The Freight Capacity Model:

A tool for exploring the future of road freight and its impact on the Environment

Authors:

Yannick Michel
Final year student, Monash University
Ph: (03)98811597
Email 1: ymic1@student.monash.edu.au

and

James Luk
Chief Scientist, Transport Operations, ARRB Group Ltd
Ph: (03)98811531
Email: james.luk@arrb.com.au

Abstract:

With the freight task predicted to double in the next 20 years, one reaction is to increase the fleet size to satisfy the increased demand over time. However from any perspective, let alone environmental, this is an unsustainable option. Increases in fleet sizes inevitably results in increased network congestion levels and other externalities. Improved fleet management in conjunction with high-productivity or performance-based standards (PBS) trucks is one possible way to alleviate the stress on the road network and the environment.

With what began as exploratory work and a final year project of Monash University, the American Transport Research Institute (ATRI) commissioned ARRB for the creation of a freight capacity model to address these freight issues. The model integrates several carrier and network metrics including: delay, fuel consumption, distance, air pollution, noise pollution and trip performance. The objective of the model is to act as a decision-support tool by simulating how a change in fleet can potentially impact on the road network and the environment, aiming to improve the management of the freight industry. This paper outlines the issues faced by the freight industry, highlighting the necessity of having a tool such as this. In addition, the approach taken and the methodology for the creation of the model are also discussed. As a result of this model, ATRI has pushed for its further development for national distribution in the United States.

1 INTRODUCTION

The increase in freight movement plays an integral part for the sustainability of Australia's growth. Parallel to this growing industry, adequacy of transport infrastructure to support such growth is a leading issue (Manders 2006). Increasing environmental, social and economic costs are resultant of congested road networks, accidents and increased air and noise emissions. Therefore, the use of models can assist in the prediction of inefficiencies prior to them eventuating and help to plan for the future.

The increase in freight demand will result in deceased efficiency, hence requiring an increase in productivity to be sustainable (Manders 2006). A solution to increase productivity is to encourage the deployment of high productivity vehicles (HPVs). Such vehicles are able to carry a greater load therefore requiring fewer trucks to satisfy the same freight demand. Associated with fewer trucks is the reduction in impacts of externalities such as exhaust emissions, accidents, noise and congestion. Reduced impacts on the environment along with more efficient freight movement will result in a more environmentally and economically sustainable future for the freight industry.

As part of work placement with the ARRB Group, the *American Transportation Research Institute* (ATRI) contracted ARRB to develop the specifications for a freight capacity model. ARRB undertook preliminary research and included the development of the *ATRI Freight Capacity Model* (*AFCM*), a working version using an Excel platform. This model was based on a previous model titled the *ARRB Travel Cost Model* (*ATCM*), which was created in 1994. The model was spreadsheet based but without a user-friendly front end. The *AFCM* provides a front end to facilitate the input of data and output of performance metrics.

This paper addresses the broader issues associated with freight, the impacts on the environment and the benefits of the *AFCM* in relation to freight logistics. The objectives of this paper are to:

- Understand the freight task; past, present and future
- Understand the environmental impacts associated with freight movement
- Establish where the *AFCM* sits in the freight logistics context
- Establish areas of further research to enhance the *AFCM*

2 FREIGHT ISSUES

The freight industry in Australia contributes to the country's economic growth (Luk and McRobert 2005). Recognition of this relationship has alerted the industry to the fact that growth potentially leads to increased impacts on the environment, traffic conditions and other social aspects. In the absence of improved logistics and innovation in best practice, these impacts can be detrimental towards a sustainable environment and sustainable freight industry.

2.1 PRESENT FREIGHT TASK

The road freight task transported in Australia over the years has illustrated a substantial augmentation (Figure 1). The tonne-kilometres of all freight types (bulk and non-bulk) recorded for road freight transportation have more than doubled over the last 15 years, as can be seen in Table 1. This occurred at a growth rate of 6.8 percent per annum (BTRE 2003). Currently, the split of modes for combined bulk and non-bulk freight transportation are estimated to be:

- 37.3 % by road
- 33.1 % by rail
- 29.5 % by coastal shipping
- 0.1 % by air (BTRE 2006).

