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National Roadworthiness Baseline Survey – Sampling Report

January 2016

Project: NHVR/1

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Project: NHVR/1

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Executive Summary

The National Heavy Vehicle Regulator (NHVR) is planning a national survey to assess the mechanical condition of the national heavy vehicle fleet (the fleet). The aim of the National Roadworthiness Baseline Survey (NRBS) is to gather sufficient information about the fleet to judge the standard of roadworthiness and identify causal factors resulting in adverse safety, economic and environmental outcomes.

To ensure that information gained from the survey gives a true representation of the roadworthiness situation of heavy vehicles in Australia and provides a comparative baseline for further studies, appropriate sample sizes are required and the sampling must be undertaken in a manner that is unbiased and representative. Data Analysis Australia, an independent statistical and mathematical consultancy with particular expertise and experience in survey design and analysis, was contracted by NHVR to provide advice on the sampling design for this survey, with a particular focus on sample sizes and the implementation methodology. While both elements are related to some extent, they can for the most part be considered largely independently and this approach was taken except where there are necessary overlaps.

In this survey, as in many other survey contexts, the information about the population is not ideal and the survey is used to answer a wide range of questions. As such the design must consider a range of possible uses, make judgements about the priorities of each and access the required accuracy in each case, resulting in a design that minimises the compromises while still being practical. There will be no single 'true and correct' solution.

Being a baseline survey which is intended to provide not just an understanding of the population at the current point in time, but also as a base against which to make future comparisons, it is arguably more important to get the sampling 'as right as possible' in this than any future survey. It is also the most difficult to optimise, as future surveys can leverage from findings and results in the baseline survey to iteratively improve the sample design, adjusting for any observed biases or other sampling imperfections.

In the absence of such data, a common (and in this case recommended) strategy is to be more conservative in setting the sample sizes in the baseline year – sampling at a rate slightly higher than may be necessary in future years and implementing secondary sampling strategies to complement the main sampling regime, mitigating against any biases that may result.

High Level Summary of Recommended Approach and Sample Size

Data Analysis Australia took a statistical approach to developing a recommended sampling regime in terms of sample sizes and implementation methodologies. **After consideration of a number of issues, the recommended sampling regime includes a roadside intercept survey component (Rigid Trucks, Articulated Trucks, B-Doubles and Road Trains) and a present-for-inspection list based sampling component (Buses, Coaches and Plant Heavy Vehicles), with a national sample size of approximately 8,700 vehicles.** A small scale complementary present-for-inspection survey for vehicles in-scope of the roadside intercept scheme is also recommended with an additional sample size of approximately 400 vehicles.

Within the large scale survey, two alternative sample size options have been recommended, both with an overall sample size of approximately 8,700. The first option places higher emphasis on achieving similar levels of accuracy and precision for each sub-group of interest (broadly defined as vehicle type, state and metropolitan/non-metropolitan) and the second option places higher emphasis on achieving a more balanced proportional representation of the sample compared to the population, at the expense of the precision level of some of the smaller sub-groups.

Sample Sizes, Precision, Stratification and Weighting

A key element in ensuring that the results from a survey sample can be applied to make inferences about the entire population is that the sample must, in some way, be *representative* of the population, and not be *biased*. Primarily, this means that all members of the population have the *chance* of being sampled, that sufficient sample sizes are obtained to achieve sufficient levels of *precision* in the estimates, and that the individual members chosen to take part in the survey are chosen in a *random* (yet tightly controlled) manner.

The *precision* of a survey estimate relates to the amount by which the survey results may have differed if a different random sample had been chosen, and is a statistical measure of the uncertainty due to surveying a sample of the population, rather than the full population. The aim for this survey is to generate a sampling design that provides an acceptable level of uncertainty (or sufficiently high *precision*) in the results for the population overall and for key sub-groups of interest, whilst maintaining a practically achievable sampling regime.

As a general sampling principle based on sound statistical theory, the higher the sample size is, the higher the precision in the estimate will be. This rule also applies to sub-groups within the population. As another general sampling principle, the *population* size impacts on precision levels far less than the *sample* size. This means that one sub-group of interest in the population may have a far larger population size than another sub-group, but the recommended *sample sizes* may be similar.

Stratification is a sampling method whereby each unit (in this case, heavy vehicle) is assigned to one and only one sub-group (or *stratum*, plural strata) and a sample size is assigned to each stratum separately. Defining a stratified sampling regime has many advantages, including ensuring sufficient sample sizes are obtained for each sub-group of interest, ensuring that an appropriate representation of *all vehicles* is included in the sample to enable subsequent weighting and analysis to take place (mitigating against potential biases) and allowing each stratum to have a different *implementation* methodology if there is no best 'one size fits all' approach. Data Analysis Australia recommends a stratified sampling regime for the NRBS, with strata defined by vehicle type (Rigid Trucks, Articulated Trucks, B-Doubles, Road Trains, Buses and Coaches, and Plant Heavy Vehicles) and geographic location (state/territory and metropolitan versus non-metropolitan, except for ACT which is considered at the territory level only).

In the case of a survey, the survey weight refers to a multiplier (or scaling factor) attached to each unit in the sample to scale it to the population. Essentially, the multiplier represents how many units in the population each sample unit is representing, including itself. Weighting is needed for any sample survey, and particularly for those where the makeup of the sample doesn't match the makeup of the population in key ways. Importantly, what weighting allows is for the sample makeup to be *different* to the overall population makeup (that is, some vehicles may have a higher chance than being sampled than other vehicles), *while still obtaining unbiased results at the analysis stage.*

The caveat on weighting is that all *non-sampling biases* will remain and therefore must be minimised. This includes ensuring that the random sampling of vehicles to meet the sample sizes must be truly random (vehicles can't be more or less likely to be sampled based on whether they are more or less likely to have defects or faults) and having inspection points as geographically disperse as possible, over different days of week and times of day, and over a sufficient time period to maximise the chances of not inspecting a certain type of vehicle (eg. vehicles that only travel at night, or only travel in certain regions).

Sampling Population

Ideally, surveys use information relating to the population from which inferences are to be drawn when determining appropriate sample sizes. After assessing a number of possible options, including the Australian Bureau of Statistics' 2015 Motor Vehicle Census, 2014 Survey of Motor Vehicle Use and 2014 Road Freight Movement Survey, the 2015 Motor Vehicle Census was identified as being the best source of population data to use to determine sample sizes for the NRBS. This is primarily due to the survey being a Census of all Heavy Vehicles (rather than a survey based on only a subset of the population), with a focus on vehicle counts rather than vehicle usage. Both of these properties are well aligned with the requirements for the NRBS, although it is noted that the definitions of road trains requires further consideration in the sampling design.

Sampling Methodology/Survey Implementation

A number of potential methodologies were considered in the design of the baseline survey. Two primary options were identified – roadside 'intercept' inspections and list based 'present-for-inspection' inspections. Of crucial importance in considering the implementation methodology is that not all vehicles have to be subject to the same methodology – with appropriate sampling considerations, different vehicles can be targeted in the most appropriate way for them. Often, the choice of methodology is not based on an ideal, but on the option that provides the least in the way of limitations and disadvantages. A comprehensive review of the relative advantages and disadvantages of the two approaches was undertaken, including discussion of their importance and potential mitigation strategies.

It was determined that the most appropriate solution consists of a three component sampling methodology. All components maintain statistical integrity and leverage off the relative advantages of each methodology where it is appropriate to apply it. The three recommended components are:

1. A large scale roadside intercept survey for rigid trucks, articulated vehicles and B-Doubles (including road trains).
2. A present-for-inspection survey for buses, coaches and plant heavy vehicles.
3. A complementary present-for-inspection survey for vehicles in-scope of the roadside intercept scheme.

All survey components are based on a stratified sampling plan, with geographic region and vehicle class forming the basis of each stratum classification. When undertaking the sampling and inspections, it is important to collect and maintain all appropriate information that may be used in the weighting and analysis. For all survey components, weighting of the survey results is required to maintain an unbiased and representative set of findings.

Survey Component 1 – Large Scale Roadside Intercept Survey (Rigid Trucks, Articulated Vehicles and B-Doubles Including Road Trains)

Roadside intercept surveys are deemed the most appropriate for these classes of vehicle for a number of reasons, including the logistics and extent of disruptive impact on both vehicle owners/operators and inspectors, being able to take advantage of the immediate nature of the inspection (vehicles are sampled and immediately inspected while in transit, hence not allowing any opportunity for maintenance or repairs) and providing a potentially useful weighting towards vehicles that are more heavily used.

Although sample counts have been determined based on place of the vehicle owner's postcode and the sampling is taking place on the road (and hence where the vehicle is currently travelling), all in-scope vehicles passing the inspection point must be considered in-scope of sampling (for example, even if the inspection is taking place in Western Australia, vehicles registered in any state or territory can be sampled). This doesn't mean that all vehicles will be *randomly selected* for inspection, but they must all have the *chance* of being randomly selected. Failure to do so could result in biases.

It is also crucial that inspectors are given detailed sampling rules, to enable them to *randomly select* the vehicles for inspection, without unintentionally introducing biases to the sample. For example, if a vehicle is visually seen to be defective and hence pulled over for inspection when it otherwise would not be based on the sampling rules, this would introduce a bias and the sampling procedures will preclude this. A sampling rule of *"Select a particular in-scope vehicle as it approaches the inspection point. This vehicle is **not** to be sampled. Instead, the **next** in scope vehicle passing the inspection point is to be selected for inspection..."* enforces this random selection.

While for implementation purposes the sampling itself will be based on counts of vehicle type by *sampling location*, rather than the vehicle type by *registration location*, for analysis and weighting, the resultant counts by *registration location* should be used. Recommending sample sizes that are on the conservative side (that is, targeting higher precision than may be minimally acceptable) is a mitigation strategy against the limitations of this methodological approach.

