The Transportation of Sugar Cane in Queensland's Sugar Industry

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Abstract

The sugar industry is Queensland's most significant rural industry and one of the most important agricultural industries in Australia. Queensland's sugar industry produces 95% of Australia's sugar cane, worth almost $2 billion dollars to the state's economy (Australian Sugar Milling Council; Canegrowers 2010). Despite the significance of the industry, the transport task and the associated environmental and social impacts have not been accurately quantified, especially in recent years.

The aim of this study is to develop a methodology that will provide a greater insight into the transportation used in Queensland's sugar industry to haul the sugar cane from the farm to the mill. This involved surveying the 22 sugar mills operating in Queensland during the 2009 cane crushing season using a purpose designed questionnaire. Using the information provided by the mills, the transport task, which included the tonnages, freight task and vehicle task, for each transport mode was quantified. The environmental impacts, including the fuel consumption, energy consumption and greenhouse gas emissions, and social impacts (crashes) produced by the transport task have also been enumerated.

It should be noted that this study only examines the transportation of sugar cane from the farm to the mill. It does not include the transportation of the cut cane as it is harvested on the farm or the transportation of processed sugar from the mill. Nor does it consider the costs or benefits of the sugar industry transport infrastructure, including the life-cycle costs, utilisation, replacement of capital equipment, the versatility of trucks over a range of tonnages, seasonal costs and alternative storage and stockpiling costs.

1 Background

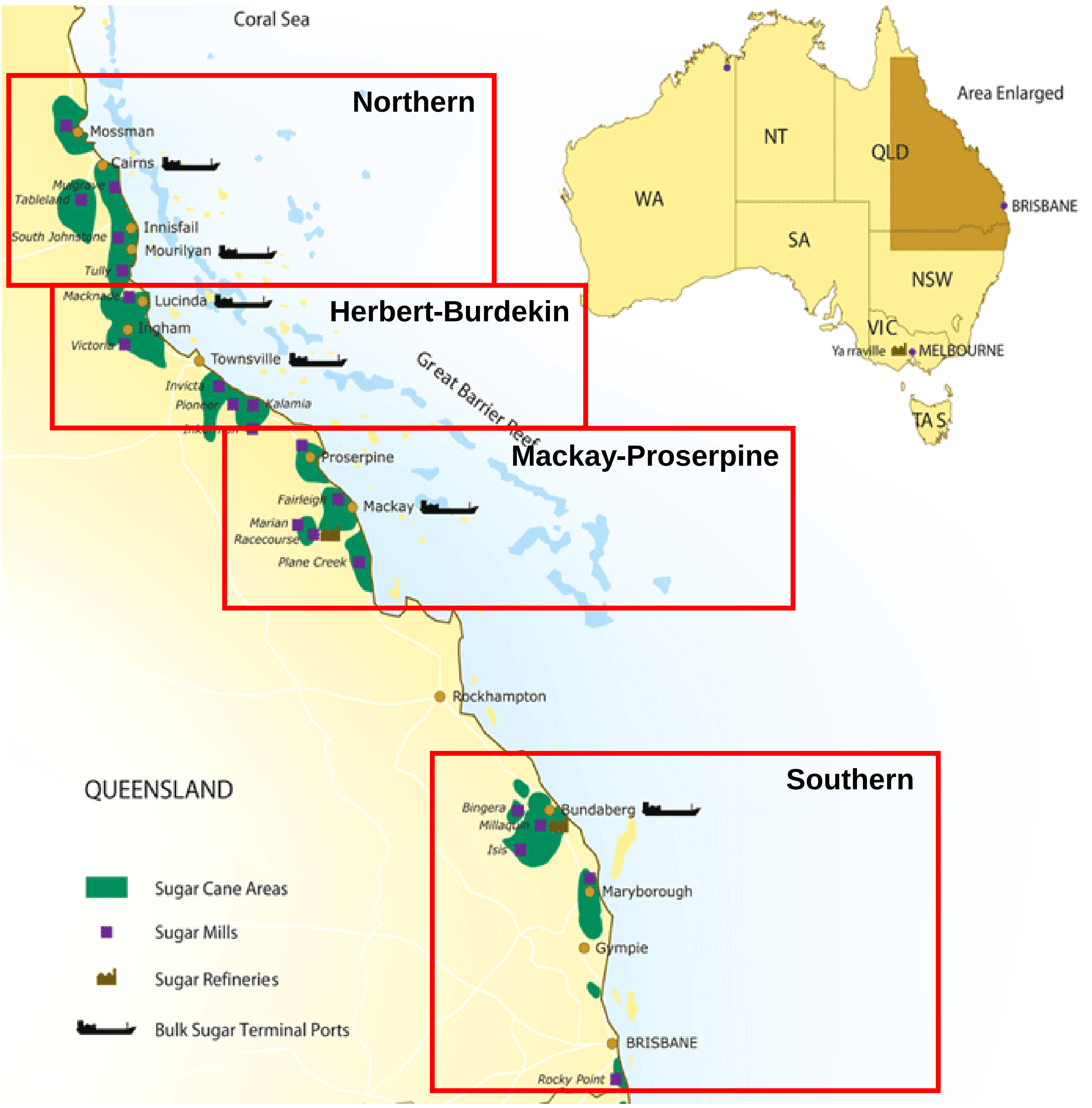
Queensland's cane crushing season occurs annually from early June to late November/early December (Bundaberg Sugar; Maryborough Sugar Factory 2012). During the 2009 crushing season, which occurred over 117 days between 16 June and 10 October (Australian Sugar Milling Council 2010), 22 sugar mills were operating along the east coast of Queensland, between Mossman in Far North Queensland and Rocky Point, south of Brisbane (Anonymous 2009; Browning 2007; Zelmer 2009). The mills operate within four mill regions, as classified by the Australian Sugar Milling Council (2010), shown in Table 1.

Table 1 Queensland sugar mills operating during the 2009 cane crushing season

Northern Region	Herbert-Burdekin Region	Mackay-Proserpine Region	Southern Region
Mossman Mill	Victoria Mill	Proserpine Mill	Maryborough Mill
Tableland Mill	Macknade Mill	Marian Mill	Millaquin Mill
Mulgrave Mill	Pioneer Mill	Farleigh Mill	Bingera Mill
Babinda Mill	Inkerman Mill	Racecourse Mill	Isis Mill
South Johnstone Mill	Invicta Mill	Plane Creek Mill	Rocky Point Mill
Tully Mill	Kalamia Mill		

The locations of the Queensland sugar mills operating during the 2009 crushing season are shown in Figure 1.

