UNDERSTANDING EMISSION REDUCTIONS IN THE FREIGHT TRANSPORT SECTOR THROUGH SYSTEM DYNAMICS

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ABSTRACT

The National Climate Change Response White Paper presents the government's commitment to moving to a lower carbon economy in South Africa. The White Paper requires significant greenhouse gas (GHG) emitting sectors, including transport, to define "bottom up" carbon budgets. This work forms part of the WWF low carbon frameworks transport project and explores the implications of strategies for GHG emission reductions in the freight transport sub-sector within this context. The study uses system dynamics modelling to interrogate mitigation opportunities in this sector by looking specifically at the transport of processed food along the Cape Town-Gauteng corridor. Stakeholder input from business, labour and government is used to guide the modelling process. The objectives are to explore the implications of strategies for GHG emission reductions in the freight transport sub-sector as well as its impacts on the wider economy and environment; determine the barriers to change, with a specific focus on the mode switch from road to rail; recommend appropriate measures that could ensure developments towards achieving sustainability in transportation planning; and identify possible opportunities for further research and innovation. The methodology behind the model as well as the initial casual loop diagrams for the system dynamics model are presented in this paper.

1 INTRODUCTION

Low carbon economy policy and planning in South Africa is evolving rapidly with the National Climate Change Response White Paper outlining the government's commitment to moving to a lower carbon economy (Republic of South Africa, 2011). The White Paper requires significant greenhouse gas (GHG) emitting sectors, including transport, to define "bottom up" carbon budgets. Transport is one of the sectors identified as a large contributor to South Africa's greenhouse gas (GHG) emissions, contributing 39.4 Mt CO_2e (9%) to the country's latest official greenhouse gas inventory, published in 2009 but reflecting data from 2000 (DEAT, 2009). The latest available data from 2007 however indicate that transport emissions has increased to 46.3 Mt CO_2e, now contributing 13% to South Africa's overall emissions (WWF SA, 2012). Freight accounts for about half of transport emissions.

With continued growth in the transport sector, and due to the vast number of stakeholders and dispersed nature of emissions, realising change is a challenge. An integrated assessment is required to identify appropriate mitigation strategies for transport and understand what the impact of these strategies on the wider economy and environment will be. This work forms part of a larger study commissioned by WWF on low carbon frameworks for transport and builds on previous work conducted by the authors for WWF on low carbon planning (WWF, 2011) in which a quantitative modelling framework to support national low carbon planning was proposed. This framework had at its core a system dynamics model developed through a stakeholder engagement process known as 'mediated modelling'. System dynamics allows for the exploration of the evolution of a complex system over time, through consideration of the feedback loops and dynamic behaviour of the system. This approach is useful in that it overcomes some of the problems inherent in linear thinking, compartmentalised and non-participatory decision-making. Similar international transport system dynamics modelling was conducted by the French Ministry of Transport (Salini & Karsky, 2003) and for the EU15 countries via the ASTRA model (IWW, 2000).

2 OBJECTIVES

The objectives of this study are to:

- Explore the implications of strategies for GHG emission reductions in the freight transport sub-sector, and the impacts on the wider economy and environment;
- Determine the barriers to change, with a specific focus on the mode switch from road to rail;
- Recommend appropriate measures that could ensure developments towards achieving sustainability in transportation planning, and;
- Identify possible opportunities for further research and innovation.

However, it is not the intention to model the entire transport system and thus duplicate national planning efforts, but rather to demonstrate the value and insights to be gained from taking a system dynamics view of the problem. Therefore, in this study, a system dynamics model is constructed to interrogate GHG mitigation options related to a subset of freight transport: the transport of processed food along the Cape Town-Gauteng corridor.

3 METHODOLOGY

The methodology for the development of the system dynamics model consists of two phases:

- Conceptual phase:
  - System conceptualisation; and
  - Model representation.
- Technical phase:
  - Data collection;
  - Model behaviour; and
  - Model evaluation.