To maximise the randomness and representativeness of the sampling, the following steps are strongly recommended to be followed:

- Sampling each vehicle type at a **range of locations** in a region.
- Best effort should be made to include as many different inspection points as feasible – **a minimum of at least one from every stratification region and other region as best as possible**. An appropriate spread must be obtained **including rural and remote areas**;
- Minimising time spent at sampling locations that have, for example, a strong **bias** towards or away from a particular transport operator;
- Sampling over a **number of weeks, days of the week and times of day**;
- Attempting to achieve **surprise** for at least a component of the sampling and not sampling too many vehicles before moving to another location – the aim must be that there is no strategy by which a vehicle can eliminate the possibility of being sampled;
- Inspectors doing their best to **minimise opportunities for drivers to stop and 'wait out' or divert their route from the inspection points**, for example, turning the inspection zones 'on and off' at regular intervals (a strategy that we understand is currently employed); and
- **Training staff** to use processes that will reduce their subconscious subjectivity when sampling. For example a rule of the form "randomly select a vehicle and then sample the one that follows it" can provide a discipline to avoid some subjectivity.

Implementation practices must be put in place to ensure that no vehicle is sampled twice. The exception to this rule is trailers, which may be sampled multiple times if they are attached to different prime movers that are both randomly sampled at different times.

Survey Component 2 – Present-For-Inspection Survey for Buses, Coaches and Plant Heavy Vehicle

Present-for-inspection surveys consist of operators being contacted in advance and requested to bring their vehicles to an inspection site at an arranged time. The vehicles are selected by randomly sampling the appropriate number of vehicles from a comprehensive list of all in-scope vehicles (the registration databases for each jurisdiction form the obvious basis for this list).

This methodology is deemed most appropriate for these classes of vehicles to minimise disruption to passengers in the case of buses and coaches and to capture a sufficiently representative sample of vehicles in the case of plant heavy vehicles (it is considered unlikely that this class would be adequately captured via a roadside intercept survey).

The key limitation to this present-for-inspection methodology is the opportunity it provides owners to undertake maintenance in preparation for the inspection. To minimise this risk for bias, it is recommended that inspections be booked in as soon as feasibly possible from the time of notification, although it will not be possible to prevent this completely.

There is the *potential*, once more detailed vehicle ownership information is known following inspection of registration lists, that the sampling could involve more sophisticated techniques to minimise the total number of vehicles inspected for any single owner, allowing for great representation of owners to be included in the overall sample.

Survey Component 3 - Complementary Present-for-Inspection Survey for Vehicles In-Scope of Roadside Intercept Scheme

One of the major disadvantages of the roadside intercept scheme is that some in-scope vehicles will not have a chance of being sampled due to not travelling on the roads at all, rarely, not during the inspection periods (for example vehicles used for seasonal work only) or travelling, but not travelling via networks that may reasonably be considered to include inspection points (for example, travelling only short distances between neighbouring properties). To mitigate against this, a complementary present-for-inspection survey should be undertaken. From an analytical perspective it also enables validation of the results from the main survey.

The compatibility of the results will always be questioned because of the notice being given before inspection and consequently the roadside component must be large enough to stand alone. This dictates a smaller sample size for the third component, but one large enough to enable comparative analysis and provide meaningful results in its own right. Data Analysis Australia recommends a minimum sample size of 400 nationally (to complement the roadside component of many thousands), being the smallest sized sample that would indicate whether nationally across classes there is any systematic issue between the populations covered in the intercept survey compared to the present-for-inspection survey.

There will be some limits on just how this survey component can be used. While it is a fill-in for the less travelled (or infrequently used) vehicles, it could also be used to explore a specific vehicle type to some extent. For example, if there is a vehicle type that is known to be missing from the roadside intercept surveys (such as seasonal vehicles) additional sample *or* a portion of the existing sample can be targeted to those vehicle types. The details of these latter options would need to considered on a bespoke basis.

This methodology could also be applied to meet any quotas that were not met in the roadside component, but this should be seen as a last resort. In this case, the ‘make-up sample’ for the quotas are additional to the 400.

Recommended Sample Sizes

In considering the determination of sample size it is necessary to trade off between the ideal – that would almost certainly dictate a sample size well in excess of what is achievable – and the practical, both in terms of cost and the burden placed upon road users. In this survey (as with almost all others) a combination of statistical principles with informed judgment must be applied.

The sample sizes need to balance achieving good performance when considering vehicle types and good performance when considering regions. It is also necessary to recognise that when considering just one category – say rigid trucks – the sample size required is not substantially influenced by the category population size. Hence ideally one might have the same sample for buses as for plant, even though the population sizes are very different. However, when the same data is used to consider a region, one wants to have the sample in some sense reflective of that region, and that will mean not having the sample sizes too disproportionate to the population sizes.

As a result of the necessary trade offs, two alternative sample size options have been recommended, both with an overall sample size of approximately 8,700. The first option places higher emphasis on achieving similar levels of accuracy and precision for each sub-group of interest (broadly defined as vehicle type, state and metropolitan/non-metropolitan) and the second option places higher emphasis on achieving a more balanced proportional representation of the sample compared to the population, at the expense of the precision level of some of the smaller sub-groups.

Both options are presented in the tables below. The choice of which option to proceed with must be made based on which of these two factors is considered most important.

These options are presented overleaf.

First Recommended Sample Option - Higher emphasis on achieving similar levels of accuracy and precision for each sub-group of interest.

State	Region	Rigid Truck	Articulated	B-Double	Road Train	Bus / Coach	Plant	Total
NSW	Metropolitan	200	140	95	0	130	120	685
NSW	Non-Metropolitan	200	140	95	60	130	120	745
	NSW Total	400	280	190	60	260	240	1,430
VIC	Metropolitan	200	140	105	0	130	130	705
VIC	Non-Metropolitan	200	140	95	60	130	130	755
	VIC Total	400	280	200	60	260	260	1,460
QLD	Metropolitan	200	140	105	0	130	120	695
QLD	Non-Metropolitan	200	140	95	60	130	120	745
	QLD Total	400	280	200	60	260	240	1,440
SA	Metropolitan	160	90	75	0	90	90	505
SA	Non-Metropolitan	150	90	65	40	80	90	515
	SA Total	310	180	140	40	170	180	1,020
WA	Metropolitan	190	130	115	0	130	130	695
WA	Non-Metropolitan	180	130	95	50	120	130	705
	WA Total	370	260	210	50	250	260	1,400
NT	Darwin	120	60	80	0	80	80	420
NT	Other	120	50	50	20	70	80	390
	NT Total	240	110	130	20	150	160	810
ACT	ACT	120	50	20	0	80	70	340
	ACT Total	120	50	20	0	80	70	340
TAS	Major Cities	140	80	50	0	90	50	410
TAS	Other	120	80	60	0	80	30	370
	TAS Total	260	160	110	0	170	80	780
TOTAL		**2,500**	**1,600**	**1,200**	**290**	**1,600**	**1,490**	**8,680**

Second Recommended Sample Option - Higher emphasis on achieving a more balanced proportional representation of the sample compared to the population, at the expense of the precision level of some of the smaller sub-groups.

State	Region	Rigid Truck	Articulated	B-Double	Road Train	Bus / Coach	Plant	Total
NSW	Metropolitan	380	130	60	0	135	70	770
NSW	Non-Metropolitan	360	150	85	60	115	90	865
	NSW Total	740	280	145	60	250	160	1,635
VIC	Metropolitan	390	150	75	0	125	110	850
VIC	Non-Metropolitan	340	170	85	60	105	120	880
	VIC Total	730	320	160	60	230	230	1,730
QLD	Metropolitan	330	130	80	0	135	70	745
QLD	Non-Metropolitan	370	135	105	60	100	70	840
	QLD Total	700	265	185	60	235	140	1,585
SA	Metropolitan	205	70	50	0	85	100	510
SA	Non-Metropolitan	185	100	65	40	50	100	540
	SA Total	390	170	115	40	135	200	1,050
WA	Metropolitan	315	115	85	0	120	150	785
WA	Non-Metropolitan	290	105	80	50	70	160	755
	WA Total	605	220	165	50	190	310	1,540
NT	Darwin	100	25	30	0	40	45	240
NT	Other	75	20	20	20	35	35	205
	NT Total	175	45	50	20	75	80	445
ACT	ACT	75	20	10	0	40	25	170
	ACT Total	75	20	10	0	40	25	170
TAS	Major Cities	150	45	20	0	65	20	300
TAS	Other	80	40	25	0	35	10	190
	TAS Total	230	85	45	0	100	30	490
TOTAL		**3,645**	**1,405**	**875**	**290**	**1,255**	**1,175**	**8,645**

Future Survey Designs

This survey is intended as a point in time baseline survey, with the possibility of undertaking future surveys to measure the roadworthiness of the heavy vehicle fleet in the years to come. While the design for future surveys has not been specifically covered in this report, they have been considered in decisions and recommendations for the baseline survey, minimising the risk of implementing procedures that limit options and opportunities for future surveys.

A key point in this regard is that Data Analysis Australia proposes that future surveys follow essentially the same sampling and implementation methodology as the baseline survey, appropriately updated for new population data and to correct for any sampling biases that were identified to have occurred in the previous survey and that *can be corrected for*.

Conclusions

This report proposes a sampling regime covering both sample sizes and implementation methodologies for a baseline survey to measure the roadworthiness of the national heavy vehicle fleet. The sampling regime includes both a roadside intercept survey component and a present-for-inspection list based sampling component.

The sample sizes have been recommended to be on the conservative side – that is, targeting a higher level of precision than may be strictly necessary – due to inherent uncertainties that exist the first time any survey is carried out for the first time and due to the extra emphasis that is likely to be placed on the baseline survey results for many years going forwards.

Numerous recommendations have been given regarding the sampling and implementation procedures to generate a robust and representative sample of vehicles, but certain details can only be prescribed once detailed logistical planning of the survey commences.