Figure 1 Map of Queensland sugar mills and mill areas



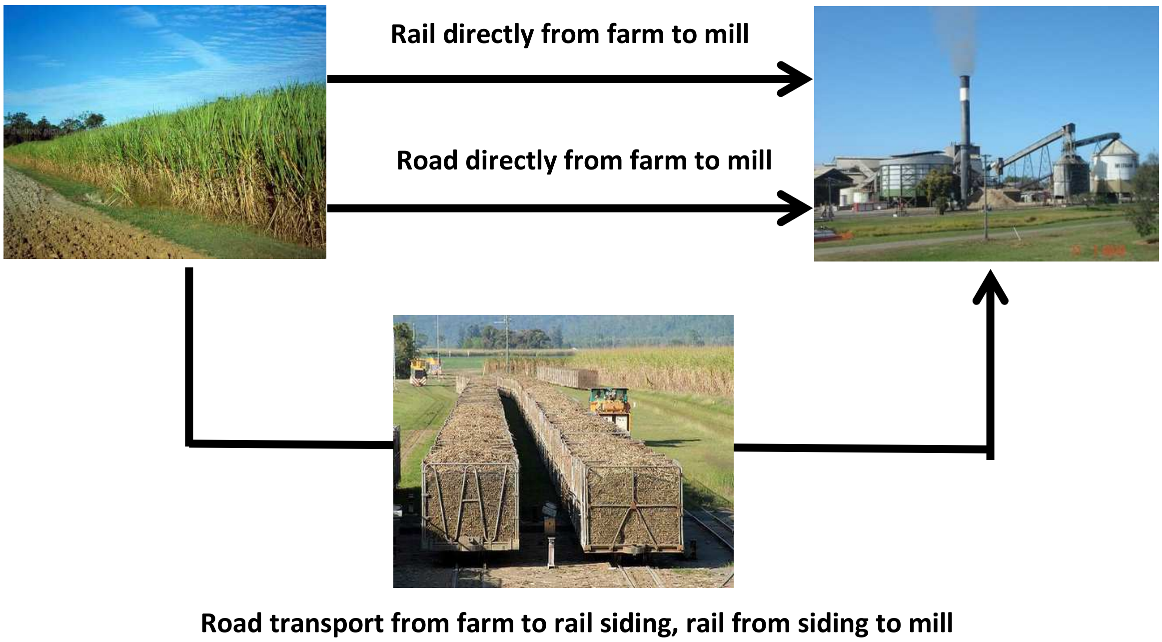
Source: Canegrowers 2010

These mills utilise three methods of transportation to haul sugar cane from the farm to the mill:

- Direct transport from the farm to the mill by rail using cane trains
- Direct transport from the farm to the mill by road
- Combined road/rail transport - firstly by road from the farm to a rail siding, then by cane train from the siding to the mill

The above methods are demonstrated in Figure 2.

Figure 2 Transportation methods used in Queensland to haul sugar cane from the farm to the mill



Source: http://dwpicture.com.au/picture.asp?picture=33302; http://en.wikipedia.org/wiki/Cane_sugar_mill; http://nqr.farmonline.com.au/news/state/property/general/few-buyers-for-cane-farms/2303595.aspx

1.1 Rail

The above transportation methods utilise two transport modes – rail and road. Rail transport, using cane trains, is used to transport approximately 88% of sugar cane from the farm to the mill. The rail used in the industry is a specialised form that is owned and operated by 19 of 22 sugar mills, with eight of these transporting 100% of the sugar cane produced by cane train. These mills collectively own approximately 250 18t to 50t diesel hydraulic locomotives and 52,000 4t to 15t capacity bins (Browning 2007; Geraghty 2005). Some examples of the cane train infrastructure are shown in Figure 3. Approximately 3,980km of track extends across 20 cane train networks throughout Queensland, with 19 of these using a 610mm gauge, and one using a 1067mm gauge that is connected to adjacent 610mm gauge lines using a dual gauge track (Australian Sugar Milling Council ; Browning 2007; Martin, Pinkney & Yu 2002).

Figure 3 Various types of locomotives carrying empty and full rail bins

Source: http://www.zelmeroz.com/albumquery/farleigh.htm

1.2 Road

Road transport in one form of another is used to transport approximately 12% of sugar cane from the farm to the mill or rail siding. A total of 14 mills use road transport with three of these using it as the only transportation method. The heavy vehicles used are either owned by the individual mills or contracted out to private haulage companies. Three types of heavy vehicles are used: tri-axle semi-trailers with a 14t - 24t capacity (Figure 4); multilift vehicles with a 21 - 24t capacity; and b-doubles with a 36t - 39t capacity.

Figure 4 Tri-axle semi-trailer unloading bins at rail siding

Source: http://www.sa-transport.co.za/trains/sugar_cane_rail/bins.html

2 Data Collection

The majority of the data used for this study was obtained by surveying the 22 sugar mills operating in Queensland during the 2009 cane crushing season. It was aimed to achieve a 100% sample of the industry to minimise the amount of data estimation and maximise data accuracy. Surveying was undertaken using a purpose designed questionnaire, intended to maximise the number of responses while minimising respondent burden. The questionnaire contained the following questions:

1. Sugar cane production for 2009 season (t)
2. Sugar cane that arrived at the mill in 2009 season (t)
3. Farm area providing sugar cane for 2009 season (ha)
4. Transportation modal split (% and/or t)
5. Litres of fuel used by locomotives for 2009 season (L)
6. Litres of fuel used by road transportation for 2009 season (L)
7. Length of locomotive lines (km)
8. Do you have a map of the locomotive network and/or rail sidings available and are you able to enclose this information upon returning this survey? (Y/N)
9. Train kilometres for 2009 season (train.km)
10. Average distance cane travels to mill (km)
11. Tonne-kilometres for 2009 season sugar cane freight task (tkm)
12. Tonne-kilometres for 2009 season sugar cane freight task by mode (tkm)
13. With what sensitivity would you like us to report on the information supplied in this survey?

