Transportation Engineering

- Road funding policy and options
- Massive N3 upgrade on the cards
- Running dry – assessing the fuel levy
System dynamics as a tool for exploring greenhouse
gas emission mitigation potential in freight transport

CONTEXT
South Africa’s latest Greenhouse Gas Inventory indicates that in 2010 the transport sector contributed a total of 47.4 Mt CO₂e in direct greenhouse gas (GHG) emissions, or 8.4% of the country’s total emissions. Freight transport is thought to account for about half of the emissions from the combustion of fossil fuels.

It is widely recognised that the shift from road to rail is one of the biggest opportunities for reducing GHG emissions from the freight transport sector. Along with improved and alternative vehicle technologies and fuels, it is included as a mitigation option in government’s Mitigation Potential Analysis. The road-to-rail shift forms part of the Department of Transport’s strategic goal to deliver an efficient and integrated infrastructure network, and will in part be facilitated by government’s rail re-capitalisation programme. However, a shift from road to rail is not without its challenges. It is important to also understand the degree to which freight can be shifted to rail. Currently, most mitigation modelling efforts tend to assume a linear (or other simple) transition to a desired future modal split, without much consideration of how this can be achieved. For example, the Mitigation Potential Analysis assumes that a 70:30 rail-to-road split for freight transported along corridors is technically possible by 2050, based on work done in the development of the Western Cape Infrastructure Plan.

OBJECTIVES
WWF South Africa commissioned The Green House to develop a system dynamics model to explore the workings of a shift of freight between road and rail. The work in this study aims to advance the understanding of the drivers and barriers to a freight modal shift, by identifying types of decision-makers in the freight sector and investigating the impact of mitigation measures on costs, reliability and resulting decision-making behaviour, as well as the bigger picture impacts on jobs, emissions, water use and other externality costs. An interactive online tool has been developed that aims to facilitate the dialogue between industry, government and other interested parties in the freight transport mitigation space. This article explores the development of the modelling tool.
MODEL STRUCTURE
System dynamics models have been successfully applied to investigate the implications of policy decisions on transport systems internationally. In this study, system dynamics modelling was used to facilitate a better understanding of the complexities of the freight transport system amongst decision-makers, with a particular focus on the drivers and barriers to mode-shift decisions. The model also evaluates the impacts of mitigation measures in the freight subsector in terms of greenhouse gas (GHG) emissions, direct job creation, water usage and various externality costs.

The model was developed and populated based on an understanding of the South African freight transport system gained from literature, and extensive stakeholder and expert consultation throughout the process. Specific attention was given to capturing the process of decision-making in the model. Other components of the model are presented in Figure 1.

With its focus on mode-shift decision-making and mitigation, the model does not attempt to replicate national freight flow models, and considers a reduced scope of a single commodity transported along a major corridor, i.e. the transport of processed food along the Cape Town–Gauteng corridor. The rationale behind this selection is that the nature of processed food and the distance of the selected corridor make it suitable for intermodal transport solutions, even though currently most of this freight is transported by road. Furthermore, processed foods make up a large portion of the total freight transported via this specific corridor.

The route simulated provides for a road leg at either end of the rail corridor to account for the fact that rail links are often not located directly adjacent to the origin or final destination of the freight. In contrast, road freight was assumed to take place as one trip (see Figure 2).

Once set in motion with initial settings, the model simulates freight transport year on year over the period 2012 to 2050, based on decision-makers' responses to the starting situation and feedback loops or knock-on effects that occur.

DECISION-MAKERS: FREIGHT OWNERS AND FLEET OWNERS
Interviews with stakeholders suggested that cost and reliability are the main criteria by which mode-shift decisions are currently made by freight owners (those who own the cargo) or their proxies (being providers of logistics services). Additional decision-making criteria (jobs, emissions and externality costs) were added to the model to investigate the impact of decision-makers bringing these criteria into their decision processes. In the model, three freight owner decision-makers were distinguished:

- **Cost-focused**: Cost is identified as the main driver for this type of decision-maker. Typical companies have large volumes of products and serve the majority of consumers.

- **Reputation-focused**: Reliability is the main driver for this decision-maker, within a cost-parity band. Environmental issues may be considered to enhance the brand value. Typical companies cater for a higher-end market with consumers willing to pay more for better quality and consistent availability of products.

- **Sustainability-focused**: This type represents a theoretical decision-maker who makes decisions for the greater good – for example a government decision-maker attempting to drive a development agenda rather than the interests of a specific business. Priorities are to reduce emissions, increase employment and reduce externality costs.

In terms of the current landscape of processed food freight owners, the default setting is that the market consists of 90% cost-focused decision-makers, with the remainder being reputation-focused. For the base case, sustainability-focused decision-makers were judged to be effectively non-existent.
Within vehicle fleet companies, a distinction was made between two types of decision-makers:

- **First-adopters**: These companies are at the forefront of adopting new technologies to improve vehicle efficiency. They are typically larger companies with a balance sheet (capital or cash flow) that allows for such investment and can tolerate longer payback periods. The model also conflates these with companies that have stringent maintenance and driver-training programmes.

- **Late-adopters**: Here capital is limited, therefore these types of fleet owners rarely consider adopting new technologies if not required by law. They are typically smaller companies or single driver-and-truck operations. Sometimes these decision-makers utilise second-hand trucks, and drivers do not typically receive training in fuel-efficient driving.

We made assumptions about the mapping between the freight owners and fleet companies. Reputation-focused freight owners predominantly use first-adopter fleets, although they may occasionally make use of late-adopter trucks during times of high demand. Cost-focused decision-makers utilise a far greater percentage of late-adopter fleets.