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1. Introduction

The National Heavy Vehicle Regulator is planning a national survey to assess the mechanical condition of the national heavy vehicle fleet (the fleet). The aim of the National Roadworthiness Baseline Survey (NRBS) is to gather sufficient information about the fleet to judge the standard of roadworthiness and identify causal factors resulting in adverse safety, economic and environmental outcomes.

To ensure that information gained from the survey gives a true representation of the roadworthiness situation of heavy vehicles in Australia and provides a comparative baseline for further studies, appropriate sample sizes are required and the sampling must be undertaken in a manner that is unbiased and representative. Data Analysis Australia, an independent statistical and mathematical consultancy with particular expertise and experience in survey design and analysis, was contracted by NHVR to provide advice on the sampling design for this survey, with a particular focus on sample sizes.

There are three main elements in designing any survey – the sample sizes, the implementation methodology (including how the sample is administered and how the specific units to sample are selected) and the questionnaire. While all related to some extent, they can for the most part be considered largely independently. This report takes the approach of discussing the sample sizes and implementation methodologies independently except where there are necessary overlaps. The questionnaire design is out of scope of the current work, except insofar as recommendations for data collection to aid in analysis of survey data as it relates to sampling (for example, any adjustments for biases that may be evident).

When determining sample sizes and implementation methodologies, the ideal situation is that there are a limited number of well defined questions which are to be answered. However in this, as in many other survey contexts, the information about the population is not ideal and the survey is used to answer a wide range of questions. As such the design must consider a range of possible uses, make judgements about the priorities of each and access the required accuracy in each case, resulting in a design that minimises the compromises while still being practical, and there will be no single 'true and correct' solution.

Being a baseline survey which is intended to provide not just an understanding of the population at the current point in time, but also as a base against which to make future comparisons, it is arguably more important to get the sampling 'as right as possible' in this than any future survey. It is also the most difficult to optimise, as future surveys can leverage from findings and results in the baseline survey to iteratively improve the sample design, adjusting for any observed biases or other sampling imperfections.

In the absence of such data, a common (and in this case recommended) strategy is to be more conservative in setting the sample sizes in the baseline year – sampling at a rate slightly higher than may be necessary in future years and implementing secondary sampling strategies to complement the main sampling regime, mitigating against any biases that may result.

2. Sampling Principles

Sampling is used to provide information about a population without the cost of gathering data from every member of the population. Rather, information is collected from a subset of the population in a *controlled manner* that then allows, through statistical and mathematical theory, inferences to be made about the full population with a known degree of accuracy.

Ideally the following principles should be followed:

A. Every member of the population should have a non-zero probability of being sampled. This ensures that the sample can speak for the whole population.

B. All probabilities of sampling every member of the population should be known or estimable once the data is collected. This ensures that the sample results can be projected onto the whole population.

C. If the probability of one member being sampled is affected by whether or not another member is sampled, this relationship must be known.

D. The sample should be of sufficient size to answer the questions for which the survey is being carried out.

The simplest sampling (often termed simple random sampling) has each population member having equal probability of being sampled and the sampling being independent. This has certain optimality properties and is often used as a baseline when considering sampling procedures.

In practice, sampling is often constrained to depart from these principles. Where such departures are necessary, it is good practice for the departures and the reasons for them to be properly documented.

2.1 Sample Sizes and Precision

One component of uncertainty in the results of a sample survey relates to the fact that it is a survey which, if repeated, will have a randomly different sample selected and hence a different result will be obtained due to this alone. The precision of a survey estimate relates to the *amount* by which the survey results may have differed if a different random sample had been chosen and the aim is for precision to be high – high precision equates to a small deviation in the result. For example, if a survey gives a prevalence estimate of 40% (that is, 40% of sampled units displayed a particular characteristic), the precision of the estimate may be ±5% or ±10%. In this case, if the survey precision was ±5%, one would be confident that the true prevalence estimate lies between 35% and 45%, whereas if the survey precision was ±10%, one would be confident that the true prevalence estimate lies between 30% and

50%[1]. In both cases, the best estimate is 40% (and is unbiased), but the precision relates to how much variation around the 40% may be expected if a different sample was chosen.

Mathematical theory provides a comprehensive analysis of this uncertainty and the effect of sample size. Hence, one way of determining an appropriate sample size is to use a target precision for an estimate (prevalence among the population) which is to be obtained from the sample. The required sample size n to achieve a target precision of e given population N and expected prevalence p can be expressed using the following formula:

$$n = \frac{1}{\left(\frac{\left(e/z_{\alpha/2}\right)^2}{p(1-p)} + \frac{1}{N}\right)}$$

where $z_{\alpha/2}$ is the critical z value taken from the normal distribution to obtain a desired confidence of (100 – α)%. In this report, α will be set at 5%[2] - a very commonly used value in survey design and analysis - giving $z_{\alpha/2}$ a value of 1.96.

For example, if the prevalence is 40% (0.4), the desired precision was ±5% and the population size was 5,000, the required sample size is 343, calculated as follows:

$$n = \frac{1}{\left(\frac{(0.05/1.96)^2}{0.4(1-0.4)} + \frac{1}{5000}\right)}$$

If the desired precision was ±10%, and all the other values were the same, the required sample size is 90, calculated as follows:

$$n = \frac{1}{\left(\frac{(0.1/1.96)^2}{0.4(1-0.4)} + \frac{1}{5000}\right)}$$

This demonstrates that the desired precision has a large impact on required sample sizes.

If however, the prevalence is 25%, and all other values were the same as the first example (that is, with a desired precision of ±5%), the sample size is 272, calculated as follows:

$$n = \frac{1}{\left(\frac{(0.05/1.96)^2}{0.25(1-0.25)} + \frac{1}{5000}\right)}$$

This demonstrates that the prevalence estimate also has an impact on required sample sizes, although not as large an impact as desired precision rates. It can be shown that the maximum sample size is obtained when the prevalence rate is 50% (the midpoint between 0% and 100%). For this reason, sample sizes are often set using the

[1] Technically, one should say 'how confident' they are. A typical value is 95%, meaning that 95 out of every 100 randomly generated samples would give an estimate that lies within the calculated range. All calculations in this report assume this 95% confidence level. This is *not* to be confused with a precision of ±5% - they are two distinct concepts.

[2] Corresponding to a 95% confidence interval as discussed in the preceding paragraphs.

assumption that the prevalence rate will be 50% - this means that the precision for the *actual* prevalence will be no worse than planned for, and in many cases will be better.

Figure 1 provides examples showing the ranges of required sample sizes to achieve certain precision based on predefined population and prevalence figures.

It can be seen from the plots that the required sample size quickly reaches a stable figure as population becomes larger, demonstrating that the number of required samples is less impacted by the size of the population, unless there are strata with very small population. A general implication of this is that the more strata there are in the survey, the more sample it will need to collect to obtain desired precision for each stratum's estimate.

Another key observation to make is how the desired precision makes a notable difference in the required sample size as discussed above – it has a much greater impact than the population size. In determining appropriate precision levels to target, it is common practice to accept a lower level of precision for sub-groups of interest, than what is desired for the overall sample. For example, if a precision of ±5% at the overall level may be desired, ±10% (or 15%, 20% or even higher) may be acceptable for individual sub groups in order to keep sample sizes at reasonable levels.

The figure also demonstrates that the highest sample sizes are needed for prevalence estimates of 50% and close to 50%, with lower sample sizes needed to achieve the same precision for prevalence rates deviating from 50% (whether higher or lower).

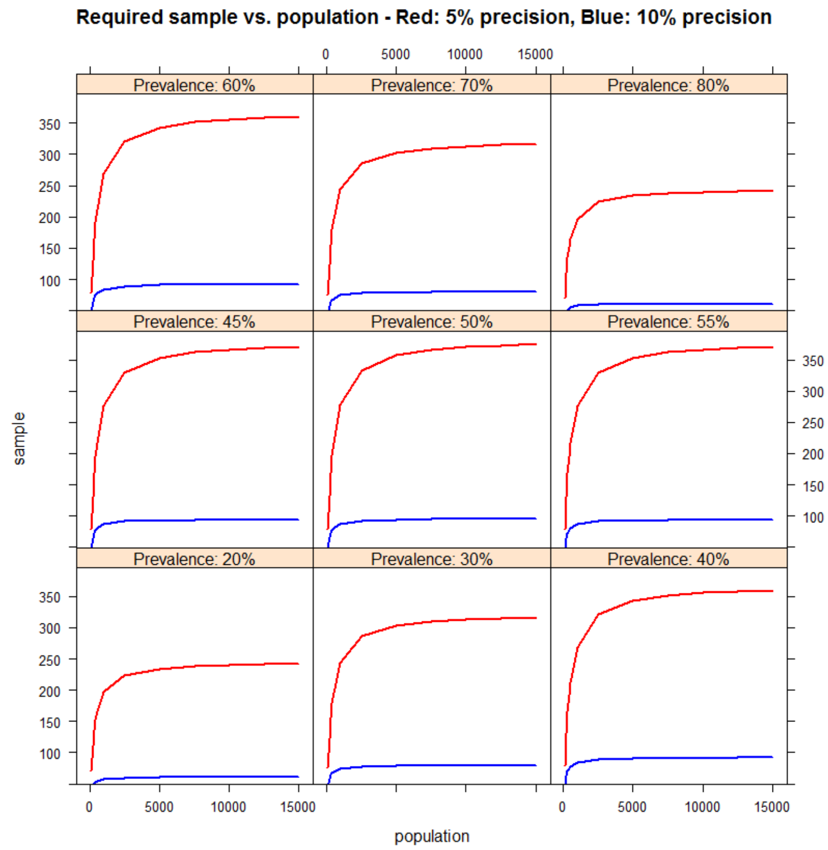


Figure 1. Plot of sample counts by population for defined defect prevalence and precision.