The survey process involved the following steps:

1. **Industry Liaison:** Contacted industry bodies by telephone to identify the key industry parameters and contacts.
2. **Define Sampling Frame:** Compiled a list of sugar mills that crushed during the 2009 season and their respective contact details using *Australian Sugar Mills* (2009).
3. **Questionnaire Design:** Devised a questionnaire to collect the required data and drafted a covering letter to be attached with the questionnaire.
4. **Pre-survey Contact:** Contacted each sugar mill by telephone to outline the scope of the study and the information required so that a mill employee who could provide the data could be identified. A method to distribute the questionnaire was then ascertained and the email or postal address for the mill contact was obtained.
5. **Questionnaire Distribution:** Sent the questionnaire and attached covering letter using the agreed method.
6. **Post-survey Follow-up:** Contacted the mills that had not yet responded and reminded them to complete the survey. Additional time was allowed for late respondents. A final telephone call was made after the extension deadline to those mills that had not yet responded.

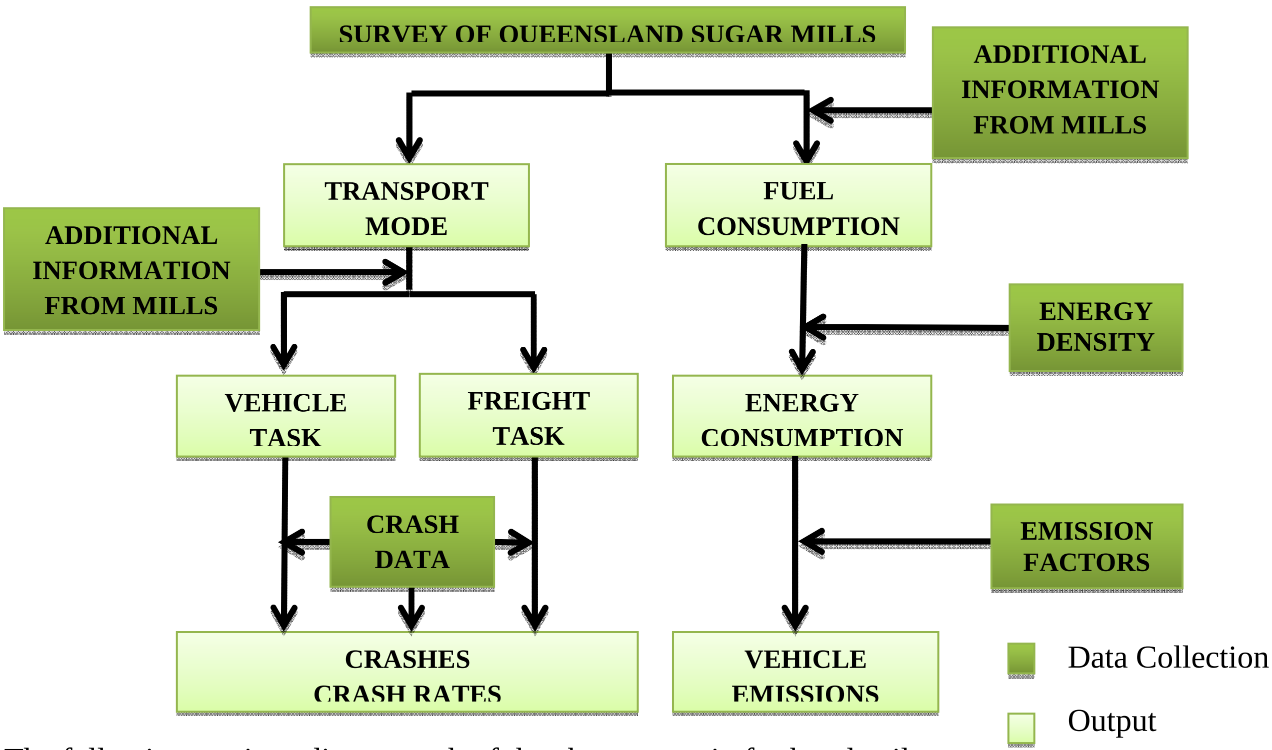
Although 100% of questionnaires were returned, only six of the 22 questionnaires were fully complete due to the mill not recording the information or understanding the terminology. As a result, additional information that was not requested in the questionnaire was obtained from the mills to allow the missing responses to be estimated. This included:

- Average load of sugar cane per train (t)
- Train.km travelled for maintenance trips (train.km)
- Average laden distance by road to mill and/or rail siding (km)
- Heavy vehicle type/s
- Average load of sugar cane per heavy vehicle/s (t)
- Average fuel consumption rate of heavy vehicle/s (L/100km)

3 Data Analysis

Once the surveys had been returned, the data analysis was undertaken for both rail and road transport for each sugar mill using the method outlined in Figure 5.

Figure 5 Data analysis methodology



The following sections discuss each of the above steps in further detail.

3.1 Transport Mode

The tonnes of sugar cane transported by rail and road at each sugar mill were determined using the tonnages transported by each method, obtained from the questionnaires, as follows:

$$T_{rail} = T_{direct\ rail} + T_{combined\ road/rail}$$

$$T_{road} = T_{direct\ road} + T_{combined\ road/rail}$$

Where:

T_{rail} = Tonnes of sugar cane transported from farm to mill by rail [t]

T_{road} = Tonnes of sugar cane transported from farm to mill by road [t]

$T_{direct\ rail}$ = Tonnes of sugar cane transported directly from farm to mill by rail [t]

$T_{direct\ road}$ = Tonnes of sugar cane transported directly from farm to mill by road [t]

$T_{combined\ road/rail}$ = Tonnes of sugar cane transported by road from the farm to a rail siding, then by cane train to the mill [t]

3.2 Vehicle Task

The vehicle task excluding maintenance trips by road and rail was obtained from the mills or calculated using the tonnages, laden distances and loads as follows:

$$VKT_e = N \times D \times 2 = \frac{T}{L} \times D \times 2$$

Where:

VKT_e = Vehicle task excluding maintenance trips [vkm]

T = Total tonnes of sugar cane transported [t]

L = Average load per vehicle [t]

N = Number of laden trips [#]

D = Average laden distance [km]

For rail, the vehicle task including maintenance trips was obtained from the questionnaires or calculated using the vehicle task excluding maintenance trips and maintenance trips. The vehicle task including maintenance trips was not determined for road transport due to the trips undertaken for repositioning, maintenance and refuelling being negligible compared to the trips undertaken for sugar cane transportation.