The first step in the conceptual phase, system conceptualisation, entails outlining the scope of the model, identifying the parameters in the system and the relationships between these parameters, which subsequently result in casual loop diagrams. This step is largely based on literature review, although testing the conceptual model structure through stakeholder engagement is integral to the approach to ensure that the important influences are identified and the right connections made. The model representation can happen simultaneously with the system conceptualisation. This entails capturing the conceptual model (causal loop diagrams) in computer code via a system dynamics programming software package. The STELLA simulation software was chosen for this study.

The technical phase will start by populating the computer model with relevant data and equations to describe the interrelationships between the variables. This will be based on literature and input from relevant stakeholders and experts. Computer simulation is then used in the model behaviour step to run simulations and test the sanity of the model outputs over a period of time. Stakeholder engagement will again be important in the final evaluation phase to provide feedback on the quality and validity of the model outputs.

The technical phase of this study has not commenced yet and therefore will not form part of this this paper.

4 SYSTEM CONCEPTUALISATION

4.1 Model Scope

The scope of the model is defined in terms of the freight typology, the focus commodity, the spatial scope, important model components and the timeframe of the model.

From the literature review on freight transport emissions, corridor road freight has been identified as the most significant freight typology from an emissions perspective, and indications are that the transport of processed foods makes up a particularly large proportion of this freight segment (van Eeden & Havenga, 2010). The nature of processed food also makes it suitable for intermodal transport solutions, although most of this freight is currently carried only by road (Transnet, 2012). “Processed foods” transported on corridors has therefore been selected as the focus commodity in this work.

In terms of the spatial scope, the Cape Town-Gauteng corridor is one of the most significant in South Africa, particularly on an emissions basis (due to both the distance and volume of freight transported). For the purpose of model development the corridor is identified as Cape Town-Gauteng, but this will be represented by a set of parameter values (e.g. distance, average speed, toll costs, etc.), which could be adjusted easily to represent other corridors. For this study only one corridor will be modelled, because simultaneous modelling of a network of multiple origin-destination pairs introduce considerable complexity that would detract from the core objective of examining emission mitigation options. Corridor freight will be modelled with a simplified representation of metropolitan freight to incorporate the end effects of the metropolitan travel at either end of the journey. This model structure is represented in **Figure 1Error! Reference source not found.**.

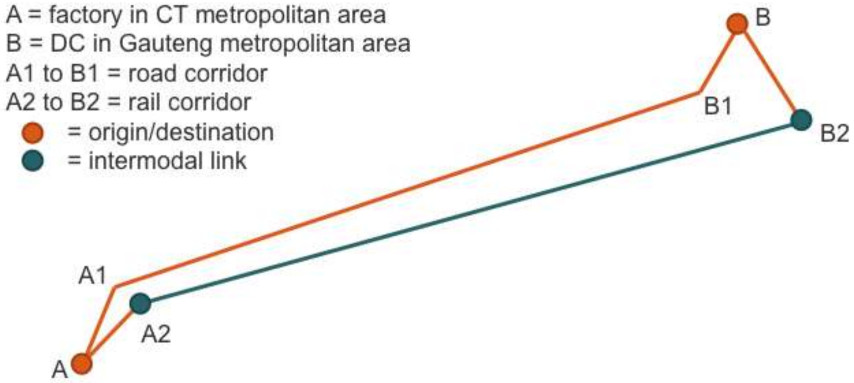

Figure 1: Conceptual model diagram of freight transport of processed food

The limitations of this simplified model structure are that by not considering the whole system, the effects of congestion and capacity constraints cannot be considered explicitly. Nevertheless, this limited scope is well suited to the objectives of the study.

