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A strategic-level modelling tool for evaluating air quality and greenhouse gas mitigation strategies for urban road freight in Sydney

By

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TITLE: **A strategic-level modelling tool for evaluating air quality and greenhouse gas mitigation strategies for urban road freight in Sydney**

ABSTRACT: This paper details the development of a strategic-level modelling tool to evaluate the impacts of air quality and greenhouse gas mitigation strategies for urban freight. The model, known as STEAR-F (Strategic Tool for the Environmental Analysis of Road Freight) combines publicly available information on freight travel, fleet characteristics, and emission factors to provide estimates of total Greenhouse Gas (GHG) and non-GHG emissions. Following details of the model development and underlying assumptions, STEAR-F is applied to evaluate strategies currently under consideration in the Sydney region. These include accelerated vehicle scrappage programs, diesel vehicle retrofit programs, Low Emission Zones, alternative fuel programs, and educational/information programs focused on driver behaviour, new technologies and proactive vehicle maintenance.

KEY WORDS: ***Road freight; emissions; policy options.***

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1. Introduction

In parallel with most major cities around the world, Sydney has witnessed a rapid growth in urban freight movements and commercial vehicle kilometres of travel (CVKT). Between 1990 and 2003, the volume of freight moved by road in Sydney increased by 59%, while CVKT increased by 37% (Bureau of Transport and Regional Economics - BTRE, 2006). This growth in commercial vehicle activity has exacerbated pre-existing concerns over greenhouse gas (GHG) and air quality impacts – for instance, in 2006 freight vehicles were deemed responsible for 33% of GHGs, 39% of Nitrous Oxides (NOx) and 65% of particulate matter (PM) coming from the transport sector in Sydney (New South Wales Department of Environment and Climate Change – NSW DECC, 2007). Looking ahead, CVKT is projected to grow by around 35-40% by 2015, which threatens to more than offset anticipated gains from the adoption of new emissions and fuel-efficiency standards for freight vehicles.

In an effort to mitigate these impacts, various technological, educational, regulatory and market-based strategies have been proposed (Vieira, 2007). However, while evidence of the effectiveness of these strategies from an air quality perspective continues to grow (Anderson et al., 2005), few analytical tools exist that provide policy-makers with the means to systematically quantify their emissions benefits with some exceptions (e.g., BTRE, 2004). With this in mind, the current paper describes the development and application of a strategic-level modelling tool designed to assist policy-makers evaluate the air quality and greenhouse gas impacts of urban freight mitigation strategies. The approach, termed STEAR-F (Strategic Tool for the Environmental Analysis of Road Freight) combines commercial vehicle traffic estimates with information on fleet characteristics (vehicle type, age, fuel type, scrappage/replacement) and emission factors to provide estimates of Greenhouse Gas (GHG) and non-GHG emissions. Operating as a Visual Basic Application (VBA) within a spreadsheet environment, STEAR-F is designed to provide a quick response to what-if questions about mitigation strategies. Strategies can be analysed individually or with other strategies enabling the cumulative effects to be assessed. Summaries of commercial vehicle kilometres travelled (CVKT) and emissions can be reported out at various spatial levels including Local Government Area (LGA), Statistical Division (SD) and the Sydney Greater Metropolitan Area (GMA)[1].

The remainder of the paper is organised as follows. First, more details are provided on the methodological development of STEAR-F. Following this the model is used to evaluate example strategies currently under consideration in Sydney including a) accelerated vehicle scrappage programs, b) an expansion of existing diesel vehicle retrofit programs, c) a Low Emission Zone around the central area of the city, d) expansion of alternative fuel programs, and e) development of educational/information programs focused on driver behaviour, new technologies and proactive vehicle maintenance. Finally, some concluding remarks about future developments of the approach are provided.

[1] The Sydney GMA comprises the Statistical Divisions (SDs) of Sydney, Hunter and Illawarra.

2. Model development

The analytical approach adopted was focused at a broad strategic level, a reflection of both the available data sources on commercial vehicle travel and emissions and (what was deemed) an appropriate level at which to analyse the scenarios of interest. The major components of STEAR-F are shown in Fig 1 together with the required data, which is all publicly available. Each of these components is now briefly described.