$$VKT_i = VKT_e + M$$

Where:

VKT_i = Vehicle task including maintenance trips [vkm]

VKT_e = Vehicle task excluding maintenance trips [vkm]

M = Maintenance and repositioning trips [vkm]

The distances travelled for maintenance trips and repositioning were obtained directly from the mills or estimated using the following relationships derived from the vehicle task data provided by the mills:

$$M = 13.183 VKT_i e^{-7\times 10^{-6} VKT_i}$$
$$M = 12.673 VKT_e e^{-7\times 10^{-6} VKT_e}$$

3.3 Freight task

The freight task was determined directly from the questionnaires or using the total tonnages and the average laden distances provided by the mills as follows:

$$\mathrm{FT} = \mathrm{T} \times \mathrm{D}$$

Where:

FT = Freight task [tkm]

T = Total tonnes of sugar cane transported [t]

D = Average laden distance [km]

3.4 Fuel Consumption

The fuel consumption was obtained from the questionnaires or calculated for the sugar mills contracting out the road transport using the vehicle fuel consumption rates and vehicle task as follows:

$$\mathrm{FC} = \mathrm{VKT_e} \times \frac{\mathrm{FCR}}{100}$$

Where:

FC = Fuel consumption [L]

VKT_e = Vehicle task excluding maintenance trips [vkm]

FCR = Fuel consumption rate [L/100km]

The fuel consumption rate was obtained from the mill or contractor. Where a fuel consumption rate was not provided, a rate from another mill using a similar type of vehicle was used.

3.5 Energy Consumption

The energy consumption was calculated using the fuel consumption and energy density as follows:

$$\mathrm{En} = \mathrm{FC} \times \mathrm{ED}$$

Where:

En = Energy consumption [GJ]

FC = Fuel consumption [L]

ED = Energy density [GJ/kL]

The energy density of diesel fuel for transport purposes was taken as 38.6GJ/kL, as per the Australian Government Department of Climate Change and Energy Efficiency's *National Greenhouse and Energy Reporting (Measurement) Determination 2008* (2010). The full-fuel cycle factors were not considered due to all transportation consuming the same fuel type.

3.6 Vehicle Emissions

The energy consumption was converted to vehicle emissions using the emission factor as follows:

$$\mathrm{Em} = \mathrm{En} \times \mathrm{EF}$$

Where:

Em = Greenhouse gas emissions [Gg]

En = Energy consumption [GJ]

EF = Emission Factor [Gg/GJ]

Emission factors, shown in Table 2, were obtained from the *National Greenhouse ad Energy Reporting (Measurement) Determination 2008* (2010).

Table 2 Greenhouse gas emission factors

Greenhouse Gas	Emission Factor (kg CO_2-e/GJ)
Carbon dioxide (CO_2)	69.2
Methane (CH_4)	0.2
Nitrous oxide (N_20)	0.5

Source: Australia Government Department of Climate Change and Energy Efficiency (2010)

3.7 Crashes

Industry specific crash data was incomplete for cane trains and absent for road transport. For cane trains, the number of crashes and casualties by severity were approximated using Queensland Workplace Health and Safety data and local newspaper reports. Crash rates per tonne.kilometre and per vehicle kilometre were then determined using the industry transport task as follows:

$$CR_{FT} = \frac{C}{FT}$$

$$CR_v = \frac{C}{VKT_i}$$

Where:

CR_v = Crash rate per vehicle kilometre travelled [#/vkm]

CR_{FT} = Crash rate per tonne.kilometre [#/tkm]

C = number of crashes [#]

VKT_i = Vehicle task including maintenance [vkm]

FT = Freight task [tkm]

For road transport, heavy vehicle crash rates were determined using the Department of Transport and Main Roads (TMR) crash data and the state's heavy vehicle freight task and vehicle task, as published in *Queensland Transport Facts* (2011). The sugar industry heavy vehicle crashes were estimated using the above equation from the state's heavy vehicle crash rates and the industry's freight and vehicle task. The number of fatalities for road transport was revised using local newspaper reports.

4 Results

4.1 Transport Methods

During the 2009 cane crushing season, 28.2Mt of sugar cane was produced in Queensland. Three transport methods were used to transport the cane – direct rail, direct road and combined road/ rail transport. The number of mills using each method and tonnes of cane transported by each method is summarised in Table 3.

Table 3 Transportation methods used by Queensland's sugar industry in 2009

Transportation Method	Number of Mills	Tonnes transported (Mt)	% of industry total
Direct rail	19	24.8	87.9
Direct road	8	2.2	7.6
Combined road/rail	9	1.3	4.5
Total	**22**	**28.2**	**100**

Direct rail transport is the most frequently used transportation method, used by 19 mills to transport 87.9% of sugar cane produced. Direct road transport is the next most significant method, used at eight mills to transport 7.6% of sugar cane. Combined road/rail transport is used to complement direct rail transport, resulting in it being the least common method used, hauling 4.5% of sugar cane produced. The net effect being approximately a direct rail:direct road:combined ratio of 19:2:1.

