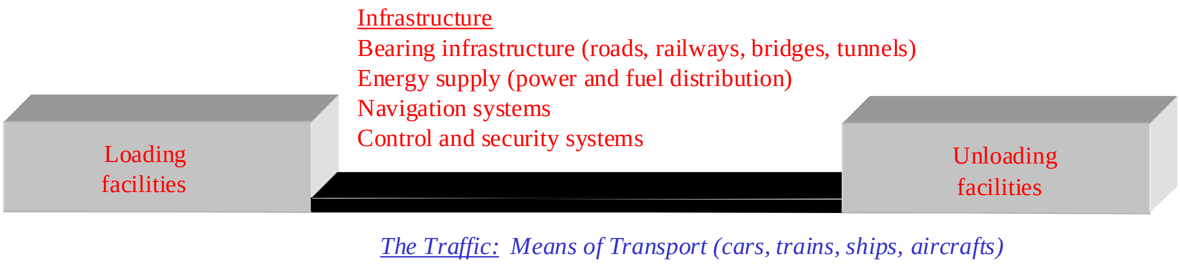

Figure 1 Schematic picture of a transport with its infrastructure.

Another important aspect is how to allocate between passenger and cargo. For aircraft transportation the weight is the determining factor independent of if the weight is caused by passengers or by cargo. For e.g. railroad transports the situation is different. A model that has been used is to represent a passenger with one tonne of cargo. This allocation has of course a significant influence on the final result.

Overview calculations of environmental performance for infrastructures compared to the traffic

Road transport

In the project, we have tried to give an example of the total emission calculation of a transport when the traffic and infrastructure parts are put together to one transport performance item.

Example road: 13 m width and 1 km length gives a CO_2 fossil emission of $1.1*10^9$ g during 60 years.

Traffic intensity: 5000 vehicles/day or $1.095*10^8$ vehicles/during 60 years.

This gives $1.1*10^9/1.095*10^8 = 10.05$ g CO_2 fossil/vehicle from the road per km.

Several different calculation and allocation methods can be applicable. One can for example divide the vehicles in passenger and freight transport and calculate the road contribution to the passenger and the goods. In the present model the weight of passenger cars and lorries have been used for the allocation.

Railroad transport

An example railroad (infrastructure) for Sweden has been calculated for a calculation period of 60 years. The total CO_2 fossil emissions during 60 years for 1 km railway has been calculated to 1 370 372 kg including uptake of CO_2 in concrete during the service life of the railway (not waste phase). A calculation example could be as follows: Energy use for the railway traffic in Sweden was for year 2010 as follows: Passenger trains: 1235 GWh (56.6 %), Freight trains 948 GWh (43.4 %). Total track length in Sweden is 11 149 km. A fictive emission during 60 years in Sweden from the railway could be 1 370 372 kg * 11 149 km = $1.528*10^{10}$ kg CO_2 fossil including construction, operation and maintenance. This can then be allocated to passenger transport; $1.528*10^{10}$ kg*0.566 = $8.648*10^{9}$ kg CO_2 fossil and to freight transport $1.528*10^{10}$ kg * 0.434 = $6.632*10^{9}$ kg CO_2 fossil. If the passenger and goods volumes are known, the CO_2 fossil emission can be allocated to the two types and the traffic emission can be added.

Aircraft transport

An aircraft transport consists of take-off and landing where the infrastructure is used and between that the traffic with the aircraft. Some navigation and control equipment can be allocated to the infrastructure along the flight, but the effect of this is probably small. The allocation of goods and passenger for air transport is strictly based on weight. Goods weight and passenger weight (95 kg/passenger). The energy and emission levels can be calculated based on an LCA for an airport expressed per transport weight equivalent (passenger and goods total weight). Knowing the traffic activity on the airport, the environmental data can be expressed as environmental effect per kg transport equivalent for one take-off and landing. This has in the model been calculated to 15.6 + 15.6 = 31.2 g CO_2 fossil for one take-off and landing, which represents the infrastructure effect per air transport.

As shown in the example above, several principles can be used for the allocation between the traffic and the infrastructure. The method to be used depends on the purpose for the allocation. For example, if the aim of the allocation is to show the impact on maintenance of the traffic on the road, the heavy traffic should probably be given a higher weight than an allocation per vehicle, maybe even more than an allocation by the vehicle weight.

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