2.1.1 Previous Survey Findings

Results from similar surveys conducted in New South Wales from 2003 to 2009 showed a moderately high rate of minor defects – around 50% – but a fortunately low rate of major defects – around 5% to 7%. While that survey was undertaken for only a subset of the current population of interest and using a different sampling design, the figures provide reasonable basis to further the discussion.

In particular, an immediate implication of the low rate of major defects is that the sample sizes required to show modest differences in the rates will need to be quite large. For example, if a change from a rate of 5% to a rate of 7% is to be demonstrated with 95% surety, each sample size would need to be almost 1,100 units. If the survey aimed to provide such precision for particular vehicle types of particular regions, such sample sizes would be required at the vehicle or regional level.

For minor defects, the sample size requirements are significantly less. For example, detecting a change in the minor defect rate from 45% to 55% with a similar surety would require sample sizes in the order of 200 in each relevant category being reported in each survey. Again, trade-offs are still required and smaller sample sizes might be acceptable for "secondary priorities" or detailed comparisons.

These survey findings have been provided for context and discussion only, and have not been used in determining sample sizes.

2.2 Stratification, Biases and Weighting

2.2.1 Stratification

Stratification refers to a type of statistical sampling whereby each unit (in this case, heavy vehicle) in the population is assigned to one and only one sub-group, with all of the sub-groups together forming the total population. Each sub-group is referred to as a stratum (plural strata) and each stratum has a sample size attached to it, as well as a methodology and means of obtaining the sample from that stratum. Stratification can often be used to improve the overall sampling, with the following being a number of the key benefits:

- Each stratum can have different rates of sampling and can have a different methodology employed to conduct the sampling (and inspections), with the results all being able to be combined for overall survey analysis.
- If one stratum is considered more important than another stratum (in some way) its relative sample size can be increased.
- If one stratum is considered more variable than another stratum (in some way) its relative sample size can be increased, leading to improved statistical precision.
- Minimum sample sizes for any sub-group of interest can be obtained, ensuring sufficient sample sizes for sub-group analysis and comparison. This is particularly important for populations with relatively rare sub-groups of interest, which may otherwise result in there being significantly few in the final sample if not taken into account via stratification.

- Stratification can help ensure a representative sample is obtained for subsequent weighting and analysis.

2.2.2 Sampling Errors and Biases

By definition a sample survey does not survey every item in the population, and as such the survey results provide an *estimate* of the true population value, an estimate that would be different if a different sample was selected. Neither of these samples is right or wrong, and the imperfections are commonly called errors, a misnomer in the sense that these do not represent mistakes as such, but simply the difference between the random subset of the population being sampled and the entire population. These errors can be divided into two types:

- Sampling errors – any 'errors' that result from changing from one randomly selected sample to another. It is the discrepancy that results from making inferences about the population from a subset rather than the entire population and can typically be controlled by taking larger sample sizes. Sampling errors can be understood and quantified using statistical theory and the related concept of *sampling biases* can be corrected for with weighting. Sampling biases do therefore not result in biased *results* as long as they are analysed appropriately, and there are numerous statistical and practical reasons why a survey sample may be biased in its design, and corrected for in its analysis.

- Non-sampling errors – all other sources of error that will be consistently and systematically observed in each randomly selected sample. These errors may be termed non-sampling biases and cannot be corrected for. Such biases typically include differing response rates (which should not be a significant issue for this survey due to legislative powers to conduct such inspections), leading questions in a questionnaire (in this case, perhaps different levels of rigour applied by different inspectors) or respondents deliberately providing misleading or erroneous responses (in this case, perhaps vehicle owners or operators knowing about an inspection in advance and performing maintenance on their vehicle, or avoiding an inspection point if they become aware of its operation). These types of errors and bias *cannot* be corrected for in the analysis and efforts must be made to minimise them in the design stage, via good planning, training, execution and quality checks.

An important element of *bias mitigation* is to collect information that *may* be useful for weighting or analysis at the time of sampling. It may not be known in advance that it will be useful or necessary to account for, but if the data is collected and becomes apparent that it could be important to account for in terms of bias and representativeness, then it can be incorporated during analysis. A particular example may be collecting the total kilometres travelled by a vehicle, or where it does most of its travel between (for example, main origin and destination locations). This type of information may also be useful for profiling and reporting.

2.2.3 Survey Weights

In the case of a survey, the survey weight refers to a multiplier (or scaling factor) attached to each unit in the sample to scale it to the population. Essentially, the multiplier represents how many units in the population each sample unit is representing, including itself. Weighting is needed for any sample survey, and particularly for those where the makeup of the sample doesn't match the makeup of the population in key ways.

In the simplest case, all survey weights will be the same. For example, in a population of 1,000 with a random sample of size 100 surveyed, each of the 100 sampled units would receive a weight of 10 (calculated as 1,000/100).

This simplest case is rarely the case in practice, with many statistical and practical reasons leading to a more complex sample design to best achieve the objectives of the survey. In these cases, the survey weights are likely to be different for different units in the sample, representing the different chance (or probability) they had of being included in the survey – without taking these weights into consideration, the overall estimates will be biased, but once taken into account, the biases are removed.

The caveat on weighting is that all *non-sampling biases* will remain. It is crucial therefore that these are minimised. In particular if any sub-groups of the population do not get included in the random sample, they cannot be adjusted for via weighting. These sub-groups are often subtly defined groups in the population, for which it may not be immediately obvious that they are missed without careful consideration. In this context, if, say, only a roadside intercept survey is undertaken, vehicles that do not travel in areas where there are inspection points will be excluded from the survey, by accident rather than design. These types of bias cannot be adjusted for in the weighting, so steps should be taken to ensure that such vehicles *can* be sampled, in some way.

It should be noted that for *profiling* of vehicle roadworthiness for example, answering questions such as *"Are older vehicles more (or less) likely to be unroadworthy?"*, weighting is less important. For estimating *proportions and prevalence rates,* it is crucial.

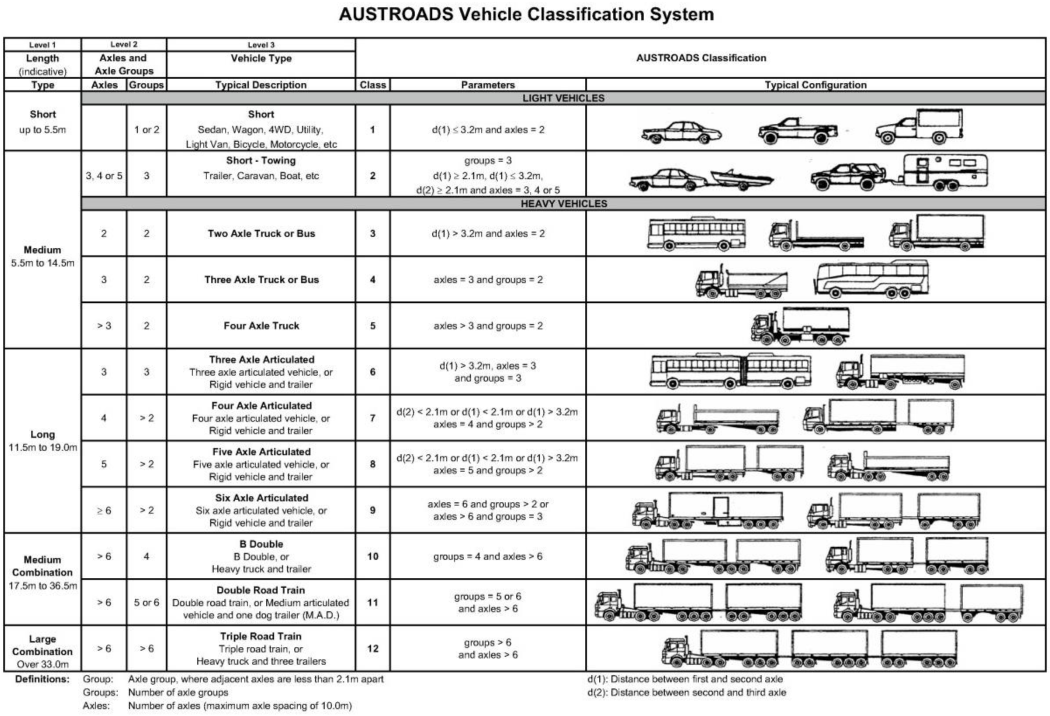
3. Sampling Population

Ideally, surveys use information relating to the population from which inferences are to be drawn when determining appropriate sample sizes. A starting point for the review of the sampling frame is an understanding of the population of heavy vehicles, where a heavy vehicle is defined as one with a gross mass greater than 4.5 tonnes. For that reason Data Analysis Australia has examined available information on the population of vehicles.

To be able to determine appropriate sample sizes within each stratum it is necessary to define population counts at the stratum level. For this survey, classification variables of particular interest include region (to be defined at an appropriate level) and heavy vehicle types, with vehicles classified into the following categories which have their own regulatory requirements:

- Rigid Truck;
- Articulated;
- B-Double;
- Road Train;
- Bus;
- Coach; and
- Plant.

Licensing and registration data often presents vehicles classified by vehicle length, number of axles and number of axle groups as illustrated by the Austroads definitions illustrated in Figure 2.