4.2 Modal Tonnages

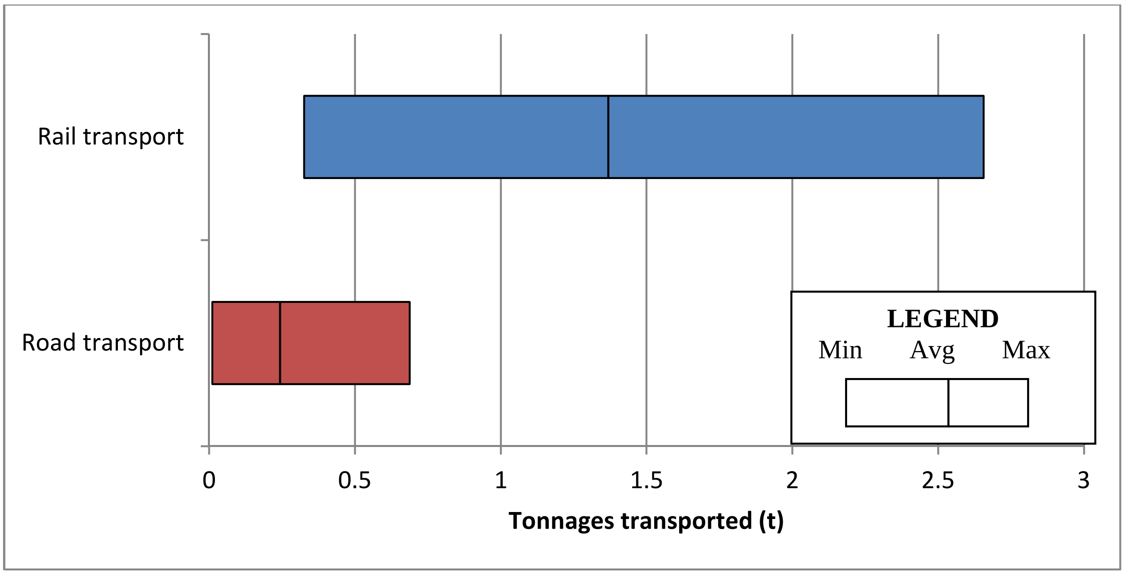
In total, 29.4Mt of sugar cane was transported during the 2009 season. This is slightly higher than the total tonnes produced due to the cane being double-handled as it is transported by road to a rail siding, then by rail to the mill. The total tonnages hauled by road and rail transport are summarised in Table 4.

Table 4 Sugar cane tonnages transported by road and rail during Queensland's 2009 cane crushing season

Transportation Mode	Tonnes of sugar cane (Mt)	% industry total
Rail	26.0	88
Road	3.4	12
Total	**29.4**	**100**

Cane trains are used to transport 88%, or 26Mt, of sugar cane from the farm to the mill. The 19 sugar mills using rail hauled between 326kt and 2.66Mt of sugar cane, with an average of 1.37Mt transported (Figure 6). Road transport hauled 3.4Mt, accounting for 12% of the industry total. The net effect being a 9:1 rail:road ratio for the modal tonnages. Road transport represents a comparatively small proportion of the total because road transport is used at only fourteen mills, with eleven of these using it as an ancillary mode to rail. Significantly smaller tonnages were also transported by road at each individual mill, with tonnages ranging between 10kt and 0.69Mt (average 0.24kt).

Figure 6 Comparison of tonnages transported by road and rail



From Figure 6, it can be seen that rail transported larger tonnages at each mill than road. This is due to rail being the more efficient transportation mode where sugar cane tonnages are sufficient (Browning 2007). Hence, where rail infrastructure exists, cane trains are used. Additional benefits resulting from the use of cane trains instead of road transport include improved energy efficiency while keeping approximately 18,000 to 25,000 heavy vehicle movements per day off the road network (Australian Sugar Milling Council 2011).

Despite relatively small tonnages transported by road, road transport plays a significant role within the industry. With the expansion of farmland away from the existing rail network, aging rail infrastructure and new mills opening in recent years, road transport has been introduced as an alternative to constructing new line and extending the existing rail network (Browning 2007; Zelmer 2009), due to the high capital expense of approximately $300,000 to $500,000 per kilometre of line, in addition to maintenance costs (Australian Sugar Milling Council). Furthermore, road transport is used where it is not economically feasible to transport the cane directly from the farm to the mill by road due to the shortest route having heavy vehicle restrictions (e.g. through a township), which would result in increased trip distances (Pers. Comm.). In these instances, the cane is transported to a rail siding by road, then hauled to the mill by rail.

4.3 Vehicle Task

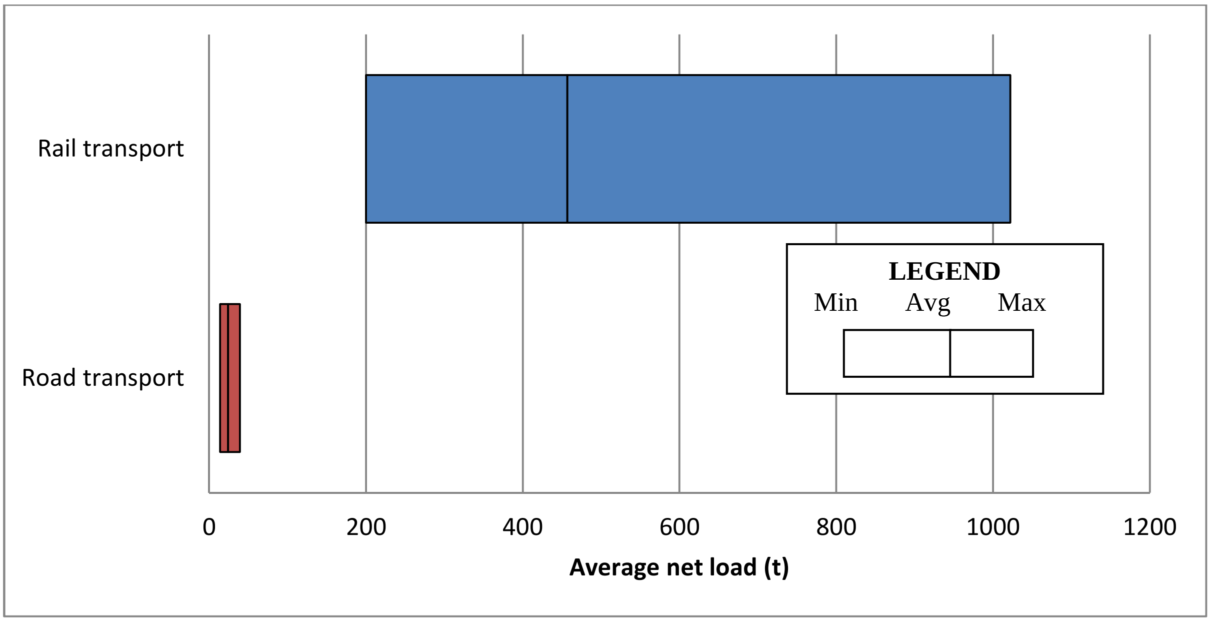
A total of 8.64Mvkm were undertaken to transport the sugar cane from the farm to the mill. Road transport undertook 6.07Mvkm, which accounted for 70% of the state's total whereas cane trains undertook 2.57Mvkm. The vehicle task is summarised in Table 5 and indicates a net 3:7 rail:road ratio.

