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# A TOOL FOR CALCULATING EXTERNAL COSTS AND EFFICIENCY OF FREIGHT TRANSPORT SYSTEMS

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## ABSTRACT

It becomes increasingly important to analyze the environmental impact and effectiveness of goods transport systems. The impact of transport on environment, climate and health can be calculated as external costs. This paper presents a tool that can be used to internalize the external effects and analyze the effect of changes in goods transport solutions. The tool provides estimates of 1) transport efficiency and effectiveness, expressed as total logistics cost, and 2) environmental and other external interference, expressed as external costs. The tool addresses all modes of transport and a wide variety of parameters besides $CO_2$ emissions. The tool has been tested in case studies with conflicts or synergies between environmental and logistical efficiency. A challenge in the case studies was to get the required data. In order to capture the intrinsic uncertainties in these types of models, uncertainty calculations are made.

## INTRODUCTION

Goods transport comes with a number of unwanted external impacts. These comprise impact on climate, most notably through emissions of carbon dioxide, health risks through emissions of particles and other substances to air but also from noise emissions and of course accidents, environmental impact such as acidification, eutrophication, barrier effects, toxic emissions to water etc., and loss of peoples time though congestion.

These impacts can be valuated using the concept of external costs. These are costs that arise due to an activity, in this case goods transport, and are taken by others, in general society at large. The ways to calculate these costs vary between the impact categories. For example costs due to health problems from air pollution are calculated by assessing the exposure to humans using emission and dispersion models, and then dose-response functions are used to obtain mortality and morbidity associated with the emissions. These cases are then valuated to obtain the costs. There are also a number of other methods to assess the externalities (Maibach, 2008).

Goods transport systems are measured through the logistics efficiency and the direct costs but there are also external service effects that need to be accounted for and these are very hard to evaluate. It could be a matter of having long or short lead times, being on time or not, being

able to deliver a complete order etc., which have consequences for the customer. In a similar way as for the external environmental effects there is a managerial advantage to internalize the external costs and be able to present a total cost and not only the direct transport costs. The logic for internalizing environmental and service effects is the same and so are the challenges. There is a lack of data or the data quality is bad, and when the costs are to be calculated there is limited knowledge about how to allocate costs to different service outcomes.

In this paper we describe a tool for calculating external costs and at the same time logistics efficiency and effectiveness for goods transport systems. The tool requires input from the user on certain details about the transport systems, direct costs etc. The tool explicitly calculates emissions of air pollutants and climate gases as well as external costs for these and for a number of other parameters. These are related to the direct transport costs and the time for delivery and precision of delivery. Further, as will be discussed, there are uncertainties, sometimes large, in the ingoing variables in the calculations. This especially applies to the valuation of external effects and the valuation of delivery precision. In order to capture this, the tool calculates uncertainties for all results using a Monte Carlo algorithm.

## THE MODEL

With the model a certain goods transport system can be studied. The user needs to provide certain information about the goods (weight, volume, value) and the distance traveled. 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). The values for congestion, accidents, noise, up/down stream, ecosystems, soil and water are from (Handbook).

In the total cost model described by Stock and Lambert (2001) the role of cost trade-offs in marketing is highlighted. Their idea of a total cost model of logistics is to minimize the total cost, and not only the cost of one single category. Another type of total cost analysis was developed by Ellram (1995) and this was called the total cost of ownership model (TCO).

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.

## DISCUSSION

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 ongoing 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 gives a way to calculate the benefits and drawbacks of the four transport modes and from different vehicles and vessels. This will give decision support when choosing, e.g., between rail, road and sea in a transport systems. 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 these days fairly accurate due to, for example, the modeling 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 where 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 time and place 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 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 (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 placement of units and warehouses. So far a number of case studies have shown the usefulness of the tool.

## CONCLUSIONS

This paper presents a tool for calculating external costs and logistics efficiency for freight transport systems.

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