Table 1. The Australian domestic freight task by sector and mode: Estimates of tonne-kilometres of bulk and non-bulk commodities performed (Billion tonne-kilometres).

Year Ending June	ROAD		RAILWAY		SEA	AIR	TOTAL
	Urban	*Non-Urban*	*Public Access*	*Private*			
1971	9.39	16.67	25.2	13.8	72	0.1	137.16
1985	23.77	44.58	44.21	28.4	96.3	0.15	237.41
2000	46.13	96.5	79.28	47.45	112.9	0.2	382.46

(Source: BTRE 2006)

Road freight has satisfied the growing demand for door to door delivery thus capturing a share of the market for non-bulk freight from rail (BTRE 2006). Now, approximately 75 percent of the non-bilk freight task is undertaken via road transportation as depicted in Table 2. Consigned tonnes of non-bulk freight (Table 2) indicate that road has the greatest modal share of Australian domestic freight.

Table 2. Australian domestic freight by mode: Estimates of tonnes of non-bulk freight consigned (Million tonnes).

Year Ending June	ROAD	RAILWAY			SEA	AIR	TOTAL
		Government	*Private*	*Total*			
2000	1399.00	278.97	203.47	482.44	50.33	0.15	1931.92

(Source: BTRE 2006)

According to literature, for the period of 1999-2000, the total freight task for Australia was estimated at 382.5 billion tonne-kilometres (Table 1). Freight logistics for this period accounted for nine percent of Australia's gross domestic product, which approximated to $57 billion, thus making the freight logistics sector one of the largest in the Australian economy (Freight Transport Logistics Action Agenda 2002). These figures demonstrate the present importance of freight in Australia.

According to Figure 1, the freight task to the present time depicts a growing trend and is an indication of continued growth.

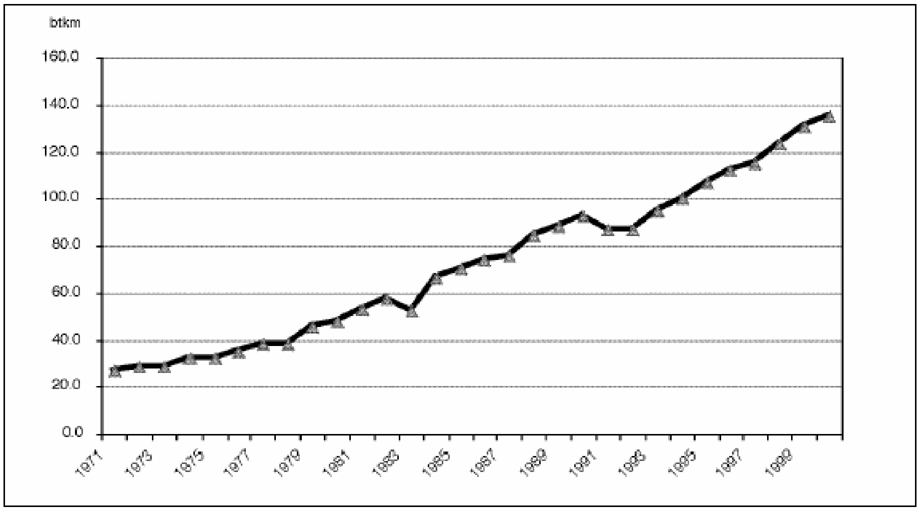

Figure 1. Total road freight task trend for the years 1971-2000. (Source: BTRE (2002b), Report 107).