AUSTROADS Vehicle Classification System

Level 1 Length (indicative) Type	Level 2 Axles and Axle Groups Axles	 Groups	Level 3 Vehicle Type Typical Description	AUSTROADS Classification Class	 Parameters	 Typical Configuration
			LIGHT VEHICLES			
Short up to 5.5m		1 or 2	**Short** Sedan, Wagon, 4WD, Utility, Light Van, Bicycle, Motorcycle, etc	**1**	d(1) ≤ 3.2m and axles = 2	
Medium 5.5m to 14.5m	3, 4 or 5	3	**Short - Towing** Trailer, Caravan, Boat, etc	**2**	groups = 3 d(1) ≥ 2.1m, d(1) ≤ 3.2m, d(2) ≥ 2.1m and axles = 3, 4 or 5	
			HEAVY VEHICLES			
	2	2	**Two Axle Truck or Bus**	**3**	d(1) > 3.2m and axles = 2	
	3	2	**Three Axle Truck or Bus**	**4**	axles = 3 and groups = 2	
	> 3	2	**Four Axle Truck**	**5**	axles > 3 and groups = 2	
Long 11.5m to 19.0m	3	3	**Three Axle Articulated** Three axle articulated vehicle, or Rigid vehicle and trailer	**6**	d(1) > 3.2m, axles = 3 and groups = 3	
	4	> 2	**Four Axle Articulated** Four axle articulated vehicle, or Rigid vehicle and trailer	**7**	d(2) < 2.1m or d(1) < 2.1m or d(1) > 3.2m axles = 4 and groups > 2	
	5	> 2	**Five Axle Articulated** Five axle articulated vehicle, or Rigid vehicle and trailer	**8**	d(2) < 2.1m or d(1) < 2.1m or d(1) > 3.2m axles = 5 and groups > 2	
	≥ 6	> 2	**Six Axle Articulated** Six axle articulated vehicle, or Rigid vehicle and trailer	**9**	axles = 6 and groups > 2 or axles > 6 and groups = 3	
Medium Combination 17.5m to 36.5m	> 6	4	**B Double** B Double, or Heavy truck and trailer	**10**	groups = 4 and axles > 6	
	> 6	5 or 6	**Double Road Train** Double road train, or Medium articulated vehicle and one dog trailer (M.A.D.)	**11**	groups = 5 or 6 and axles > 6	
Large Combination Over 33.0m	> 6	> 6	**Triple Road Train** Triple road train, or Heavy truck and three trailers	**12**	groups > 6 and axles > 6	

Definitions: Group: Axle group, where adjacent axles are less than 2.1m apart
Groups: Number of axle groups
Axles: Number of axles (maximum axle spacing of 10.0m)

d(1): Distance between first and second axle
d(2): Distance between second and third axle

Figure 2. The standard Austroads Vehicle Classification System.

Comparisons between the categories required for this NRBS and the Austroads standard set of classification definitions are presented in Table 1. From this comparison it is evident that the classifications required for the NRBS cannot be uniquely identified through the Austroads classifications alone, which may be a potential issue when attempting to separate population counts into the vehicle types of interest if only the axles and length of vehicle are known.

Table 1. Comparison of the NRBS heavy vehicle categories and Austroads classification.

Vehicle Categories for NRBS	Austroads Classification
Rigid Truck	Part of 3, 4 and 5
Articulated	Part of 6, 7, 8 and 9
B-Double	10
Road Train	11 and 12
Bus	Part of 3 and 4 (mainly 3)
Coaches	Part of 3 and 4. (mainly 4)
Plant	Parts of 3 to 12.

A review of the population of the NRBS heavy vehicles categories at different regional levels can provide insight into identifying appropriate sampling regions as it is preferable for each sampling region to display similar characteristics in heavy vehicles throughout the region. A discussion of available and appropriate data sources to help aid defining sampling region and population counts by vehicle type and region follow.

3.1 Review of Australian Bureau of Statistics Data Sources

Data from the Australian Bureau of Statistics (ABS) was recognised as providing the most appropriate source of information to derive a baseline population which can be collated into most NRBS vehicle classifications and allocated to state and regional level. The ABS collects data on motor vehicles through a number of collections and for a number of different metrics. These include total counts of vehicle registrations based on the state of registration and on the owner's postcode, as well as conducting surveys to obtain information about motor vehicle use including an estimate of the kilometres travelled.

3.1.1 Microdata: Census of Motor Vehicles, Australia, 2015

The 2015 Motor Vehicle Census (Cat No. 9309.0.55.003) was identified as providing the most recent and valuable source of information about the population of registered vehicles, with information provided by state and territory motor vehicle registration authorities. This data was available for both the state of registration of the vehicle and the owner's postcode, and categorised vehicles into several classifications which could be aggregated into most of the desired vehicle type categories with GVM over 4.5 tonne. The exceptions are road trains which are not identified separately from other heavy trucks and buses and coaches, which were also not separated from each other.

Figure 3 on page 10 illustrates the level of vehicle classification provided in the motor vehicle census data, separating Rigid Trucks, Prime Movers, Buses, Special Purpose Vehicles and Trailers, with further information on vehicle length and axles. Appendix B provides a detailed comparison of the heavy vehicle categories available in the Australian Bureau of Statistics 2015 Motor Vehicle Census, the Austroads classification and the desired breakdown for this survey.

A key problem with vehicle licensing data is that the population is treated in a conceptually different manner with regard to articulated vehicles. Trailers are considered to be separate vehicles, registered in their own right. Hence, there is no concept of a "road train", only of vehicles that may be used to make up a road train. There are some distinctions between trailers that might or might not be used in certain configurations, but it is quite feasible for many trailers to be observable in the survey in several different configurations.

Although not providing fully sufficient information to derive population counts for all vehicle types desired for the survey stratification, the 2015 Motor Vehicle Census does provide valuable information on the most up to date counts of registered vehicles including several breakdowns of heavy vehicles not available through other data sources. Combined with other information on heavy vehicles, this data will provide a suitable means of defining the population of heavy vehicles at stratum level.

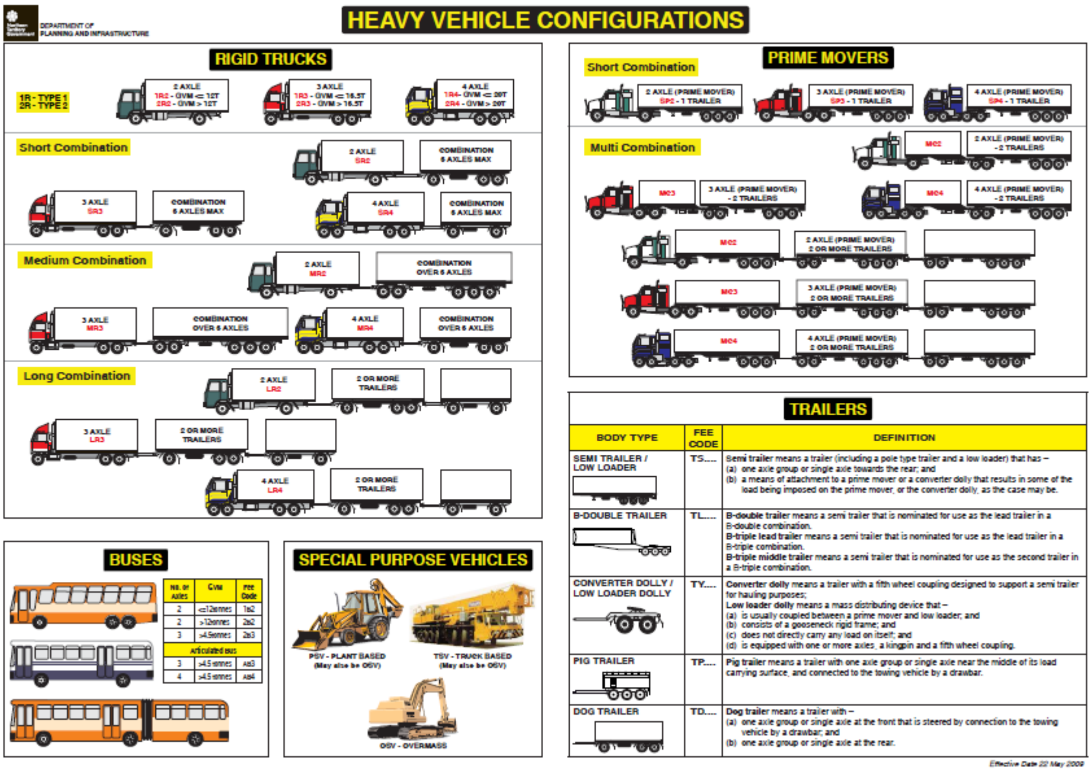


Figure 3. Heavy Vehicle Configurations available in the Australian Bureau of Statistics 2015 Motor Vehicle Census. These vehicle configurations were used as a guide for aggregating vehicles counts in the census to vehicle classes defined by NHVR.

To select a sample from a region with known number of vehicles it would be ideal to obtain population counts reported by where the vehicle most commonly resides. Though this information is not available, the 2015 Motor Vehicle Census does report counts by the state of registration as well as postcode of owner of the vehicle, which both may provide a reasonable indication of the number of vehicles likely to be present within a given region – particularly if region is not defined too narrowly. Comparisons of the two are presented in Table 2 and Table 3 which show relatively small differences between these counts at state level. This relative consistency between the different means of reporting data gives greater assurance in resultant population counts irrespective of whether the vehicle registration location or owners' residence is used, particularly when considering higher level regions.

Table 2. State derived from the postcode of the vehicle's owner as a count and percentage of the state of the vehicle's registration.