Table 5 Vehicle task for road and rail transport during Queensland's 2009 cane crushing season

Transportation Mode	Total VKT (Mvkm)	% industry total
Rail	2.57	30
Road	6.07	70
Total	**8.64**	**100**

Despite transporting 88% of the sugar cane, cane trains produced only a small proportion of the vehicle task due to their higher average load of 457t, with the individual mill values ranging between 200t and 1,022t (Figure 7). Road transport has significantly smaller average load of 24t with loads ranging between 14t for tri-axle semi-trailers and 39t for b-doubles. Due to the smaller loads for road transport, more trips are required to transport a given amount of cane, and hence the vehicle task by road is greater.

Figure 7 Comparison of average net loads for rail and road transport



4.4 Freight Task

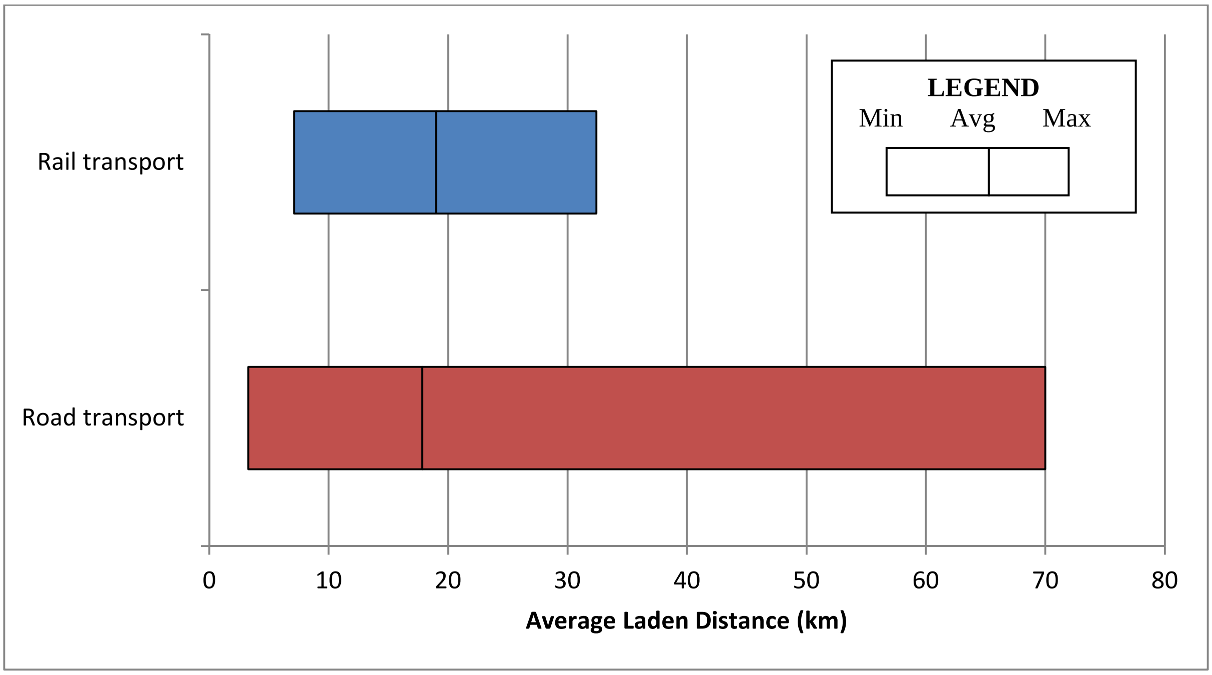
A freight task of 607Btkm was generated to transport the sugar cane during the 2009 crushing season. Cane trains generated 535Btkm, accounting for 88% of the industry's total freight task, whereas road transport only accounted for 12% of the state's total, as shown in Table 6 with the net effect being a 9:1 rail:road ratio.

Table 6 Freight task generated by road and rail transport during Queensland's 2009 cane crushing season

Transportation Mode	Freight Task (Btkm)	% industry total
Rail	534.6	88
Road	72.8	12
Total	**607.3**	**100**

The 9:1 ratio of the freight task is the same as that observed for the modal tonnages due to the average laden distance between the farm and mill being similar for rail and road. As shown in Figure 8, the average laden distance for road transport is 21.3km, with distances ranging between 3.27km and 70km. Rail transport had a similar average distance of 20.6km, with minimum and maximum distances of 7km and 32km respectively.

Figure 8 Comparison of average laden distances for road and rail transport



4.5 Fuel consumption

The sugar mills operating in Queensland use diesel fuel for both rail and road transport, consuming a total of 10.4ML during the 2009 crushing season. Sixty-two per cent of the fuel was consumed by cane trains, with only 38% of the total consumed by road transport. The fuel consumption for road and rail is included in Table 7 and indicates a net effect being a 3:2 rail:road ratio.

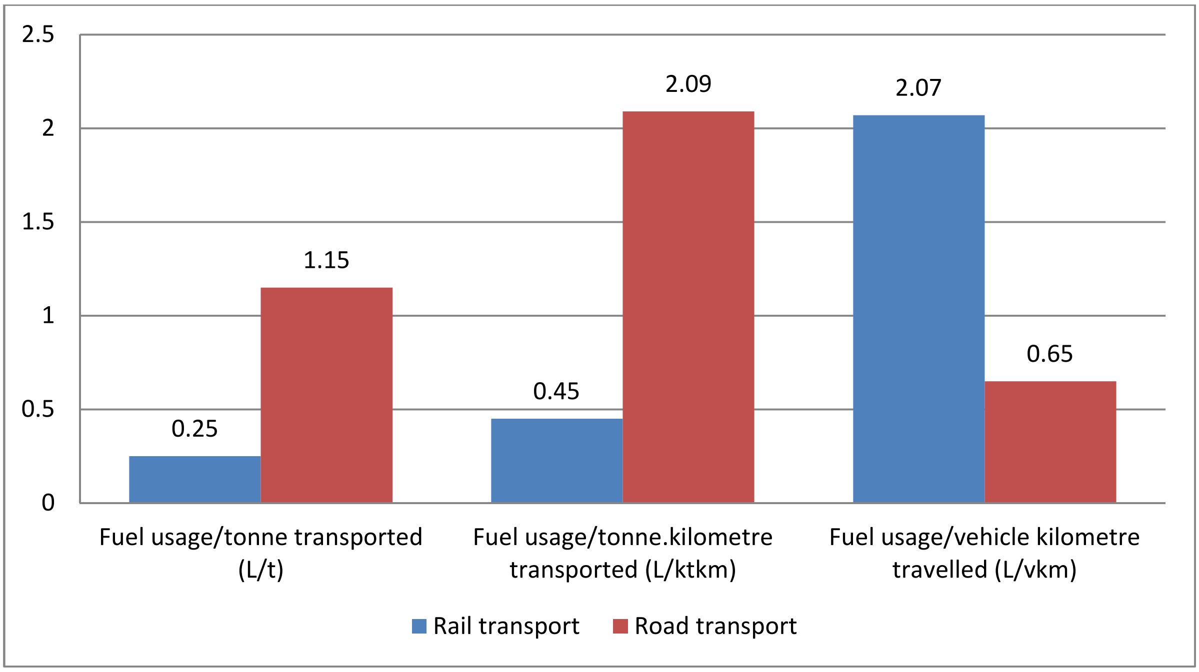
Table 7 Fuel consumption by road and rail transport during Queensland's 2009 cane crushing season