2.2 THE FREIGHT TASK AHEAD

Forecasts from the Bureau of Transport and Regional Economics (BTRE) indicate that the freight task will double from 2000 to 2020. However, occurring at a reduced rate of 3.89 percent per annum as opposed to 6.8 percent during the 1970 to 1990 (BTRE 2003). Despite the decreasing growth rate, the freight task is expected to increase by approximately 154.36 billion tonne-kilometres for the period of 2000 to 2020 (Manders 2006). A growing transport industry places immense pressure on transport services and infrastructure. According to forecasts from a number of transport authorities, growth is inevitable.

There are many factors that support growth in transport. Two of the most important factors identified by Manders (2006) include:

- Economies of scale whereby the processing, manufacture and transport of goods occur from centralised large production and processing plants. From these large plants, goods are distributed out to the market. This form of operation and wider dispersal of output results in increased transportation requirements.

- The other factor involves the demand sector of the transport chain. The increasing diversification of product types, to satisfy demand and increase market share, causes producers and manufactures to subdivide and supply to small market sectors. These products need to be effectively transported to respective consumers, all of which is achieved from the centralised distribution points.

In addition, other growth drivers include gross domestic product levels, the growing prosperity of countries within our economic zone, growing trade performance of the world and population growth (Manders 2006).

As demand increases, fleets sizes will proportionally increase to be able to satisfy the demand, as can be seen in Figure 2. Increases in fleet size are associated with undesirable impacts on residential amenity, congestion delay, air quality, noise and other aspects related with the quality of life. These impacts are inevitable with the current trends (Manders 2006). If there is no implementation of management actions, the impacts mentioned would become increasingly costly to society through health care and environmental remediation especially in urban areas.

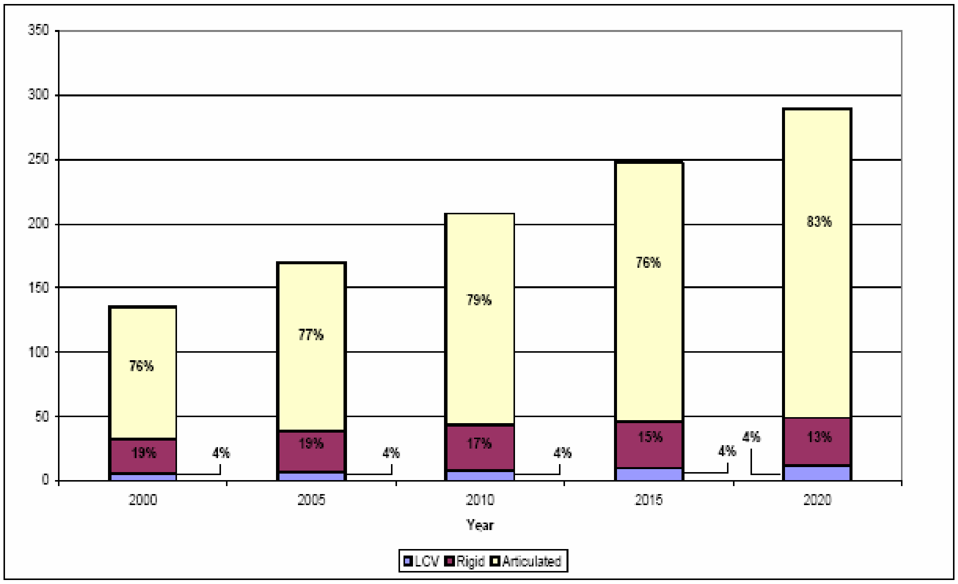

Figure 2. Comparison of freight vehicle fleet for the years 2000 to 2020
(Source: Manders 2006)

2.3 ENVIRONMENTAL IMPACTS OF FREIGHT MOVEMENT

In the context of the freight industry, externalities are gaining greater importance. Externalities such as accidents, congestion, ambient air and noise pollution, greenhouse gas emissions and road damage caused by heavy vehicles, all impact on efficiency (BTRE 2003). These externalities are difficult to control, however can be managed indirectly through best management practices.