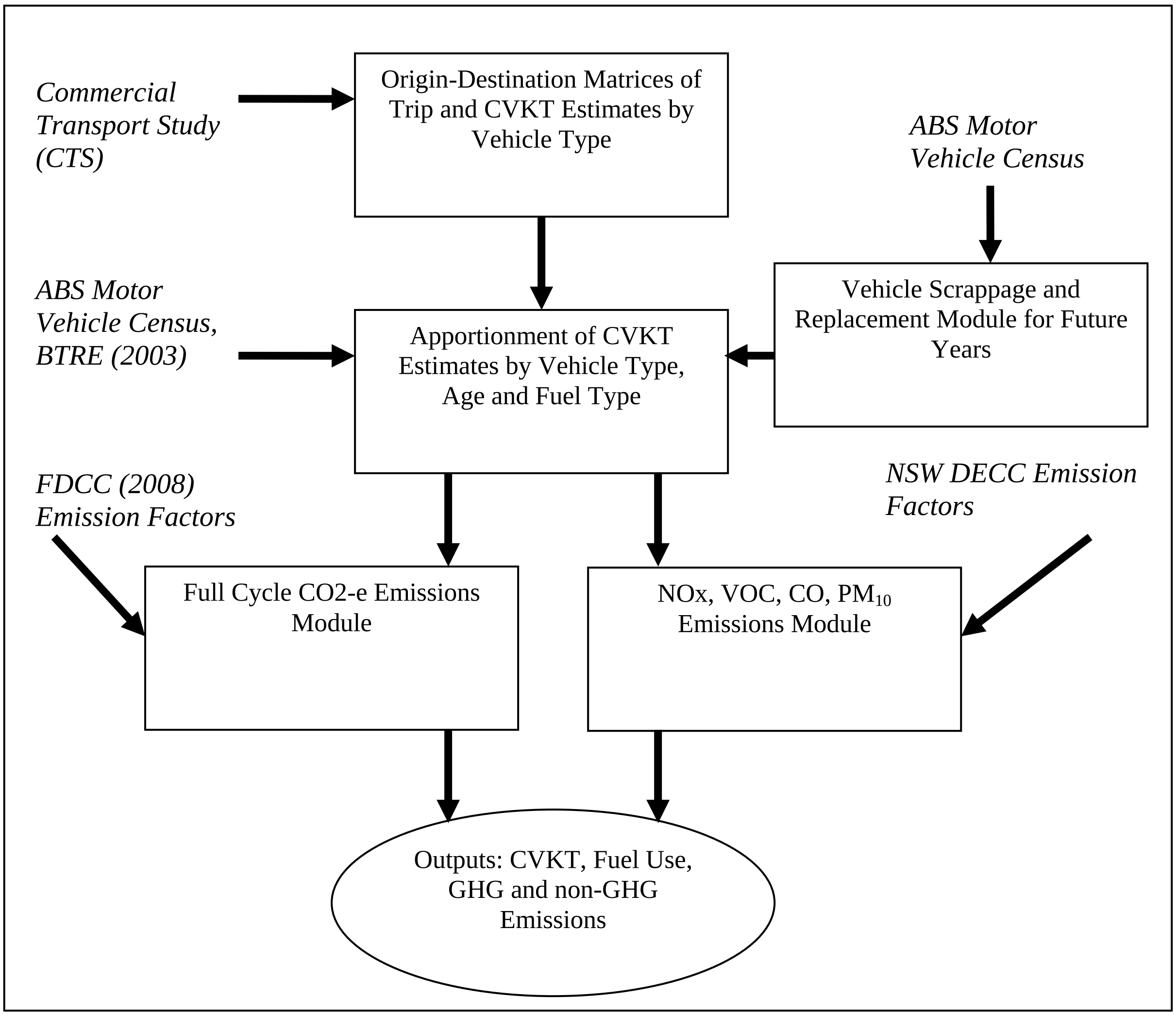

Fig 1: Overview of the STEAR-F post-processor modelling approach

Origin-Destination trip and CVKT matrices by vehicle type were provided by the New South Wales Transport Data Centre (TDC), the agency responsible for preparation of such forecasts in Sydney. The TDC estimates are prepared using a four-step freight model, which has been progressively refined since the mid-1990s, mainly from the perspective of better data on commodity movements (Mendigorin and Peachman, 2005). The trip tables provide average weekday movements between the 1,129 traffic zones covering the Sydney GMA for three vehicle types, namely Light Commercial Vehicles (LCVs), rigid trucks, and articulated trucks - definitions of these categories (as they pertain to this study) are provided in Appendix A.

Apportionment of CVKT by vehicle type, age and fuel type is necessary to reflect the variability in emissions associated with different vehicles, how much they are driven and how they are fuelled. As this information was not directly known, a process was employed to indirectly apportion the CVKT based on known information on CVKT derived from the Australian Bureau of Statistics (ABS) Survey of Motor Vehicle Use (ABS, 2007a). The SMVU provides CVKT estimates based on a quarterly sample of self-reported vehicle odometer readings from around Australia. Unfortunately, it does not include fuel type and it is subject to high standard errors resulting from very small sample sizes when the data are used at a disaggregate level. Consequently, these data were supplemented using information from the ABS Motor Vehicle Census (MVC), which provides a full enumeration of registered vehicles down to postcode level by vehicle type, age, and fuel type (ABS, 2007b).