Transportation Mode	Fuel consumption (ML)	% industry total
Rail	6.48	62
Road	3.94	38
Total	**10.4**	**100**

The 3:2 rail:road ratio for the fuel consumption is significantly different to the 3:7 ratio for the vehicle task and the 9:1 ratio for the freight task. This indicates that the fuel consumption for rail exceeds that for road transport on a per vehicle kilometre travelled basis, however rail consumes less fuel per tonne.kilometre. Thus indicating the fuel efficiency of rail with a larger freight task being produced than road for a given quantity of fuel.

To gain an appreciation of the fuel efficiency of each mode, the fuel consumption rates have been compared. The fuel consumption rates per tonne, per tonne.kilometre and per vehicle kilometre travelled, is shown in Figure 9.

Figure 9 Fuel consumption rates of road and rail transport used in Queensland's sugar industry



From above, it is evident that cane trains consume less fuel per tonne transported and per tonne kilometre but more fuel per vehicle kilometre travelled. However, due to the freight task considering both the tonnages transported and distance travelled, cane trains are considered to be the most fuel efficient transport mode.

4.6 Energy consumption

A total of 394TJ of energy was consumed to undertake the transportation. Cane trains consumed 242TJ or 62% of the industry's total, while heavy vehicles consumed 152TJ, as summarised in Table 8 with a net effect being a 3:2 rail:road ratio. Table 8 Energy consumption of rail and road transport during Queensland's 2009 cane crushing season

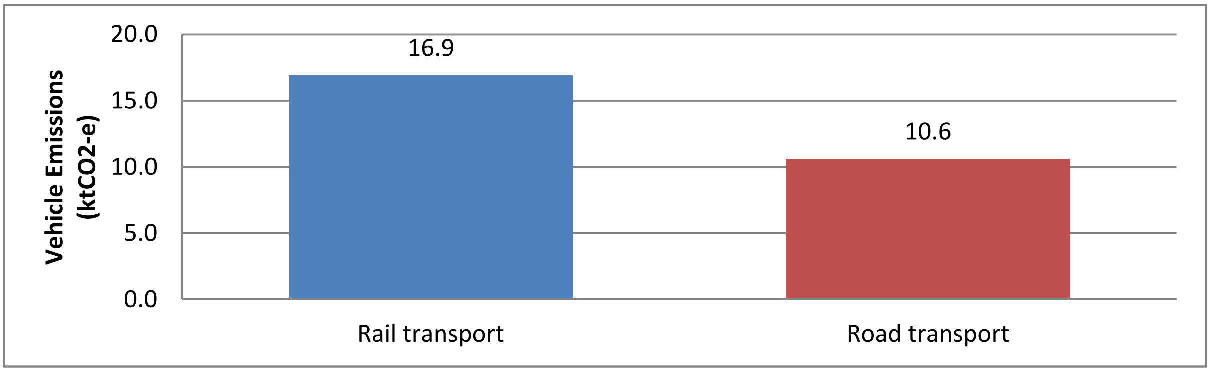
Transportation Mode	Energy Consumption (TJ)	% industry total
Rail	242	62
Road	152	38
Total	**394**	**100**

The 3:2 ratio observed previously for the fuel consumption (Table 7) remains unchanged for the energy consumption because the road and rail transport used in the industry during the 2009 season both used diesel fuel.

4.7 Vehicle emissions

The industry produced 28.1ktCO_2-e of greenhouse gas emissions during 2009 crushing season. Sixty-two per cent or 17.5ktCO_2-e was produced by cane trains while road transport produced 10.6ktCO_2-e, which accounts for 38% of the state's total. The greenhouse gas emissions produced by the sugar industry to transport the cane are shown in Figure 10.

Figure 10 Emissions produced by rail and road transport during Queensland's 2009 cane crushing season

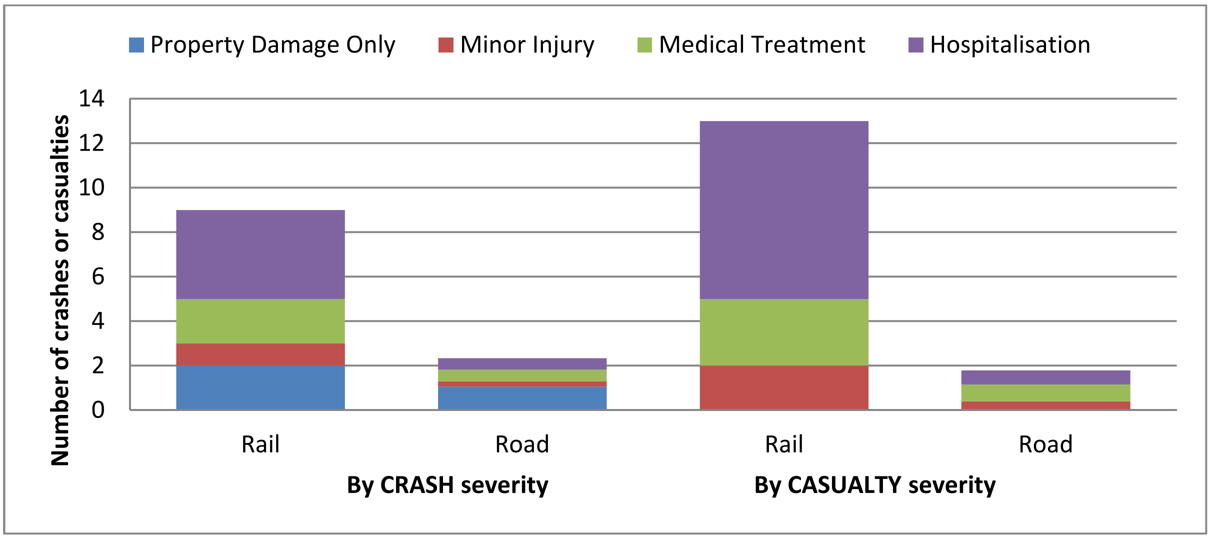


Again, the 3:2 ratio for rail:road is evident for the vehicle emissions, as was for fuel and energy consumption, due to both modes consuming diesel fuel.