Road freight movement is achieved by the use of light commercial vehicles, ridged trucks and articulated vehicles, where the majority of which operate on diesel fuel. The predictions of heavy-duty diesel vehicle emissions inventory have had substantially less attention in comparison to petrol vehicles. However, it is now recognized that diesel vehicles are significant contributors to the atmospheric inventory of particulate matter (PM), oxides of nitrogen (NOx) and hydrocarbons (HC) (Clark *et al* 2002). Within urban areas, diesel emissions are disproportionate contributors of pollutants (Beer et al 2006). The diesel vehicle fleet comprises less than 10 percent, yet contributes approximately 60-80 percent of fine particulates and 40 percent of NOx (NEPC 2001).

NOx are a precursor to the formation of photochemical smog and have demonstrated to react with other pollutants to form suspended particles (Beer et al 2006). In the case of fine particulates, the health risks are related to the respiratory area where by the smaller the particles, the greater the risk. Particles of 10 micrometres (PM_{10}) or smaller are of health concern (NEPC 2001). These particles can potentially absorb carcinogenic organic compounds thus facilitating the pathway into the lungs, impacting on the health of people exposed.

In addition, diesel emissions pose an environmental impact on amenity, being odorous and visually unpleasant. They contribute to levels of haze and are unwelcomed by cyclists, pedestrians and other road users (NEPC 2001).

Growth rates of the road freight task are estimated to be approximately 3.89 percent per annum for the period of 2000 – 2020 (Manders 2006). With these estimates the freight logistics industry needs to implement better environmentally friendly practices such as moving more freight with fewer resources (Freight Transport Logistics Action Agenda 2002). This can be achieved through the introduction of High Productivity Vehicles (HPVs), which are able to transport more mass, however fitted with road friendly suspension to reduce impact on road surfaces. Through changes in standards and further measures aimed at addressing the natural growth, reductions in environmental impacts, congestion and efficiency of logistics are likely to result (Freight Transport Logistics Action Agenda 2002).

2.4 DO NOTHING APPROACH

Doing nothing is almost certain to increase congestion, reduce social amenity and air quality, increase the nuisance of noise in urban areas and increase costs on society. According to Manders (2006), the estimated changes from 2005 to 2020 of either doing nothing or taking action indicate that the forecast increased freight task will cause or be complemented by reduced efficiency in the absence of actions to increase productivity.

3 The *AFCM* in Context

The *AFCM* would be classified as a conceptual-empirical model with a deterministic approach for the input and parameter specifications. It is conceptual-empirical as there are separate basic processes such as fuel consumption, emissions, trip calculations and congestion delay that are all stand alone to some extent. However the equations used to describe the processes are simply input-output relationships (CRC for Catchment Management Hydrology 2005). The model is also deterministic as it requires a single set of input values and parameters and produces single output values rather than a range or distribution of values. The model does not need to be run many times to produce an output.

With past trends alerting to a doubling of the freight task, to maintain efficiency in freight logistics, more freight will need to be moved over a similar period of time. Therefore as a response to this increasing demand, more vehicles are introduced into the fleet to cater for the increase in demand, as demonstrated in Figures 2 and 3. This is a concern according to growing populations in the Western countries, as growth in the freight industry leads to adverse impacts on air quality, noise, residential amenity, congestion and other areas of life (Manders 2006).

Manders (2006) identified four mitigative measures by which to reduce the adverse impacts of the growing freight transport task. One of the measures identified is to improve freight transport efficiency. The mentioned approach aims to reduce the number of trips required for a given task. One means of doing so would be to introduce the deployment of HPVs. These vehicles are able to carry greater loads whilst fitted with air suspension systems to reduce the impact on road surfaces. Larger freight tasks can potentially be undertaken more efficiently through the use of HPVs, therefore future freight task increases will cause less of a problem. This concept has been seen in past trends, however has been more so of a natural change rather than a change in policy and standards.