The corridor model will consist of a number components, including:

- Company types ranging from large companies with extensive fleets to one-man-one-vehicle operators will be included explicitly in the model as their decision making behaviour and access to resources etc. is likely to differ significantly;
- With in these company types, decision making behaviour will be explicitly accounted for in terms of the proportion of companies that can be considered "first movers", "second movers" and "late adopters";
- As cost is the most often quoted driver of change, a generalised cost calculation for transport by each mode (road and rail) will be included as far as possible, incorporating the transport price paid by the cargo owner as well as other cost factors such as inventory costs and handing costs;
- Non-cost influences on mode choice, such as prevailing perceptions related to the different modes of transport in terms of reliability, functionality, service etc. will be included in the model;
- To incorporate efficiency effects it is necessary to include a dynamic fleet model, representing the vehicle types, ages and efficiencies in use on the corridor. A consideration of the mak , characteristic of different company "types" (large firms vs. one man one truck operators); and
- To simplify the number of efficiency measures applicable to freight transport, these will be grouped into bands of: high cost, medium cost and low cost interventions, each associated with an average level of emissions savings.

The intended time period for modelling is up to 2050, to align with the National Climate Change Response White Paper's description of a National Benchmark Trajectory range and sector carbon budgets.

4.2 Stakeholder engagement

The WWF has an established network of role players and stakeholders, within the transport sector, who are engaged and are willing and able to effect change. While a fully mediated modelling approach has not been possible due to the time investment required of the stakeholders, stakeholder input has nonetheless been used as input to the models and to ensure buy-in in their construction. A series of stakeholder workshops is underway with each of “business”, “labour” and “government” stakeholder sets.

The stakeholder interaction process to date has focused on understanding the landscape of the freight transport sector and the drivers and barriers to changes in behaviour, in particular the shift from road to rail.

5 MODEL REPRESENTATION

It should be noted that the model representation presented in this section is preliminary and it is likely that it will develop further as the modelling progresses.

For ease of presentation the model was constructed in 3 separate modules:

- Module 1: Decisions on mode shift
- Module 2: Role of efficiency
- Module 3: Summing the effects: indicators

Causal loop diagrams have been developed for each of these modules, which are presented below.

The system dynamics tool used to represent these causal loop diagrams, STELLA, has four basic building blocks:

- Stocks – graphically indicated by a large square, represent variables that accumulate over time;
- Flows – graphically indicated by a thick arrow with a flow controller, represent activities that increase and decrease stocks (a rate that changes the magnitude of a stock).
- Connectors – graphically indicated by a thin red lined arrow, used to establish the relationship among variables in the model; and
- Converters – graphically indicated by circles, transform inputs to outputs, and can accept input in the form of algebraic relationships, graphs or tables.

The model variables and parameters are presented in different colours to distinguish between input parameters (orange), mitigation instruments (green), mitigation measures (light blue) and modelled variables (dark blue). Question marks in the circles indicate that the variable is not currently specified, and the layered circles represent that the variable is an array. It should be noted that there are links between the diagrams and some variables are necessarily repeated where they are relevant.

Figure 2 shows the causal loop diagram for unpacking decisions on mode shift.