Full Cycle CO_2-e emissions were determined by first estimating the fuel efficiency of each vehicle type/age/fuel type combination. This was done using information from the Bureau of Transport and Regional Economics (BTRE), the primary source of such data in Australia (BTRE, 2003). These figures were then multiplied by the latest full cycle CO2-e/kL estimates provided by the Federal Department of Climate Change (FDCC), shown in Table 1, to derive a CO_2-e g/km for each vehicle type and year of manufacture.

Table 1: Fuel combustion emission factors

	Petrol	Diesel	Biodiesel (canola)	LPG
Energy content (GJ/kL)	34.2	38.6	23.4	26.2
Combustion (kg CO2-e/kL)	2,291	2,694	9	1,577
Full cycle (kg CO2-e/GJ)	72.3	75.2	62.5	65.5
Full cycle (kg CO2-e/kL)	2,473	2,903	1,463	1,716

Source: Australian Government Federal Department of Climate Change (2008) National Greenhouse Accounts Factors

Estimates of NOx, VOCs, CO, and PM_{10} emissions for petrol and diesel were derived using emission factors provided by the NSW DECC. The factors are based on local emissions test data supplemented by evidence from the US and Europe – note that ultra-low sulphur diesel (ULSD) standards were mandated in Australia as of January 1st, 2008, which lowered the sulphur content from 500 parts per million (ppm) to 50 ppm. In the case of alternative fuels, the only source of Australian information is that provided by a large study of heavy vehicles at the turn of the millennium (Beer et al., 2000). It must be noted these factors represent fleet averages, with no breakdown by vehicle age and type so clearly must be used with caution.

The vehicle scrappage and replacement module is designed to capture the turnover that occurs as older vehicles are retired and newer vehicles enter the fleet. The previously noted ABS Motor Vehicle Census provides annual registered vehicle type/age breakdowns up to 2007 from which empirically-derived scrappage rates were obtained. Future year (i.e., beyond 2007) scrappage rates were determined by simple trendline extrapolation from the existing data.

3. Results

3.1 2003 Base case

The 2003 Base Case provided a starting point for the analysis – a summary of results is shown in Table 2 for the Sydney GMA. A few points are worthy of note. First, LCVs are responsible for more than three-quarters of trips and over half the CVKT in the Sydney GMA, a reflection of the demand for quicker, more frequent deliveries of smaller loads. Second, rigid and articulated trucks are responsible for the majority of NOx (85%) and PM_{10} (72%), while LCVs are responsible for the majority of CO (63%). This is primarily a reflection of the predominantly diesel-based heavy-duty vehicle fleet and the still largely petrol-driven LCV fleet (approximately two-thirds of LCVs run on petrol). Third, heavy-duty vehicles are responsible for a disproportionately high (75%) proportion of GHGs relative to their CVKT reflective of their substantially higher fuel intensities on a per kilometer basis. This should be qualified, because (arguably) the measure should be based on tonne-kms *not* simply kilometers. If this is the measure used, heavy-duty vehicles work out be around 5-10 times more efficient in terms of GHGs/tonne-km.

Table 2: 2003 Base Case Estimates in the Sydney GMA

	LCV		Rigid		Articulated		Grand Total
Trips	935,832	78%	179,400	15%	84,479	7%	1,199,713
CVKT	10,231,493	53%	5,106,992	27%	3,805,485	20%	19,143,970
NOx (t)	14.3	16%	29.7	32%	47.8	52%	92.4
VOC (t)	9.7	44%	8.7	40%	3.5	16%	22.7
CO (t)	101.6	63%	42.3	26%	18.1	11%	163.0
PM10 (t)	1.2	27%	1.7	39%	1.4	33%	5.0
CO2-e (t)	3,209	25%	3,808	29%	5,929	46%	12,947
Petrol (litres '000)	905	73%	259	21%	75	6%	1,240
Diesel (litres '000)	283	8%	1,077	32%	1,978	59%	3,338
Alt. Fuels (litres '000)	87	77%	25	22%	1	1%	115

**Results are for an average weekday*
***Alternative fuels include LPG and biodiesel only.*

3.2 2015 Business as usual (2015BAU)

The 2015 Business as Usual strategy formed the basis for evaluating the various strategies. It assumes that CVKT will grow in proportion to that predicted by BTRE (2003), that vehicle scrappage and replacement cycles will continue as per the period 2003-2007 and new emission standards are enforced. It also assumes that government mandates will be applied in NSW that require two percent of diesel sold to be biodiesel.