As illustrated in Figure 3, the increase in freight task results in an increase in the use of articulated vehicles and a decrease in the use of rigid vehicles. Articulated vehicles are able to carry greater loads in comparison to rigid vehicles, hence the increase in percentage contribution.

A tool capable of yielding the relative impacts of fleet configurations can assist in fleet management and consequently reductions in the impact of externalities. The *AFCM* addresses the issue of environmental impacts by being able to compare fleet configuration in order to obtain the greatest savings in emissions. In addition, the model indirectly addresses the issue of congestion to a small extent. Optimising the fleet configuration to reduce the trips required to complete a task, results in less time a truck is in operation, thus contributing less to the congestion issue.

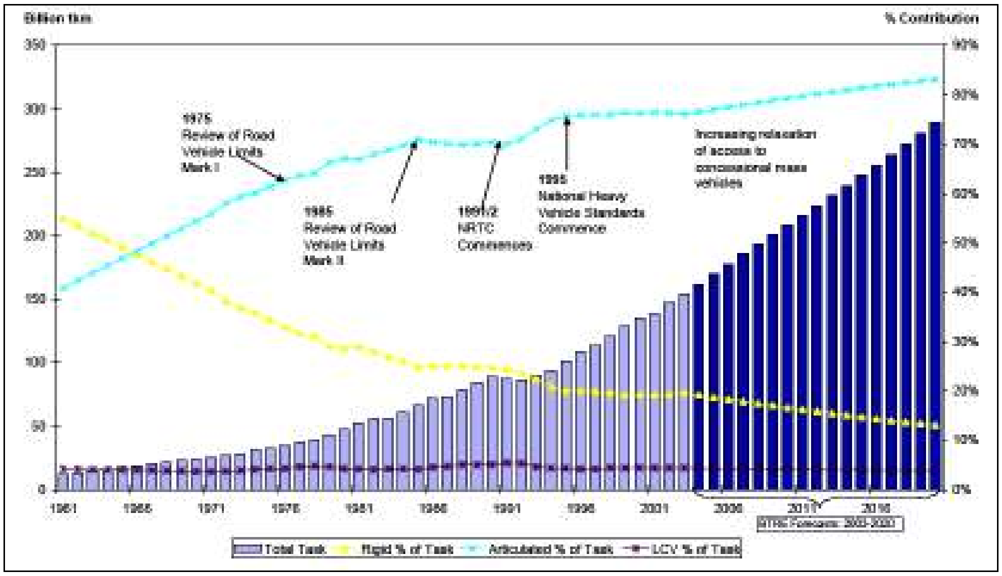

Figure 3. The road freight task and vehicle types used for the period of 1961 to 2000 along with BTREs freight task predictions for 2003 to 2020. (Source: Manders 2006)

3.1 MODEL SPECIFICATIONS

The model is designed to facilitate the forecasting of current and future impacts of freight movement in a road network and on a fleet level. The model has been developed with four basic components:

- Common input data
- Level 1 -Shipment and trip analysis
- Level 2 –Network analysis
- Level 3 – Cost analysis