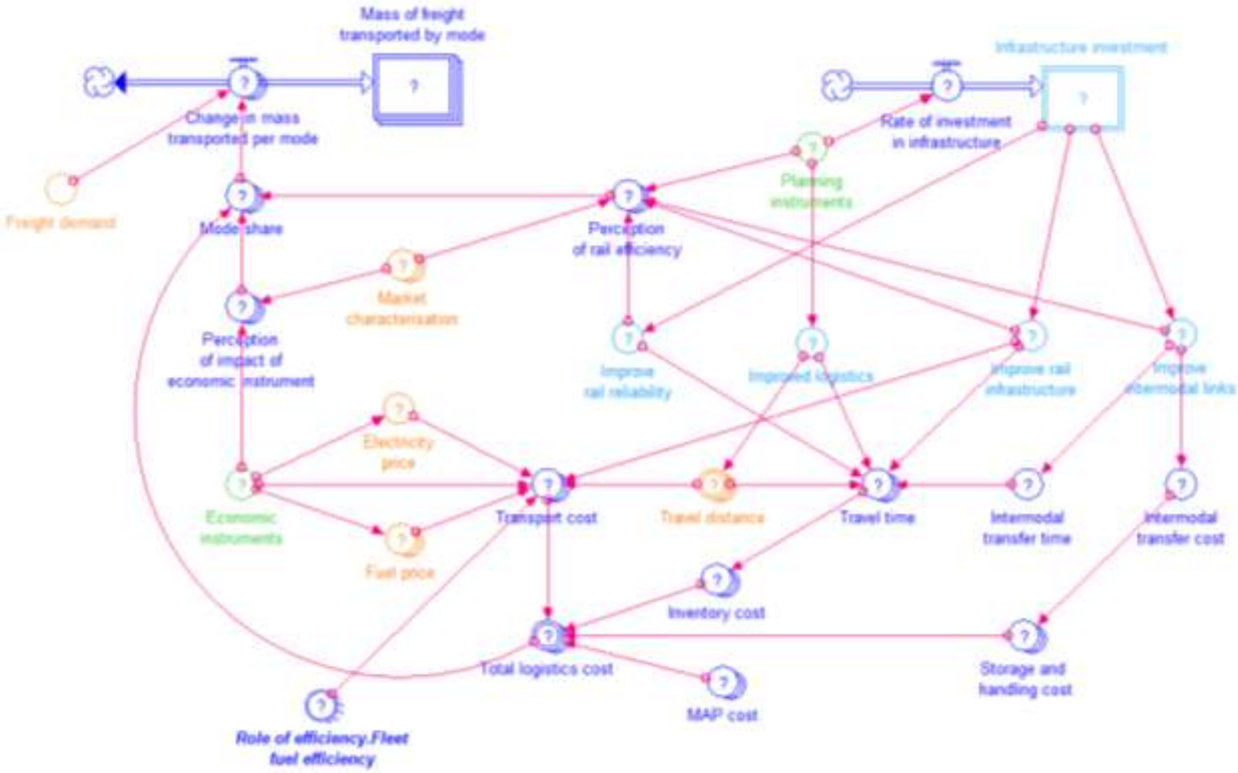

Figure 2: Module 1: Decisions on Mode Shift

The stocks for Module 1 are "Mass of freight transported by mode" and "Infrastructure investment". The flow controlling the mass of freight transported is a bidirectional flow, which means that the total accumulated values for the different modes of transport can increase or decrease depending on the converter "Change in mass transported by mode" which is governed by "Mode share" and "Freight demand". These stocks will allow that in any point in time it will be possible to see the total mass transported per mode as well as the total investment in infrastructure from the start of the modelling period up to the desired point in time.

From **Figure 2** it can be seen that one of the main drivers of mode choice is cost. Here, logistics cost is made up of the actual transport cost, the inventory cost and other associated costs. Economic instruments act on costs, by either increasing the fuel price, the electricity price or directly through a carbon tax. Road tolls can be similarly modelled. Importantly, in this model we explicitly recognise that the relationship between cost and mode shift is not linear in that as cost increases by x%, mode share won't necessarily increase immediately by y%. Thus we have included the variable "perception of impact of economic instrument" which captures different companies' responses to the economic instrument, including their tolerance to cost increases, the time lag between needing to reduce costs and implementing a mode shift (or other efficiency measures), early mover behaviour, etc.

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In the context of encouraging a mode shift, planning instruments result in infrastructure investment, which in turn result in improved rail infrastructure and intermodal links. These measures impact cost through reducing travel time and transfer time, but also possibly increasing the cost of rail services. More importantly, perhaps, is the impact of investment and planning on the perception of rail as a viable alternative to road freight transport. As before, different companies may be seen to respond differently to these improvements, a consideration that the model will aim to capture. Another measure, which doesn't necessarily link to a higher-level instrument, is Transnet improving the reliability of their freight rail service. Reliability might however increase with increased investment in infrastructure. Again, this measure has a direct link to cost, but also may influence company behaviour and the propensity to shift to rail. A mitigation measure which is company driven is improved logistics. This will impact travel distance and travel time, which indirectly impact on transport cost.