4.8 Crashes

The number of crashes and casualties by severity for each mode are summarised in Figure 11. As mentioned in Section 3.7, rail crashes are actual figures, obtained from Queensland Workplace Health and Safety records and local newspapers, while road crashes have been estimated using Queensland average crash rates (per vehicle kilometre travelled and per tonne.kilometre) for articulated vehicles.

Figure 11 Social impacts of road and rail transport during Queensland's 2009 cane crushing season



Sources: Adam Pekol Consulting & The Centre for Transport Energy & the Environment (2011); Australian Sugar Milling Council (-); Cairns Post (2009); Crash Data Analysis Unit (2012); Daily Mercury (2009); Jacques (2009); Kellett (2009); Marsh (2009)

During the 2009 season, cane trains were involved in approximately nine crashes involving 13 casualties, whereas road transport was involved in an estimated three crashes involving two casualties. Road transport produced fewer casualties than rail transport, with 0.76 casualties per crash compared with 1.44 casualties per crash for cane trains. The net effect being a 3:1 rail:road ratio for the number of crashes and a 6:1 ratio for the number of severities. Thus road transport was involved in fewer crashes than rail and resulted in those involved sustaining fewer injuries. Also the severity of crashes resulting in injury was generally worse for cane trains, with the most frequent severity resulting in hospitalisation, unlike road transport, which most frequently resulted in medical treatments.

Using the industry freight task and vehicle task, crash rates for cane trains and road transport have been determined and are shown in Table 9.

Table 9 Comparison of rail and road crash rates during Queensland's 2009 cane crushing season

Severity		**Number/Btkm**		**Number/Mvkm**	
		Rail	**Road**	**Rail**	**Road**
Crash severity	Fatal	0	0	0	0
	Hospitalisation	7.48	3.74	1.556	0.092
	Medical treatment	3.74	3.70	0.778	0.083
	Minor Injury	1.57	1.78	0.389	0.040
	Property Damage	3.74	7.63	0.778	0.173
	TOTAL	16.84	17.4	3.500	0.396
Casualty Severity	Fatal	0	0	0	0
	Hospitalisation	15.0	4.59	3.111	0.104
	Medical treatment	5.61	5.60	1.167	0.128
	Minor Injury	3.74	2.79	0.778	0.064
	TOTAL	24.32	13.0	5.055	0.311

Sources: Adam Pekol Consulting & The Centre for Transport Energy & the Environment (2011); Australian Sugar Milling Council (-);Cairns Post (2009); Crash Data Analysis Unit (2012); Daily Mercury (2009); Jacques (2009); Kellett (2009); Marsh (2009)

An approximate 1:1 rail:road ratio for the total number crashes per tonne.kilometre is evident with cane trains have a slightly lower total crash rate per million tonne.kilometres than road transport overall, due to rail transport generating a larger freight task. When considering the crash rate per tonne kilometre by severity type, rail has a higher crash rate for crashes resulting in hospitalisation, medical treatment and minor injury with a total net effect being a 2:1 rail:road ratio of casualtieis per tonne.kilometre. On a per kilometre basis, a 9:1 ratio is observed for the total number of crashes per vehicle kilometre travelled with road transport results in fewer crashes and casualties per vehicle kilometre travelled than rail for all severities. The net effect being a 16:1 rail:road ratio of the total number of casualties per vehicle kilometre travelled.

By examining the crashes that occurred during a single year, it is unclear which mode is safest in terms of the crashes, due to annual variation in crash statistics and industry specific crash data being absent or incomplete. Hence further research is required to obtain a greater insight into the crashes involving the transportation of sugar cane in Queensland.

5 Conclusions and Recommendations

This paper has established a methodology that enabled the transport task and associated environmental and social impacts of the Queensland sugar industry to be quantified. However, it has not considered the costs or benefits of the sugar industry transport infrastructure. Using a survey process involving contacting each of the 22 individual sugar mills and distributing a purpose-designed questionnaire, the required data was obtained. It was found that 28.2Mt of sugar cane was transported during the 2009 crushing season, generating a freight task of 607Mtkm and a vehicle task of 8.64Mvkm. For both the tonnages and the freight task, a 9:1 rail:road ratio was evident whereas for the vehicle task a 3:7 ratio was observed. To undertake this transport task, 10.6ML of diesel fuel was consumed producing 28.1ktCO_2-e of greenhouse emissions. A 3:2 rail:road ratio for the fuel consumption, energy consumption and vehicle emissions was evident, as a result of both rail and road transport consuming diesel fuel, with rail being the most fuel efficient mode. In total, 12 crashes producing 15 casualties occurred during Queensland's 2009 cane season.

A similar methodology to that used in this study may be applied to quantify the transport task for other industries, such as grain, cattle and coal, and is applicable to various sample sizes. As the sample size increases, prudent questionnaire design becomes crucial as the sample size increases to ensure that all of the required data is obtained during the survey process. However, increasing the questionnaire size may reduce respondent participation due to increased respondent burden.

Another restricting factor to the application of a similar survey methodology is the nature and extent of the transport operations. Transport tasks that involve de-centralised trips (i.e. trips with a range of destinations) may increase the survey complexity and reduce accuracy. Additionally, the transport data required for the study must be recorded by, and readily available from, the transport operators. Hence industry liaison early in the study to assist with developing a study methodology and questionnaire is vital. With the above points in mind, it may be possible to quantify the transport task of numerous industries provided that the sample size is manageable.

6 References

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