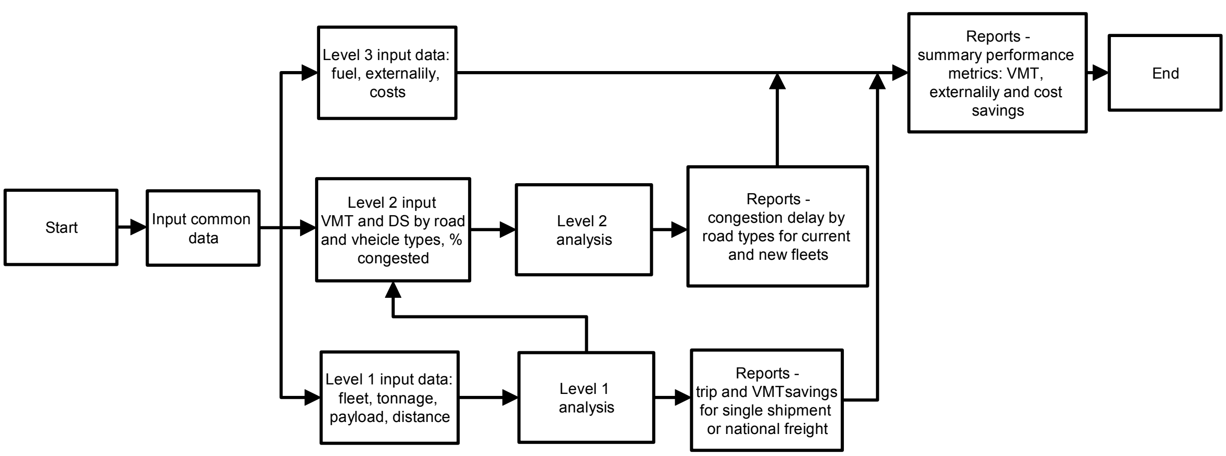

Figure 4. Flow chart of the AFCM

3.1.1 Common input data

The *Common input data* component allows for the input of variables which are common to all levels to calculate the specified performance metrics. These variables, which may not all necessarily be required, include:

Vehicle-kilometres travelled
The user can enter the annual VKT (Vehicle Kilometres Travelled) of a maximum of eight vehicle types, of which, seven are heavy vehicle types and one passenger car type.

***Fuel consumption**,*
The fuel consumption rates (km per litre) of seven heavy vehicle types along with the current price of fuel can be input into the model.

***Vehicle NOx, PM, CO, HC and CO_2 emissions**,*
The emission rates can be entered as either grams per litre or grams per km and can either be entered for each of the seven truck types or as an average for all vehicles. This would be the case where individual emission rates are not available.

3.1.2 Level 1 – Shipment and trip analysis

The *Level 1-Shipment & Trip Analysis* component is aimed to determine the associated savings with proposed fleet configurations in comparison to current fleet configurations. It is a tool that may be employed for national freight movement or for a small scale freight company. The input variables and outputs for the loading simulator are as follows.

Current or future freight tonnage
The model allows the user to either input the current tonnage of freight moved or the predicted tonnage. The predicted tonnage option allows for the simulation of current fleet limitations whilst facilitating the prediction of a minimum future fleet size, which satisfies the increased tonnage.

Number of vehicles
If the model is being utilised for a large scale scenario, information on the number of vehicles per vehicle type may not be readily available. Thus through the input of the total number of vehicles, in addition to knowing a rough percentage of each vehicle type, an estimate of the number of vehicles per vehicle type is possible.

GVM
The user is able to input the correct gross vehicle mass (GVM) for the respective vehicle. Furthermore, there is the option to change the tare weights for the accurate calculation of payloads. Both GVM and tare weights are then able to be set as default weights for an alternative modelling scenario.

Current and proposed fleet configurations
Current fleet configuration can either be input as the number of vehicles per vehicle type or as a percentage of the total number of vehicles. The number of vehicles per vehicle type option takes precedence over the percentage of vehicles.
The options for the proposed fleet configuration are equivalent to the current fleet configuration options and designed for the user to input a comparative scenario. The comparison is designed to establish associated differences with differing fleet configurations for the same amount of freight.

Truck loading trip summary
The truck loading trip summary outputs the number of trips predicted to complete the specified tonnage with both the current and proposed fleet configuration. The differences of the current and proposed configurations are summarised in a trip savings table.

Fuel consumption as well as NOx, PM, CO, CO_2 and HC emissions are calculated for each vehicle for the current and proposed fleet. A fuel and emissions savings table is presented in the model so that the user can view the changes in fuel consumption and emissions due to the proposed fleet configuration.

As mentioned not all variables are required, the detail of the performance metrics is in proportion to the input data.