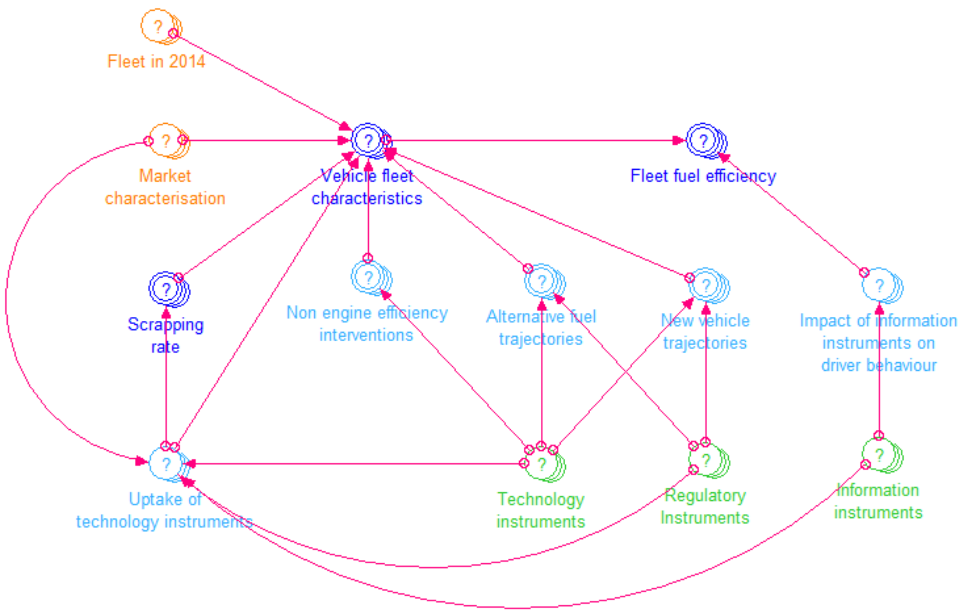

Figure 3: Role of Efficiency

Figure 3 unpacks the role of efficiency in mitigating emissions. Here, the key variable is fuel efficiency, which is dictated by the vehicle fleet characteristics. As mentioned previously, we disaggregate the road freight sector into different types of companies and within that different types of decision makers. Each decision maker type within each company type is associated with a different "starting fleet" in terms of age and type of vehicles. Furthermore, each decision maker type will respond to the instruments applied here in different ways and at different times. Information instruments are seen to impact driver behaviour and will directly impact on fuel consumption. Information instruments may also serve to educate businesses and influence their propensity to implement change. Regulatory instruments will affect the choices in terms of new vehicle purchases and the uptake of alternative fuels. Technology instruments will determine the availability of technology measures locally including new vehicles, alternative fuels and also non-engine efficiency interventions.

Given that mode shift is not considered relevant to the metropolitan transport typology, the causal loop diagram for the metropolitan model will closely resemble the one presented here, but with different mitigation measures investigated together with a consideration of congestion effects and feedbacks.

5.1 Output indicators

A key step in developing the freight system dynamics model is to identify a set of indicators with which to interpret the modelled outcomes of the investigations into mitigation. These indicators should be relevant and unbiased in terms of demonstrating the direct and knock-on implications of mitigation activities and also be feasible to model by virtue of data availability. The emphasis needs to be on measures that can be readily populated and/or calculated within the modelling framework, and which can be influenced by the mitigation interventions considered in the model.

The following indicators will be calculated in the model:

- GHG emissions (baseline and with measures): This is calculated directly from fuel consumption;
- Life cycle GHG emissions can be calculated for the provision of the fuel and electricity consumed, emissions embodied in new vehicles and infrastructure;
- Land use: associated with infrastructure and biofuels;
- Water use: associated with electricity and fuel provision;
- Human health impacts are dependent on the vehicles in operation, fuel combusted and distances travelled;
- Employment associated with freight transport, operation and maintenance, infrastructure development, alternative and conventional fuel refining, technology (new vehicle) manufacture;
- Total logistics cost;
- Capital cost associated with mitigation measures;
- Cost per tonne CO_2e abated (derived from logistics cost and capital cost and GHG emissions); and
- Balance of payments and energy security both require a calculation of the relative contribution of imports to liquid fuel consumption.