	State derived from postcode of owner								
	NSW	Vic	Qld	SA	WA	NT	ACT	Tas	Total
State of Vehicle Registration									
NSW	119,415	1,027	1,443	193	15	3	576	41	**122,713**
Vic	3,162	126,653	994	596	57	6	46	48	**131,562**
Qld	525	1,149	112,098	28	148	6	3	3	**113,960**
SA	346	304	148	43,027	83	26		3	**43,937**
WA					96,887				**96,887**
NT	108		12	25	3	8,141			**8,289**
ACT	481	12					2,300		**2,793**
Tas	26	139	19	6	6			12,856	**13,052**
Total	**124,063**	**129,284**	**114,714**	**43,875**	**97,199**	**8,182**	**2,925**	**12,951**	**533,193**
State of Vehicle Registration									
NSW	97.3%	0.8%	1.2%	0.2%	0.0%	0.0%	0.5%	0.0%	100.0%
Vic	2.4%	96.3%	0.8%	0.5%	0.0%	0.0%	0.0%	0.0%	100.0%
Qld	0.5%	1.0%	98.4%	0.0%	0.1%	0.0%	0.0%	0.0%	100.0%
SA	0.8%	0.7%	0.3%	97.9%	0.2%	0.1%	0.0%	0.0%	100.0%
WA	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%
NT	1.3%	0.0%	0.1%	0.3%	0.0%	98.2%	0.0%	0.0%	100.0%
ACT	17.2%	0.4%	0.0%	0.0%	0.0%	0.0%	82.3%	0.0%	100.0%
Tas	0.2%	1.1%	0.1%	0.0%	0.0%	0.0%	0.0%	98.5%	100.0%
Total	23.3%	24.2%	21.5%	8.2%	18.2%	1.5%	0.5%	2.4%	100.0%

Table 3. Counts of vehicle types by state of registration and by owner's postcode aggregated to state level.

	Rigid Truck		Articulated		B-Double		Bus/Coach		Plant	
	Registered State	Owner postcode	Registered State	Owner postcode	Registered State	Owner postcode	Registered State	Owner postcode	Registered State	Owner postcode
NSW	95,481	89,460	13,721	13,033	6,796	6,928	13,398	10,357	4,439	4,283
Vic	87,877	86,734	17,313	16,777	8,884	8,022	8,696	8,672	9,193	9,079
Qld	80,028	80,594	11,524	11,634	10,110	10,123	9,105	9,144	3,270	3,220
SA	25,618	25,333	4,765	4,907	3,603	3,768	3,242	3,177	6,780	6,692
WA	60,844	59,616	7,968	7,734	7,785	7,584	6,345	6,219	16,336	16,046
NT	5,094	4,942	320	309	924	918	996	872	1,192	1,141
ACT	1,770	1,942	124	135	29	32	620	587	250	229
Tas	9,470	9,331	1,268	1,264	361	357	1,814	1,820	178	178
Total	**366,182**	**357,952**	**57,003**	**55,793**	**38,492**	**37,732**	**44,216**	**40,848**	**41,638**	**40,868**

Some of the larger differences between region classifications that can be seen from Table 3 include the Bus and Coach vehicle category where 13,344 vehicles were registered in New South Wales though only 10,708 vehicle owner's postcodes were from the same state. There is also a difference of 4,738 between the Queensland counts of rigid truck by registered state and owner's postcode, though this is relatively small considering the total number of rigid trucks.

There were a total of 1,135 postcodes and 14,286 vehicles that were unable to be allocated to a SA4[3] and so were excluded from the population counts by region. This is approximately 3% of the total vehicle population in Australia[4]. Buses and coaches are more affected by this, which should be considered in setting sample sizes.

Table 4. Number of vehicles excluded from population data.

	Rigid Truck	Articulated	B-Double	Bus/Coach	Plant	Total
Vehicles postcodes unable to be matched to SA4	8,198 (2%)	1,201 (2%)	758 (2%)	3,365 (8%)	1,006 (2%)	14,286 (3%)
Total Australian Vehicle Population	**366,182**	**57,003**	**38,492**	**44,216**	**41,638**	**547,531**

The counts of vehicles by vehicle type at SA4 regions (where count of vehicles is based on the postcode of the vehicle owner's residence which has been aggregated to SA4 level) are displayed on maps in Appendix C (Figure 4 to Figure 8). These maps

[3] SA4, or Statistical Area Level 4, is an ABS standard level of geography, against which postcodes could be mapped, using concordance data provided by the ABS.

[4] The Australian Bureau of Statistics cautions that data values have been randomly adjusted to avoid releasing confidential data which results in discrepancies when summing components – this means for example that the totals in Table 3 and Table 4 differ slightly. The discrepancies and exclusions are relatively small allowing the 2015 Motor Vehicle Census postcode of owner categories to be used as a suitable source for the derivation of vehicle population counts into broad sampling regions, noting that they are likely to be a slight undercount of the total population.

provide a visual means to understand the spread of heavy vehicles across Australia and help inform an appropriate regional level stratification. From these maps it can be observed that there are generally relatively few heavy vehicles with owner's residence in the more remote regional areas. A few exceptions include the SA4 regions:

- Outback in Western Australia - with a high proportion of registered rigid trucks, B-Double and plant vehicles;
- Wheatbelt in Western Australia - with a high proportion of rigid B-Double and articulated trucks and plant vehicles;
- Darling Downs in Queensland, and North West Victoria - with high proportions of B-Double and articulated trucks.

When considering the population of vehicles by size of the region there are considerably more vehicles based on owners' residence toward the city and metropolitan areas of each State. The counts of registered buses and coaches are particularly low in remote and regional areas with high concentrations located towards the metropolitan region. The counts provided in these maps are based on the owner's residence so there is likely to be some variation between these counts and the true population of vehicles located within a given region.

3.1.2 Survey of Motor Vehicle Use, Australia, 12 months ended 31 October 2014

The 2014 Survey of Motor Vehicle Use captured information about vehicles trips including kilometres travelled, tonne-kilometres and fuel consumption where this information was captured over a four month period between 1st November 2013 and 31st October 2014. The total survey included a sample of 16,000 motor vehicles including 63.2% freight vehicles and 9.7% buses. One of the vehicle types we are interested in obtaining population information on that was not captured in this survey include plant. The results from this survey are taken with a level of caution knowing that 42% of all responses required imputation and an overall response rate of 73% was achieved.

Although this data does not provide representative counts of all heavy vehicles, it may provide more information of the heavy vehicles likely to be captured via an intercept survey and therefore might provide some indication on vehicles that may be missed or less represented if only sampling via an intercept survey of heavy vehicles. This survey reported a number of vehicles that were not used during the 4 month period they were selected. The ABS mentions that these non-uses are due to factors such as seasonal usage, mechanical faults or economic conditions. The proportion of vehicles not used in this survey may provide some information as to the proportion of the population unlikely to have a chance of being sampled when conducting an intercept survey of vehicles travelling on the road. For the 2014 Survey of Motor Vehicle Use, there were around 8% of rigid trucks, 7% of articulated trucks and 3% of buses that were not used during the entire 4 month period (Table 5). This is a relatively low proportion so we can expect that most of the population of articulated, rigid trucks and buses will have some opportunity of being sampled via an intercept survey, but it may be judicious to include an alternate opportunity for these vehicles to be sampled via alternate means than purely an intercept survey.

Table 5. Number and proportion of registered vehicles with nil use.

	2006	2007	2010	2012	2014
Rigid trucks	36,263 (9%)	36,660 (9%)	34,647 (8%)	36,549 (8%)	38,541 (8%)
Articulated trucks	4,340 (6%)	3,680 (5%)	5,165 (6%)	6,162 (7%)	6,652 (7%)
Buses	1,343 (2%)	1,510 (2%)	2,831 (4%)	1,809 (2%)	2,006 (3%)

3.1.3 Road Freight Movement, Australia, 12 months ended 31 October 2014

Further data sources reviewed include the 2014 Road Freight Movements which combines data from 8,000 articulated and rigid trucks from the 2014 Survey of Motor Vehicle Use and a further 8,000 articulated and rigid trucks exceeding 3.5 tonnes GVM with information on vehicle travel collected for a randomly allocated week during the year ending on 31st October 2014. The survey population was identified using information obtained from the state and territory motor vehicle registration authorities as part of the 2013 ABS Motor Vehicle Census with stratification by state/territory of registration, vehicle type (articulated and rigid trucks), area of registration (capital city or rest of state), age of vehicle and vehicle size. As with the 2014 Survey of Motor Vehicle Use a level of caution needs to be taken when using this data as there is a high rate of imputed responses from unanswered questions.

Though this data does not contain complete information at SA4 level or for all seven vehicle categories of interest for the baseline survey, the data does contain some useful information. For example, one of the advantages of a survey methodology, rather than obtaining only registered vehicle information, is that further breakdowns of vehicle types can be captured. There are breakdowns by road trains which were unable to be captured in the 2015 Motor Vehicle Census. Though the classification of road trains from the ABS data does not completely align with the NHVR classification (eg. ABS classifies some rigid trucks as road trains where NHVR does not), it can still give some idea about an approximate breakdown of road trains to articulated trucks.

Table 6, which provides counts from the ABS 2014 Road Freight Movement Survey may provide some indication of the proportion of road trains likely to be captured during an intercept survey of vehicles within each State and help derive population counts of road trains separated from other articulate trucks. Approximately 15% of the distance travelled by all articulated trucks was from road trains; however, this varies considerably depending on State from 66% in the Northern Territory and 47% in Western Australia to no road trains travelling on Australian Capital Territory and Tasmanian roads. Combining this information and the knowledge that road trains are less likely to travel on metropolitan roads can help guide decisions regarding sample counts within each vehicle category and sampling region.

Table 6. Kilometres travelled by origin and destination state for rigid and articulated truck types. (Note that the definition of road train used in this ABS survey is not consistent with the NHVR definition of road trains.)