3.1.3 Level 2 - Network analysis

The *Level 2- Network analysis* component is the analysis of the road network. Inputs and outputs of this level of analysis are:

Traffic configurations and traffic conditions,
Traffic configuration encompasses the percentage of VKT a particular vehicle travels on a particular road type. These percentages are able to be set as default values to facilitate an alternative modelling scenario. The benefit of the default is predominantly to eliminate the need to re-enter a particular scenario. The traffic conditions include:

- Percentage of a road type's VKT that is congested
- Average traffic speeds on each road type at a degree of saturation x = 1 (i.e. at capacity) and at x = 0 (or free-flow condition)
- Degree of saturation for each road type when in congested conditions.

These input variables aid in the modelling of delay and travel times caused by congestion through the network.

Network distance
The network distance output outlines the vehicle-kilometres travelled per vehicle type on each road system on a yearly, daily and hourly basis. This output is only possible if the traffic configuration data is available. In addition, the model outputs the total vehicle-miles travelled in congested conditions per vehicle type on each road system.

Travel time
In terms of travel time, the model outputs the time spent on travelling in uncongested conditions. Furthermore, the model calculates the delay caused by congestion and outputs the vehicle-hours for each vehicle type on each road system

3.1.4 Level 3 – Cost analysis

Level 3 allows the user to assess the performance of either the fleet or the network on a economic basis. This level allows the user to input various costs associated with road transport. These input unit costs include the average cost of vehicle emissions on society and the value of time that is saved through decreased travel time. The output costs include:

Delay and externality cost
The model outputs the cost of delay for each vehicle type on each road system; furthermore, a cost per kilometre is calculated. The externality costs include pollution costs and noise costs for the current and proposed fleet configurations in addition to the network.

4 CASE STUDY

4.1 ATRI TEST RESULTS

ATRI had produced a document titled "*Energy and Emissions Impacts of Operating High Productivity Vehicles*" by Tunnell *et al* (2004), which was based on an investigation they had conducted in America. The *AFCM* is based on this report, utilising their results in order to verify the model outputs.

ATRI Investigation

The ATRI experiment involved two heavy vehicles; a standard tractor-semitrailer and a Rocky Mountain double (Figures 5 and 6). The Rocky Mountain double is classed as a HPV. The purpose of the experiment was to determine which of the two is the more efficient vehicle to use when both transporting an equivalent shipment size over the same route.

Figure 5. An American standard tractor-semitrailer which is equivalent to an Austroads Class 8 heavy vehicle. (Source: Tunnell et al 2004)

Figure 6. An American Rocky Mountain double which is equivalent to an Austroads Class 10 B Double. (Source: Tunnell et al 2004)

The experiment involved transporting 907.18 tons (1000 U.S tons) to a destination 805km (500 miles) away. The results of the experiment conducted by ATRI can be seen in Table 3.

Table 3. ATRI results obtained through the HPV use investigation converted in to metric units for use in the AFCM.

	Standard tractor-semi trailer	**Rocky Mountain double**
Loading (GVM) (kg)	36287.39	54431.08
Tare (kg)	16057.17	20184.86
Payload (kg)	20230.22	34246.22
Fuel Economy (km/L)	2.47	1.87
	Average Emission rates	
NOx (g/L)	13.6	
PM (g/L)	0.34	
	RESULTS	
Fuel Consumption (L)	14684	11613
NOx (kg)	199.58	157.85
PM (kg)	5.04	3.99
No. Trips to complete task	**45**	**27**

NOTE: *The results from the ATRI experiment were recorded in imperial U.S units. By converting to metric units there may be some slight differences between the results due to rounding.*

By utilising the Rocky Mountain double as opposed to the standard tractor-semitrailer there is a saving of 18 fully loaded trips and 13 million ton-kilometres. This evaluates to trip and ton-kilometre savings of approximately 38 percent and 40 percent respectively.