Figure 4 depicts the links between model variables and the desired output indicators listed above. For the calculation of the indicators additional information is required (e.g. emission factors, employment intensity factors, etc.). These are shown in orange in the diagram, with the indicators themselves highlighted in pink. Some of the indicators are depicted as stocks which will accumulate over time, whereas other indicators will be calculated as an instantaneous value at a specific point in time.

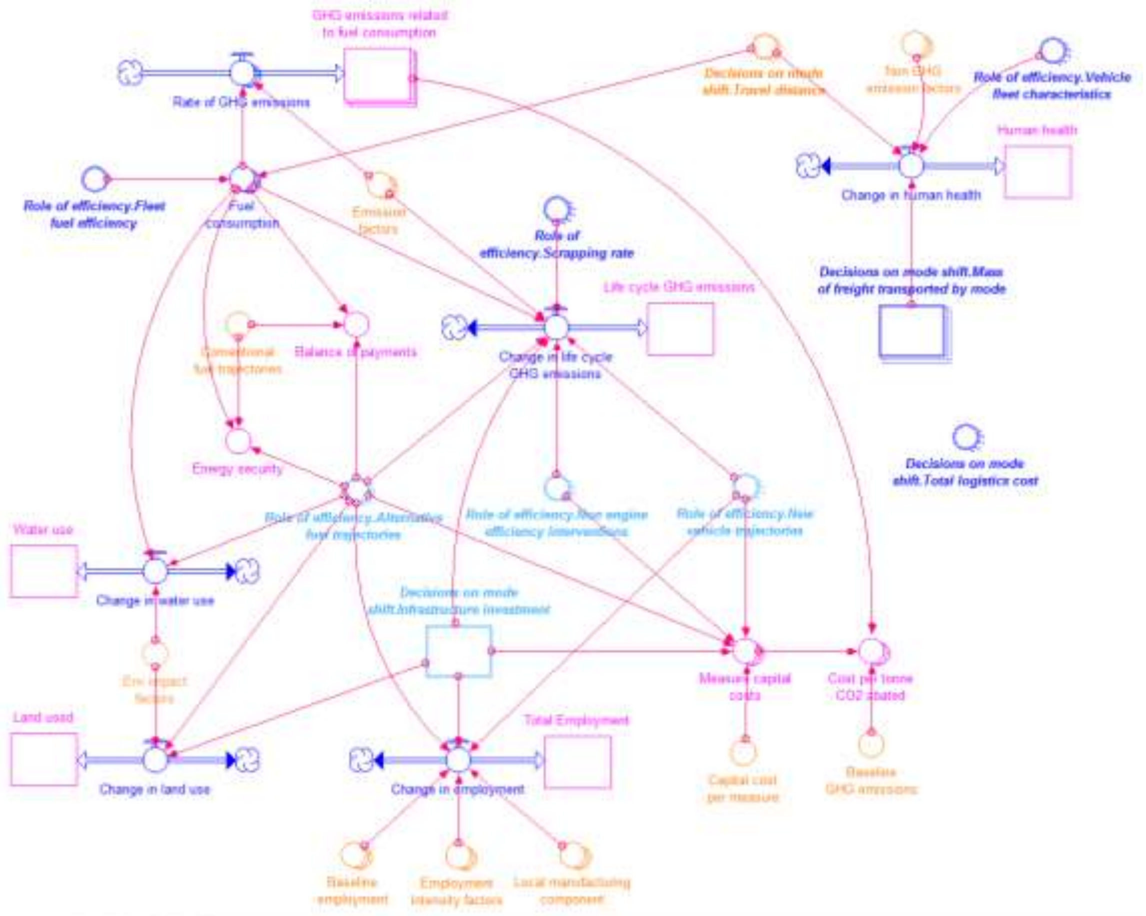

Figure 4: Summing the effects: indicators

6 FUTURE WORK

The next step in this study will be to start the technical phase of modelling by collecting the relevant data required to populate the model. Both literature and expert stakeholder input will be used as data sources. The data collection exercise will also provide further insight into the identified parameters and their relationships, which may lead to changes in the casual loop diagrams.

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