		Rigid Truck ('000 km)			Articulated Truck ('000 km)			
State		Road Train	Other	Total	B-Double	Road Train	Other	Total
NSW	Origin	0 (0%)	2853102 (100%)	**2853102**	853695.7 (39%)	86572.4 (4%)	1254943 (57%)	**2195211**
	Destination	0 (0%)	2849486 (100%)	**2849486**	857623.7 (39%)	89766.7 (4%)	1261117 (57%)	**2208507**
Vic.	Origin	0 (0%)	2064380 (100%)	**2064380**	732774.6 (43%)	5395.4 (0%)	963590.5 (57%)	**1701761**
	Destination	0 (0%)	2094180 (100%)	**2094180**	714196.7 (43%)	8613.4 (1%)	940224.3 (57%)	**1663034**
Qld.	Origin	0 (0%)	2394473 (100%)	**2394473**	707396.1 (37%)	224925.8 (12%)	971110.4 (51%)	**1903432**
	Destination	0 (0%)	2365428 (100%)	**2365428**	722084.1 (37%)	229767.8 (12%)	975817.4 (51%)	**1927669**
SA	Origin	0 (0%)	545089 (100%)	**545089**	230054.6 (34%)	131381.4 (19%)	319682.2 (47%)	**681118.2**
	Destination	0 (0%)	542482.1 (100%)	**542482.1**	221636.1 (33%)	131674.2 (20%)	317658.2 (47%)	**670968.5**
WA	Origin	36482.8 (3%)	1126285 (97%)	**1162768**	100725.6 (9%)	503545.9 (47%)	470702.6 (44%)	**1074974**
	Destination	36482.8 (3%)	1128985	**1165468**	106841.8 (10%)	498234.4 (45%)	490700.9 (45%)	**1095777**
NT	Origin	0 (0%)	94442.8 (100%)	**94442.8**	2216.6 (2%)	75983.3 (66%)	37472.7 (32%)	**115672.6**
	Destination	0 (0%)	95017.6 (100%)	**95017.6**	2216.6 (2%)	69747.6 (66%)	33590.8 (32%)	**105555**
ACT	Origin	0 (0%)	89501.5 (100%)	**89501.5**	8479.2 (30%)	0 (0%)	20166.3 (70%)	**28645.5**
	Destination	0 (0%)	91694.3 (100%)	**91694.3**	10743.4 (37%)	0 (0%)	18559 (63%)	**29302.4**
Tas.	Origin	0 (0%)	190186.3 (97%)	**190186.3**	39642.3 (33%)	0 (0%)	79046.5 (67%)	**118688.8**
	Destination	0 (0%)	190186.3 (100%)	**190186.3**	39642.3 (33%)	0 (0%)	79046.5 (67%)	**118688.8**
Aust.	**Origin**	**36482.8**	**9357459** (100%)	**9393941**	**2674985** (34%)	**1027804** (13%)	**4116714** (53%)	**7819503**
	Destination	**36482.8**	**9357459** (100%)	**9393941**	**2674985** (34%)	**1027804** (13%)	**4116714** (53%)	**7819503**

Table 7 presents rigid and articulated truck counts by year of manufacturer obtained from the ABS 2015 Motor Vehicle Census as well as the estimated total kilometres travelled for rigid and articulated trucks by year of manufacture obtained from the ABS 2014 Road Freight Movement Survey. Though care needs to be taken when comparing these two different data sources[5], the difference in proportion of older vehicles may be an indication that there is a potential to oversample the newer vehicles rather than what is representative of the population. Rigid and articulated trucks manufactured prior to 2000 account for 38% and 28% of the population of rigid and articulated trucks respectively (based on data from the 2015 Motor Vehicle Census). However, rigid and articulated trucks manufactured before 1999 only account for 15% and 7% of the total kilometres travelled respectively (based on data from the 2014 Road Freight Movement Survey) so they may be less likely to be captured if only sampling via an intercept of vehicles travelling on the road. Since older vehicles may have had more time to develop problems in terms of roadworthiness, this may under represent the estimated roadworthiness of vehicles if not taken into account. It is therefore recommended that the year of manufacture is captured in the questionnaire to be able to account for this in the analysis.

Table 7. Australian counts of registered vehicles (2015 Motor Vehicle Census) and estimated total kilometres travelled in Australia (2014 Road Freight Movement Survey) of Rigid and Articulated trucks by year of manufacture.

Year of Manufacture	Rigid Truck	Articulated Truck
Registered Vehicle Count		
1999 and earlier	178,565 (38%)	26,220 (28%)
2000 – 2009	193,670 (41%)	41,268 (43%)
2010 – 2015	100,089 (21%)	27,487 (29%)
Estimated Total '000 km Travelled		
1998 and earlier	1,408,829.9 (15%)	571,906.0 (7%)
1999 to 2008	5,021,437.2 (53%)	3,450,677.8 (44%)
2009 and after	2,963,674.2 (32%)	3,796,918.9 (49%)

Rigid and articulated trucks tend to remain within a single state as indicated in Table 8. The greatest movement between states occurs between New South Wales and Victoria though this only accounts for 3% of kilometres travelled. A high proportion of vehicle trips remaining within a single state indicates there is no major risk of capturing the same vehicles in different states and shouldn't discourage treating each state as separate independent populations/strata.

[5] Due to the different survey methodologies and potential differences in the classifications of vehicle types.

Table 8. Total '000 kilometres travelled and corresponding percentage of articulated and rigid truck trips by origin and destination state.

	Destination								
	NSW	Vic	Qld	SA	WA	NT	ACT	Tas	**Total**
Origin									
NSW	4,035,418	484,517	395,985	66,594	11,953	2,299	51,547	0	5,048,313
Vic	479,720	2,974,370	116,193	168,114	17,396	0	10,348	0	3,766,140
Qld	391,421	119,174	3,729,372	25,498	18,112	14,119	211	0	4,297,905
SA	85,237	159,361	27,104	887,487	38,266	28,753	0	0	1,226,207
WA	6,537	10,211	13,167	33,084	2,170,344	4,400	0	0	2,237,742
NT	10,198	0	11,067	32,674	5,174	151,002	0	0	210,115
ACT	49,463	9,582	211	0	0	0	58,891	0	118,147
Tas	0	0	0	0	0	0	0	308,875	308,875
Aust	**5,057,993**	**3,757,214**	**4,293,097**	**1,213,451**	**2,261,245**	**200,573**	**120,997**	**308,875**	**17,213,444**
Origin									
NSW	23%	3%	2%	0%	0%	0%	0%	0%	29%
Vic	3%	17%	1%	1%	0%	0%	0%	0%	22%
Qld	2%	1%	22%	0%	0%	0%	0%	0%	25%
SA	0%	1%	0%	5%	0%	0%	0%	0%	7%
WA	0%	0%	0%	0%	13%	0%	0%	0%	13%
NT	0%	0%	0%	0%	0%	1%	0%	0%	1%
ACT	0%	0%	0%	0%	0%	0%	0%	0%	1%
Tas	0%	0%	0%	0%	0%	0%	0%	2%	2%
Aust	**29%**	**22%**	**25%**	**7%**	**13%**	**1%**	**1%**	**2%**	**100%**

Maps illustrating the articulated and rigid truck total kilometres travelled by the origin and destination at SA4 region level are provided in Appendix C (Figure 9 and Figure 10). Comparing these maps to the rigid, articulated and B-Double maps of vehicle counts (from the ABS 2015 Motor Vehicle Census) show similarities with the greater distances travelled in regions with higher vehicle counts. This provides validation in using an intercept survey methodology to sample vehicles based on the 2015 Census of Motor Vehicle population counts.

3.1.4 Conclusions from Review of ABS Survey Data Sources

After reviewing the 2015 Motor Vehicle Census, 2014 Survey of Motor Vehicle Use and 2014 Road Freight Movement Survey, the 2015 Motor Vehicle Census was identified as being the best source of population data to use to determine sample sizes for the National Roadworthiness Baseline Survey. This is primarily due to the survey being a Census of all Heavy Vehicles (rather than a survey based on only a subset of the population), with a focus on vehicle counts rather than vehicle usage. Both of these properties are well aligned with the requirements for the National Roadworthiness Baseline Survey, although it is noted that the definitions of road trains requires further consideration in the sampling design.

3.2 Defining Sampling Regions

The 2015 Motor Vehicle Census' data was used to understand the distribution of heavy vehicles types across Australia and select appropriate regions for sampling. Particular considerations that need to be taken into account when deciding sampling regions to stratify the population include:

- The ability to define the population (or, at least, reasonable estimates of the population) of heavy vehicle types within the sampling level.
- Consistency in vehicle types throughout the region. If it is known that there is a substantially different composition of vehicle types between regions, this can suggest that the regions should be in different strata (noting that this is only one consideration in determining strata for sampling.)
- Too small a definition of regions can risk obtaining an unnecessarily large sample size or having a less accurate population of vehicles within a given area (noting that the population counts able to be obtained at regions smaller than state level are vehicles owners' postcode). Additionally, vehicles are more likely to move across smaller regions making smaller regions less independent.
- Regions should be able to provide a meaningful representation for reporting purposes. It may be desired to be able to report results at particular regional levels. However, just because sampling is not *stratified* at a particular geographic level (or other variable) this does not preclude *analysis* of the results at that level.

3.3 Final Population Counts

As discussed in Section 3.1.4, the ABS' 2015 Motor Vehicle Census is considered the best source of data to use in deriving population counts for the National Roadworthiness Baseline Survey. The resultant population counts used to derive the sample sizes are presented in Table 9. These population counts are derived using vehicles owner's postcode to aggregate counts to each regional level.

Table 9. Sampling Frame with population counts derived from the ABS 2015 Motor Vehicle Census by sampling region and heavy vehicle type.