**COST AND RELIABILITY IN THE MODEL**

The model aims to capture the total logistics cost to the freight owner (price paid per tonne kilometre), as this is the cost used in the decision-making process as one of the criteria for selecting a mode of transport. Total logistics cost comprises transport, warehousing, inventory carrying and management and administration cost, with the figures used based on the 10th State of Logistics report. The model assumes that the average punctuality for first-adopter truck owners is 98%, and that of the late-adopter fleet is 92%. For rail transport, the punctuality was determined from the average time delay per train, which was calculated from Transnet data and the tolerance levels for delays of European freight owners.11

**FREIGHT CHARACTERISTICS**

Not all freight is suitable for rail. The demand for processed food freight transport along the modelled corridor to 2050 was taken from Transnet’s Rail Forecast from April 2013,12 which informed their Long Term Planning Framework.13 The same freight classifications used by Transnet are also applied here as follows:

- **Rail-compatible**: Typically containerised or palletised freight transported in bulk to a single destination.
- **Competing**: Freight that can be transported on either rail or road. Freight might be boxed and packaged, but can require additional palletisation or have more stringent storage and handling requirements. Possibly smaller quantities transported to many destinations.

**Road-compatible**: Freight that is most suitable for road transport due to the type of packaging, volumes and dispersed destinations.

In the model, road-compatible freight is assumed to never shift to rail, whereas a cost differential is included to account for the difference in transporting rail-compatible and competing freight, with the cost to transport of the latter by rail being more expensive.

The model shifts freight between road and rail transport depending on the demand for rail in a specific year. Based on stakeholder input, it is understood that the mode shift is not immediate, but rather phased in. This is to account for the likelihood of there being binding contracts with a transport provider, or the freight owner possibly utilising in-house trucks for transport that might retard their shift as they seek to maximise existing assets. To simulate this, a first-order material delay with a delay duration of two years is built into the model.

**MITIGATION MEASURES**

The mitigation measures as depicted in Table 1 have been investigated in the model.

**MODEL OUTPUT INDICATORS**

As well as projecting the amount of each type of freight carried on each mode, other output indicators include:

- **GHG emissions (of fuels and electricity)**: These are calculated using emission factors from Defra14 and the IRP.15

- **Other life cycle GHG emissions**: For emission sources associated with the life cycle of the transport services (upstream and downstream of the service), emission factors from the eco-invent database were applied.

- **Water consumption**: Water requirements are only calculated for the production of the main energy sources, i.e. diesel, biodiesel and electricity.17

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**Table 1: Mitigation measures considered in the freight system dynamics model**

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<thead>
<tr>
<th>Planning measures</th>
<th>Regulatory measures</th>
<th>Economic measures</th>
<th>Information measures</th>
<th>Technological measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of intermodal points</td>
<td>Biofuels blending</td>
<td>Carbon tax</td>
<td>Driver training and awareness</td>
<td>Tyre improvements</td>
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<td>Rail infrastructure upgrades</td>
<td>Rail toll fees</td>
<td>Fuel levies</td>
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<td>Transmission upgrades</td>
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<td>Cleaner grid electricity</td>
<td>Rail subsidy</td>
<td>Increased driver wages and labour costs</td>
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<td>Aerodynamic trailers and engine improvements</td>
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<td>Hybrid vehicles with idle reduction</td>
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<td>Increased biofuels usage</td>
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Externality costs: These are additional costs incurred by society when a private party utilises a public good. Costs for accidents, emissions, congestion, noise, roadway land availability and policing were simulated based on literature data.

Jobs: This has to do with direct job impacts on road and rail based on literature.

COMMENTS ON MODEL OUTPUTS
Initial model runs indicate that a significant shift of the freight from road to rail is possible for decision-makers who prioritise cost over reliability. However, reputation-focused decision-makers (who prioritise reliability) are only seen to shift a fraction of their freight onto rail, and only do so much later.

With an increased volume of freight on rail, the only negative impacts are the reduction in direct jobs and a slight increase in water requirements. Jobs are lost in the road freight industry and we did not model indirect jobs, which might be gained. The water result is due to increased water requirements for producing biodiesel. All other outputs are beneficial, with large reductions in GHG emissions and externality costs.

As with any model, the relevance of the model outputs is largely dependent on the inputs. Where information was not readily available, assumptions had to be made. Through a sensitivity analysis the input parameters that have the biggest impact on the model results were identified.

The key areas that could be the subject of further investigation and refinement in the model include:

- Characterisation of the processed food market in terms of percentage of each type of decision-maker, as well as their decision-making priorities.
- Including a better understanding of current rail and road transport costs.
- Further unpacking utilisation of the rail infrastructure, available capacity, planned future capacity and the impact of capacity constraints on modal shifts.
- Accounting for additional rail delays not related to failures on the Cape Town to Gauteng corridor.
- Further understanding the implications of rail infrastructure improvements and the impact on reliability and intermodal point upgrades.

The interactive model can be found at: https://forio.com/simulate/ab755185/3013-freight-sd-model-v-100/. The interface allows one to change settings as one sees fit. A technical report is also available for those who would like to dig deeper into the modelling.

NOTE
This study is part of WWF’s programme on low-carbon frameworks in the transport sector, which has The Green House as the technical partner. More papers can be found at: http://www.wwf.org.za/what_we_do/transport/

REFERENCES


5. By the French Ministry of Transport and for the EU15 countries via the ASTRA model, http://www.astra-model.eu/


12. Data obtained from Transnet, not publicly available.


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**COMPANY BACKGROUND**

Ecsongweni Engineers is a 100% Black African owned consulting engineers company, which has been in existence since 2005 and rebranded to Ecsongweni Engineers in 2014. Upon rebranding after nine successful years we expanded to two additional branches, in Bloemfontein and Johannesburg.

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