The results of this scenario are shown in Table 3. Clearly, large increases in trips and CVKT, particularly within the LCV and articulated truck fleet are predicted. Commensurate increases are predicted for GHGs, because (in effect) none of the business-as-usual emissions standards target GHGs and in fact new emissions standards may actually lead to small increases in fuel consumption and GHG emissions. Interestingly, the current trends towards increasing diesel fuel use are predicted to continue although a significant proportion of the LCV fleet is predicted to remain petrol-driven. A final point of note is that even with the large increases in CVKT, the tightening of Australian emissions standards for new vehicles in line with Euro IV and eventually

Euro V are anticipated to lead to significant net reductions in the 'problem' diesel pollutants of NOx and PM_{10}.

Table 3: 2015 Business as Usual Estimates in Sydney GMA

	LCV		Rigid		Articulated		Grand Total
Trips	1,354,846	80%	200,666	12%	134,370	8%	1,689,882
CVKT	14,910,871	56%	5,638,064	21%	5,907,105	22%	26,456,042
NOx (t)	16.9	23%	21.8	30%	33.9	47%	73.2
VOC (t)	11.4	63%	3.8	21%	2.9	16%	18.9
CO (t)	175.0	88%	10.8	5%	12.7	6%	199.5
PM10 (t)	1.3	52%	0.7	26%	0.6	22%	3.3
CO2-e (t)	4,566	25%	4,084	23%	9,282	52%	17,932
Petrol (litres '000)	1,116	91%	47	4%	59	5%	1,224
Diesel (litres '000)	540	11%	1,342	27%	3,108	62%	4,991
Alt. Fuels (litres '000)	140	53%	46	17%	77	29%	263

**Results are for an average weekday*

It is also useful to assess the projected vehicle age distribution in 2015, particularly from the context of new emissions standards (Table 4). The figures suggest that well over half of LCVs and two-thirds of articulated trucks are anticipated to be Euro IV compliant by 2015. This contrasts with rigid trucks, where less than 40 percent are expected to meet this standard. Of more concern are the proportions pre-dating meaningful emissions standards. In the case of rigid trucks, one-fifth are expected to pre-date Euro standards, with a similar proportion pre-dating Euro III standards, when emissions were tightened significantly for heavy vehicles. For LCVs and articulated trucks, the figures suggest there will be 27 percent (LCV) and 15 percent (articulated) pre-dating Euro III standards. The proportion for LCVs is particularly troublesome, because of the vastly greater numbers of these vehicles in comparison to the other two vehicle types.

Table 4: Projected Age Distribution of the Commercial Vehicle Fleet in 2015

	Pre-1995	1995-2001	2002-2006	2007-2011	2012-2015
Euro Standard	N/A	Euro I	Euro III	Euro IV	Euro V
LCV	10.2%	17.1%	20.4%	26.6%	25.8%
Rigid	20.9%	19.8%	20.0%	21.4%	17.9%
Articulated	4.1%	10.8%	19.5%	31.5%	34.1%

4. Scenario testing

A number of different scenarios were formulated and tested using STEAR-F including a) an accelerated scrappage program, b) an expansion of existing diesel vehicle retrofit programs, c) a Low Emission Zone around the central area of Sydney, d) expansion of alternative fuel programs, and e) development of educational/information programs focused on driver behaviour, new technologies and proactive vehicle maintenance. Each of these is now described before a summary of results is presented.

Accelerated scrappage programs are designed to encourage the retirement of older, high-emitting vehicles and (potentially) their replacement with newer vehicles through a variety of financial mechanisms. Currently, no such programs exist in Sydney although it has been discussed on numerous occasions (e.g., BTRE, 2006). STEAR-F was used to assess the impacts of doubling the natural vehicle scrappage rates of pre-Euro III standard vehicles with varying rates of replacement with new vehicles – here, the extremes of no vehicles and 100% of vehicles are shown.

The *expanded diesel retrofit program* again targeted pre-Euro III vehicles, but this time considered the impacts of substantially increasing the rates of installation of particle traps – the New South Wales government has trialled such a program, in which 200 vehicles have so far been retrofitted with partial particle traps. Acknowledging the emissions reduction potential of after-treatments in service is contentious, the existing program has found partial particle traps reduce PM_{10} by 50%, CO by 45%, and impose a 1% fuel penalty, so these were the assumed savings used in STEAR-F (NSW DECC, 2007).