By utilising the Rocky Mountain double as opposed to the standard tractor-semitrailer there is a fuel saving of 3073 litres, NOx saving of 41.8 kg and a PM saving of 1.1 kg. This evaluates to fuel, NOx and PM savings of approximately 21 percent each.

As demonstrated, the *AFCM* is a tool that can aid in fleet management and promote impact reduction strategies by simulating fleet configurations. It is particularly useful when there is more that one type of vehicle in the fleet. Each vehicle type has different parameter values, therefore making it difficult to simulate without the use of the *AFCM*.

5 SCOPE FOR ENHANCEMENTS

The *AFCM* is only a policy level model and, as with all models, has its limitations. Data availability is high with respect to VKT, the freight task (ton-km), GVM and forecasts, yet low with respect to vehicle emissions data. This is particularly the case for different classes of heavy vehicles, as being able to model individual emission rates more accurately would result in enhanced predictive performance. The specific areas where the model is limited include:

- Consideration of partially laden trips – It assumes that all trips are fully laden
- Consideration of networks. For example - Multiple drop off points for more than one contract job.
- Emission and fuel consumption modelling techniques - The model does not consider the relationship between emissions and fuel consumption as vehicle load changes
- Accounting for urban and rural conditions. For example – Freeway travel as opposed to urban road travel
- Consideration of error in results.

The above mentioned limitations are contributors to a low model complexity through not considering the above aspects in the model's development. The judging of the predictive performance is entirely subjective. Research directions as a result of the AFCM include:

- **Vehicle emissions**

The poor predictive performance of the *AFCM* is largely based on the emissions modelling aspect. Research into emissions has been undertaken however not to a specific scale such as the emissions relationship for an Austroads Class 9 vehicle. There is data available for average emissions for light commercial vehicles, rigid vehicle or articulated vehicles. However within each of the three heavy vehicle categories there are different vehicle sizes, thus impacting on the predictive performance of fleet emissions modelling. Further research into vehicle class emissions would provide for more realistic modelling. This could be achieved by monitoring tailpipe emissions of in-service freight transportation vehicles. The data collected could then determine realistic relationships between load, fuel consumption and emissions.

- **Partial loading and overloading**

Not all freight moving vehicles transport goods at the GVM limits. On the other hand, not all vehicles follow the GVM regulations and overload the vehicle. According to a NTC (1997), 1 in 609 vehicles were overloaded by more than 30 percent. Further research into the average loading of each vehicle class along with the percentage of vehicles that are overloaded or partially loaded would assist in better modelling of freight movement efficiency and emissions.

6 CONCLUSIONS

At this point, the future freight task is predicted to continue increasing, potentially doubling by 2020. With these predictions and an unprepared industry, the road transportation of freight will result in stressed infrastructure, adverse environmental impacts and reduced efficiency of traffic flow and freight logistics. One means of preparing for the future freight task is through the use of models. Models operate as tools for predicting future trends or simulating impacts for proposed scenarios, but fundamentally they contribute to better freight logistics management. It is through better management that the impact of road freight movement on the environment is reduced.

The *AFCM* created is a policy level model, yet useful for comparing the impact of fleet configurations. It is not a tool that can predict future trends. It more so stands as a tool to assist in better fleet management, which in turn helps to reduce the impacts on the environment. The *AFCM* is limited in areas, however this is predominantly due to the data available and, as it was based on the *AFCM*, the client's expectations. With the limitations known, the model complexity can be augmented, to include the limitations identified. Identified areas for further research aimed to enhance the models predictive performance were:

- In-service vehicle emissions data collection and research for all classes of heavy vehicles
- Modelling techniques to better relate load, fuel consumption and emissions
- Research into the reality of partially loaded and overloaded occurrences of heavy vehicles
- Research into the benefits of inland ports or intermodal terminals

With further research, the *AFCM* is expected to be an important decision making tool in the U.S for exploring the future of road freight and its impact on the environment.

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