Low Emission Zones (LEZs) have recently been implemented in London, Berlin and Milan following earlier examples in Sweden as a mechanism for improving local air quality by targeting older, high-emitting vehicles. The evidence from Table 4 suggests there could be merit in exploring such a strategy for Sydney. To demonstrate the procedure, an LEZ was introduced in 2010, targeting commercial vehicles pre-dating Euro III standards (i.e., the same criteria as the London LEZ) entering the central Sydney area (area highlighted in Fig 2). Various potential behavioral responses were modeled ranging from replacement and/or retrofit of vehicles to a simple reallocation of newer vehicles to replace the 'banned' CVKT.

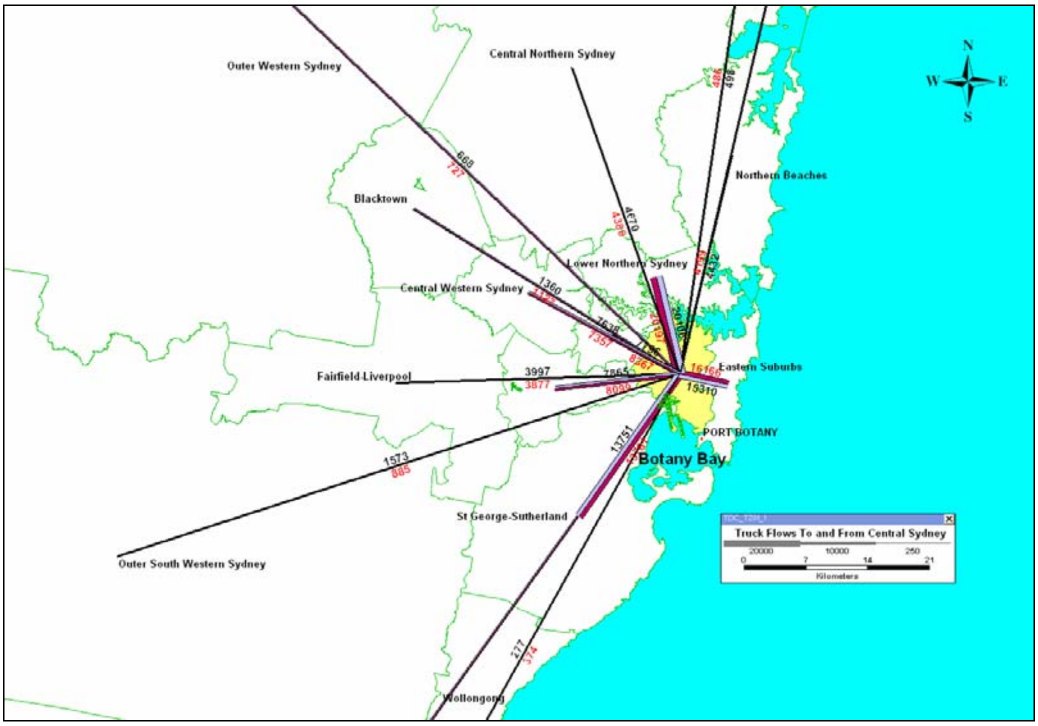

Fig 2: Proposed low emission zone with current truck flows

Alternative fuel programs are currently being heavily pushed by the federal and state governments in Australia as both a mechanism to reduce dependence on foreign oil and to realize emissions benefits. Two alternative fuel scenarios were analyzed using STEAR-F. The first involved a doubling of LPG conversions within the LCV fleet as higher fuel prices and government incentives for alternative fuels take effect. The second involved increasing the use of biodiesel significantly for heavy diesel vehicles from the current 2% assumed in the 2015BAU to 20%. While there is still heavy debate about biodiesel it is making small but significant inroads into the market in Australia mainly sold as B20 and B100 to niche operations such as garbage trucks.

5. Scenario testing results

Summaries of the air quality and GHG emissions of each scenario compared to the Business-as-Usual are shown in Figure 3 and for fuel use in Figure 4. In each case, it is assumed the programs start in 2010 with assessments made in 2015.

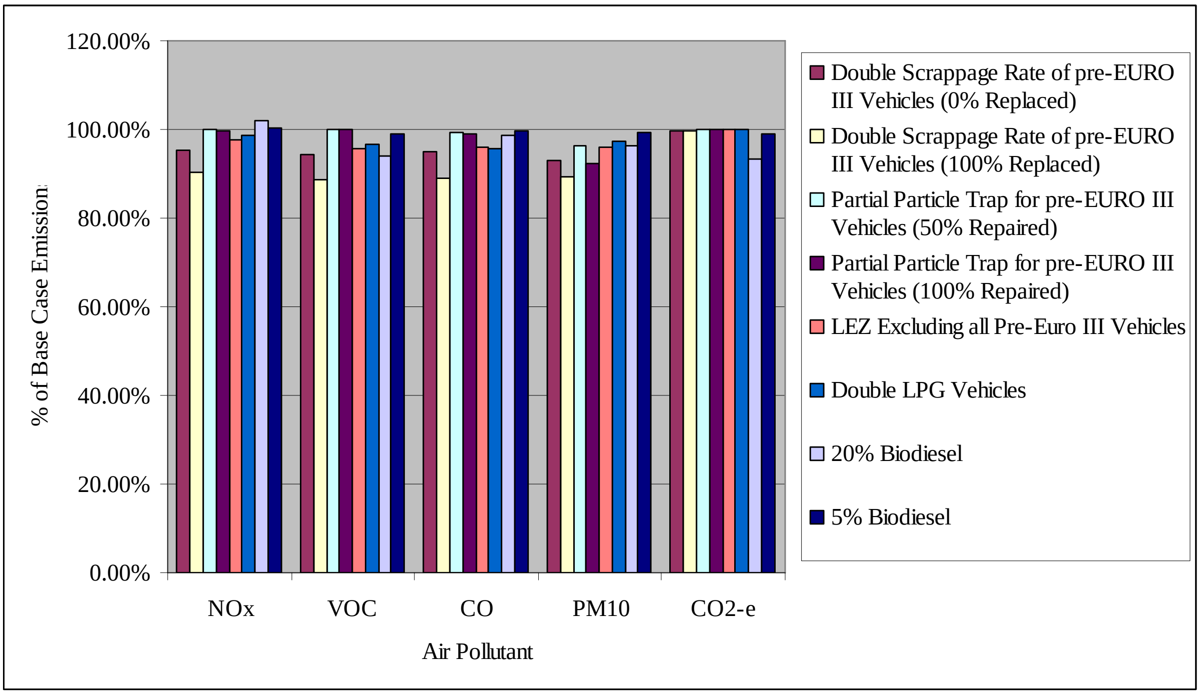

Figure 3: Air Quality and GHG Emissions for Each Strategy Compared to Business-as-Usual (2015)

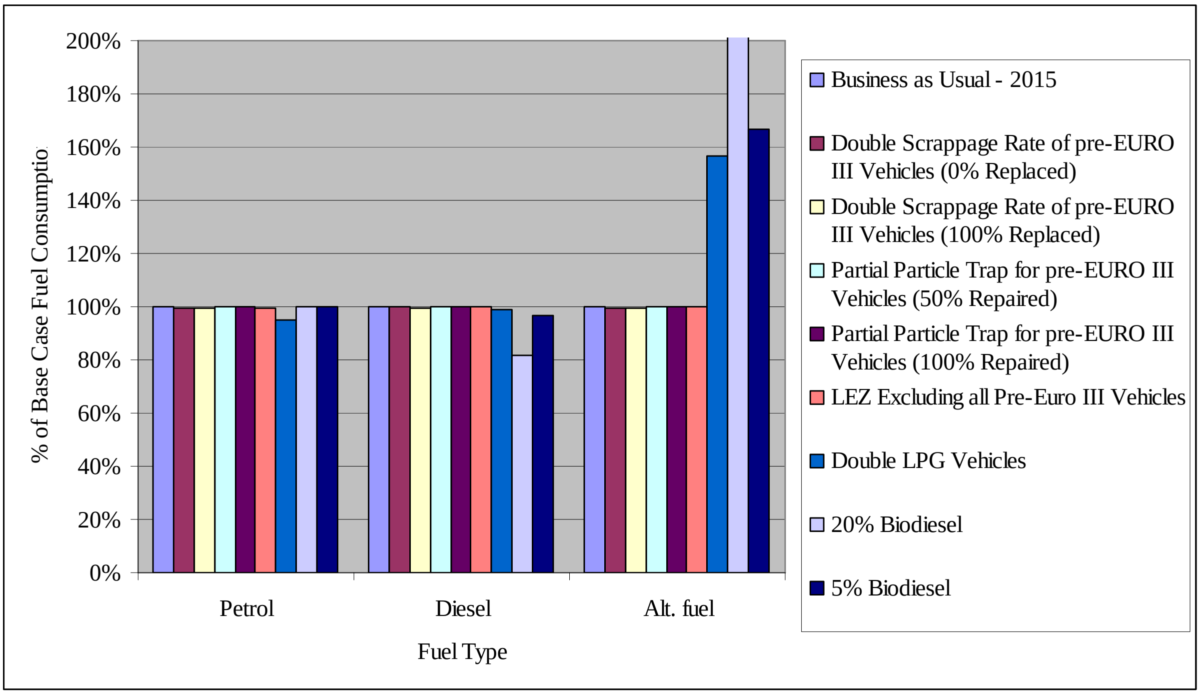

Figure 4: Fuel Consumption Changes for Each Strategy Compared to Business-as-Usual (2015)

The results show that under the *accelerated scrappage program*, reductions of 5-8% in the major pollutants are predicted, reflecting the fact that (in effect) there has been a shift in CVKT from pre- to post-Euro III vehicles. Further reductions are observed if these vehicles are replaced with brand new vehicles (arguably unrealistic, but never-the-less informative), reflecting the fact that (in effect) pre-Euro III CVKT has now been shifted to Euro V CVKT. The impacts of the *expanded diesel retrofit strategy*, suggests around a 5-7% reduction in PM_{10} depending on the rate of participation.

The *LEZ scenario* suggests around a 3-5% decrease in the major pollutants if all pre-Euro III vehicles are banned reflecting the tightening emissions standards from Euro III onwards. The NOx and PM_{10} reductions are primarily driven by the tightening of diesel standards affecting heavy trucks while the VOC and CO reductions are primarily due to tightening petrol standards affecting LCVs. The relatively small reductions in fuel consumption and GHGs are reflective of better fuel efficiency in newer model vehicles tempered by the fuel penalty associated with the retrofit technology. Arguably, of more relevance is how the results compare when viewed at the LEZ level. At this level of analysis, PM_{10} levels are 9.4% lower than the BAU strategy, with CO (16.3%), VOC (15.9%), and NOx (11.5%) respectively. The explanation behind the disproportionately large percentage reductions in VOCs and CO are because LCVs make up a greater proportion of the LEZ CVKT than the regional CVKT.

In terms of the *alternative fuel strategies*, a doubling of the LPG results in small but notable reductions in fuel use and all the pollutants - however, the drop in GHGs is minimal. The reason for this relates to the fact that while emission factors are lower for LPG on a g/km basis, it is around 20% less efficient than petrol and even more so for diesel. For the biodiesel scenarios (as anticipated) the main benefits are from savings of diesel fossil fuels – the reason it does not equate to a commensurate savings is because biodiesel is less efficient than diesel (although by no means to the extent of LPG to petrol). GHGs are reduced by 1-7% depending on the assumed proportions of biodiesel with reductions in all the air pollutants except NOx.

Educational and informational programs focusing on the purchase, use and maintenance of freight vehicles are being increasingly touted as having a significant role to play in improving fuel efficiency and reducing GHGs in particular. STEAR-F was used to evaluate the individual and combined effect of a number of programs, which are currently under consideration in Sydney including:

- *Environmentally-friendly driver training programs* similar to the ECODRIVEN and SAFE-D programs in Europe were assumed to begin in 2010 with a 10% level of participation initially rising by 5% per annum to a level of 35% by 2015. Interest in such programs is predicted to grow in response to higher fuel prices and the carbon trading scheme coming into effect in Australia in 2010.
- A region-wide *anti-idling campaign* is anticipated to begin in 2010 as awareness of the costs in terms of wasted fuel as well as emissions becomes more widely publicized. Initially, this is anticipated to have a 20% uptake increasing to 50% uptake by 2015.
- The uptake of *intelligent technologies* is expected to increase as the technology becomes more mainstream and awareness of the benefits of such systems grows. However, the cost of such systems is anticipated to remain a major deterrent for many users, restricting it to the larger operators. Levels of participation were assumed to increase from 5% in 2010 to 20% by 2015.
- The development and use of *fuel-efficient tyres* is anticipated to increase for rigid and articulated trucks from 20% in 2010 to 50% in 2015. In addition, *proactive tyre maintenance practices* are assumed to increase from 20% of vehicles to 50% of vehicles.

In addition to the assumed levels of participation/uptake, the effectiveness of these strategies is clearly dependent on the assumptions made about the fuel efficiency benefits. Given the lack of a comprehensive source of local (Australian) information, the current iteration of STEAR-F incorporates assumptions from the UK Freight Best Practice Program, shown in Table 5.

This program is a widely acclaimed national repository of case studies, reports, software and multi-material applications, designed around saving fuel, and improving operational efficiency (http://freightpractice.org.uk).

Table 5: Assumed fuel efficiency improvements in STEAR-F

Focus	Fuel Saving Measure	Average Fuel efficiency improvement		
		LCV	Rigid	Articulated
Drivers	1: Environmentally-Friendly Driver Training Programs (first time)	6.0%	6.0%	6.0%
	2: Ongoing driver training, feedback & motivation	3.5%	3.5%	3.5%
	3: Anti-idling campaign	2.0%	2.0%	2.0%
Technology	4: Computerised routing & scheduling system, vehicle telematics	7.5%	7.5%	7.5%
Fuel Efficient Tyres		0.0%	2.7%	3.1%
Proactive Tyre Maintenance	14: Tyre pressure management, re-grooving, regular wheel alignment	5.9%	5.9%	5.9%

**Source: UK Freight Best Practice Program Fuel Management Calculator available at http://freightpractice.org.uk*

The results of the various informational strategies are shown in Table 6. While the results are clearly impingent on the assumptions made (and as better information becomes available these can be refined), it is evident that such strategies could lead to significant reductions in GHGs and by default fuel consumption.

Table 6: Potential GHG savings of various informational strategies

Fuel Saving Measure	Assumed Penetration Rate		GHGs			
	2010	2015	2010		2015	
			Tonnes/day reduced	% change	Tonnes/day reduced	% change
Environmentally-Friendly Driver Training Programs (first time)	10%	35%	92	-0.6%	368	-2.1%
Anti-idling campaign	20%	50%	61	-0.4%	175	-1.0%
Computerised routing & scheduling system, vehicle telematics	5%	20%	58	-0.4%	263	-1.5%
Fuel Efficient Tyres	20%	50%	69	-0.4%	196	-1.1%
Proactive Tyre Maintenance	20%	50%	181	-1.2%	517	-2.9%
Total Savings Assuming All Strategies Applied*			456	-2.9%	1,469	-8.19%

**Not equal to the sum of the individual strategies because of double counting of benefits.*

6. Conclusions

This paper details the development of a strategic-level modelling tool to evaluate the impacts of air quality and greenhouse gas mitigation strategies for urban freight. Developed from freely available information on freight travel, fleet characteristics, and emission factors, the model is able to provide a flexible approach for decision-makers to evaluate a number of different strategies currently under consideration. Among the main findings of the evaluation are that under a 2015 Business-as-Usual (2015BAU) scenario, which assumes current vehicle scrappage/replacement patterns continue, new emission standards are enforced and government mandates for biodiesel come into effect, that even with substantial increases in CVKT, we will continue to see net declines in NOx and PM_{10}. However, GHGs are projected to increase dramatically because the marginal gains in new vehicle fuel efficiency will be overwhelmed by the growth in CVKT and the continued reliance on fossil fuels.

Scenario analysis using STEAR-F suggested that programs to expedite the scrappage and/or retrofit of older vehicles with particle traps could realize further savings across the Sydney GMA in the major pollutants of up to 8% depending on levels of participation. A Low Emission Zone (LEZ) around the city center and port areas targeting pre-Euro III vehicles was found to realize reductions in the major pollutants of 10-15% for the LEZ area, a substantial savings. Although politically problematic, other major cities such as London have demonstrated LEZs are a feasible mechanism for trying to deal with local air quality issues. The alternative fuel strategies considered here, both realized positive benefits in terms of fuel savings. However, the emissions benefits were lessened because these fuels are less efficient (particularly LPG) than fossil fuels on a g/km basis. Finally, a package of educational and information strategies were assessed based on assumed rates of participation and reported benefits. A package of driver-training, proactive maintenance, and intelligent technology strategies were considered, which collectively could lead to savings of around 8% in GHGs based on relatively conservative rates of participation.

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Appendix A: Road Freight Vehicles in Australia

Road freight vehicles comprise a wide variety of vehicle and engine types with quite different operational characteristics. For reporting and statistical purposes, freight vehicles are classified into the following three categories:

Light commercial vehicles (LCVs): vehicles constructed for the carriage of good, which are less than or equal to 3.5 tonnes gross vehicle mass (GVM). This includes utilities, panel vans, cab-chassis and goods carrying vans.

Rigid trucks: motor vehicles exceeding 3.5 tonnes GVM, constructed with a load carrying area, including normal rigid trucks with a tow bar, draw bar or other non-articulated coupling on the rear of the vehicle.

Articulated trucks: motor vehicles constructed primarily for load carrying purposes, consisting of a prime mover, which has no significant load carrying area, but with a turntable device, which is linked to a semitrailer. Articulated trucks comprise single, tandem, and triaxle trailers, B-Doubles, and Road trains.