Sampling Region	Rigid Truck	Articulated	B-Double	Bus/Coach	Plant
NSW – Metropolitan	47,259	5,572	2,276	6,044	1,691
NSW - Non-Metropolitan	42,153	7,451	4,649	4,310	2,589
Vic – Metropolitan	49,298	7,197	3,708	5,177	3,947
Vic - Non-Metropolitan	37,436	9,580	4,314	3,495	5,132
Qld – Metropolitan	35,949	5,482	3,691	5,752	1,693
Qld - Non-Metropolitan	44,522	6,134	6,420	3,387	1,526
SA – Metropolitan	13,940	1,656	1,529	2,280	3,350
SA - Non-Metropolitan	11,392	3,250	2,239	897	3,341
WA – Metropolitan	32,540	4,159	3,849	4,552	7,432
WA - Non-Metropolitan	27,024	3,567	3,729	1,665	8,594
NT – Darwin	3,117	198	583	479	699
NT - NT_Other	1,820	110	332	391	441
ACT	1,941	135	32	587	229
Tas - TAS_MajorCities	7,131	727	140	1,373	129
Tas - TAS_Other	2,194	535	217	447	49

4. Potential Sampling Methodologies

A number of potential methodologies were considered in the design of the baseline survey. Two primary options were identified – roadside 'intercept' inspections and list based 'present for inspection' inspections. Of crucial importance in choosing an implementation methodology is that not all vehicles have to be subject to the same methodology – with appropriate sampling considerations, different vehicles can be targeted in the most appropriate way for them. Often, the choice of sampling method is not based on an ideal, but on the option that provides the least in the way of limitations and disadvantages.

4.1 Roadside Intercept Inspections

Roadside intercept surveys consist of inspectors being located at numerous inspection points across the country, sampling vehicles during their travels, and inspections taking place at the time of sampling.

Key points relevant to a roadside intercept inspection methodology are provided in Table 10.

Table 10. Key points relevant to a roadside intercept inspection methodology.

Roadside Intercept Inspection Methodology	
Issue:	The sample selected will be more representative of the vehicles travelling in the area than vehicles registered in the area.
Advantage or Disadvantage:	Either, depending on the particular analysis. If analysis is focussed on vehicles travelling on the roads in a region it is an advantage due to the increased representativeness, but if analysis is focussed on a vehicle's place of registration, it is a disadvantage due to the reduced representativeness.
Mitigation:	Weighting can overcome the issues.
Importance	High, although with weighting, the analytical impact is low.
Issue:	A sampling frame – a list of all eligible units to participate in the survey, including up to date contact details and other information necessary for meeting the sampling plan (such as location) – does not need to be developed or known in advance.
Advantage or Disadvantage:	This is a key advantage when an explicit sampling frame is not available or sampling from an explicit frame is not feasible in a practical sense.
Mitigation:	NA
Importance	High
Issue:	The sample selected may be biased towards vehicles who travel more km. The sampling frame essentially becomes *vehicle trips* (or even *vehicle kilometres travelled)* rather than vehicles. Even if strategies are put in place to ensure that no vehicle is sampled multiple times, vehicles travelling more (particularly those travelling past inspection points more) will have a higher probability of being sampled.
Advantage or Disadvantage:	Either, depending on the particular analysis and focus, but likely to be more of a disadvantage for this survey. It is an advantage if the analysis is focussed on vehicles travelling on the roads, but is a disadvantage if analysis is focussed on the entire fleet, irrespective of whether the vehicles travel more or less km in a year.
Mitigation:	Bias can be mitigated during the analysis stages, by collecting information about the number of km travelled over the previous (say) twelve months
Importance	Medium
Issue:	There is no chance of selecting vehicles who do not travel in the inspection period, for reasons including, but not limited to factors such as seasonal usage, mechanical faults or economic conditions. Of these, seasonal usage is of most concern since it could lead to a systematic bias.
Advantage or Disadvantage:	Disadvantage as a subset of the population is excluded from the survey which could introduce a bias.
Mitigation:	This cannot be completely eliminated via a roadside survey alone, although it might be minimised through appropriate timing of the inspection periods.
Importance	Medium.

Roadside Intercept Inspection Methodology	
Issue:	While the sample sizes will be based on a stratified design, in practice the actual sample sizes will be selected on a quota design. In practice there is very little difference and in many respects they are equivalent[6].
Advantage or Disadvantage:	Disadvantage due to the difference between the basis used for sampling and the implementation, which could also lead to some sample sizes (or quotas) being difficult to obtain.
Mitigation:	Weighting can correct for any discrepancies.
Importance	Low.
Issue:	Sample sizes would be based on place of vehicle registration, but the sampling itself is based on place of sampling.
Advantage or Disadvantage:	Disadvantage as this could introduce biases or make some quotas difficult to achieve if there is marked discrepancy between place of registration and typical places of travel.
Mitigation:	Selecting geographic regions for sampling at a broad enough level to minimise differences. Weighting can also overcome remaining discrepancies. For future years' surveys, adjustments for marked discrepancies can be made by analysing baseline results.
Importance	Medium
Issue:	For multi-unit vehicles (such as prime movers with trailers), only the prime mover would be sampled, rather than the attachments. This means that attachments to the prime movers cannot be sampled as individual units per se, and may be inspected multiple times.
Advantage or Disadvantage:	Slight disadvantage as vehicle types that are attachments to other vehicle types rather than being driven in their own right may be sampled multiple times or may not have the opportunity to be sampled at all.
Mitigation:	Trailers are included in the survey as they are sampled when attached to prime movers. Weighting and analysis can correct for discrepancies.
Importance	Low.
Issue:	The same vehicle may be sampled more than once due to the nature of the random selection.
Advantage or Disadvantage:	Disadvantage as ideally each vehicle should only be sampled at most once.
Mitigation:	With the exception of attachments to multi-unit vehicles this can be prevented by vehicles being given a 'proof of inspection card' (or equivalent) or inspectors being able to access a database of vehicles already inspected and being instructed to check against this list after sampling and stopping a vehicle, but prior to undertaking the inspection.
Importance	Low, due to ease of mitigation.

[6] Stratified sampling is one form of quota sampling, however quota sampling usually refers to a slightly looser process where exact counts may not be able to be achieved. They are often applied in cases where it is not possible to sample the population units in advance, but are sampled via a sampling process that accesses the entire population. In this case, this means having sampling rules for inspectors to sample heavy vehicles on their travels and be inspected at that time.

Roadside Intercept Inspection Methodology	
Issue:	Drivers, operators and owners do not know in advance that their vehicle will be inspected.
Advantage or Disadvantage:	Advantage as this element of surprise aids in presenting an unbiased assessment of the vehicle's roadworthiness.
Mitigation:	Not applicable, except care still needs to be taken to minimise opportunities for drivers becoming aware of inspection points 'waiting out' or deviating their route to avoid selection.
Importance	High
Issue:	It is difficult or even impossible to sample some vehicles (either individual vehicles or particular vehicle types). These vehicles include those which travel rarely, those which travel rarely through inspection points or those who can't feasibly be sampled in situ (such as emergency service vehicles who could be on their way to an emergency, or buses or coaches for which passenger disruptions would be too great).
Advantage or Disadvantage:	Disadvantage as some vehicles may not have the opportunity to be sampled, introducing potential biases to the results.
Mitigation:	Unlikely to be feasible to devise roadside implementation strategies in isolation for these situations.
Importance	High
Issue:	It may also be difficult to meet quotas for vehicle types that, in all other respects, are suitable for roadside interviewing, but are less prevalent.
Advantage or Disadvantage:	Disadvantage as overall precision rates may be lowered and extensive effort may need to be incurred in attempting to fill quotas.
Mitigation:	Sampling strategies can be developed to overcome this issue, with rules such as *If any of the next 5 vehicles are of Category X (where X is defined to be a category whose quota is difficult to achieve), sample that vehicle,. If none of the vehicles are of Category X, sample the 5th vehicle irrespective of its type.* (In this context, the choice of the number '5' would need to be developed based on data related to the relatively frequency of passing vehicles and may not be able to be determined at the commencement of sampling).
Importance	Medium
Issue:	Inspectors need to choose vehicles randomly at the time of sampling, with no conscious or sub-conscious bias towards vehicles that they think or can see may be more or less likely to have defects.
Advantage or Disadvantage:	Disadvantage as it is intrinsically difficult for humans to select items totally 'at random'.
Mitigation:	Sampling rules can be put in place to minimise the risk of selectively choosing vehicles (such as, randomly choose one vehicle, don't inspect that vehicle, but inspect the next vehicle instead).
Importance	High, but with appropriate sampling protocols and inspector training, the impact should be reduced to 'low'.

Roadside Intercept Inspection Methodology	
Issue:	Not all feasible sampling locations (inspection points) would be representative of all types of heavy vehicles.
Advantage or Disadvantage:	Disadvantage as it may make it difficult to fill quotas and ensure a good geographic spread of vehicle types.
Mitigation:	Sampling at the widest possible range of inspection stations, including some inspections taking place in remote areas, at various times of day, week and year. Freight data (if available) may be able to be used to aid with the choice of sampling locations to assist with achieving various sample sizes.
Importance	Medium as the overall sample make up should be representative.

4.1.1 Implementation

Implementation methodologies with bias mitigation strategies include:

- Sampling at a range of locations within the region at a range of times (across the day and across the year). This has dual benefits of maximising the representative nature of vehicles captured (if different vehicle types are more or less likely to be travelling at different locations along a region) and maintaining the element of surprise (minimising the risk of drivers becoming aware of an inspection point and choosing an alternate route).
- Conducting sampling and inspections at existing inspection points and setting up mobile inspection points where feasible and in regions which would otherwise be exempt from roadside inspections due to lack of existing permanent sites.
- Implementing roadside strategies to minimise vehicles being able to bypass or 'wait out' the inspection period.
- Collecting information regarding the amount of travel the vehicle undertakes and other information on vehicle usage that may inform subsequent weighting and analysis.
- Conducting a complementary survey of vehicles via a list based 'present for inspection' survey. This sample could be comparatively small but could identify potential biases enabling them to be adjusted and accounted for in the analysis.

4.2 Present-for-Inspection/Depot Inspections

Present-for-inspection surveys consist of operators being contacted in advance and requested to bring their vehicles to an inspection site at an arranged time. The vehicles are selected by sampling from a comprehensive list of all in-scope vehicles.

From a purely theoretical viewpoint of statistical sampling, sampling from a list is *often* the preferred option as it allows tight control over the sampling, which in turn can assist with the calculation of sampling weights to feed into the analysis. However, it is *not always* the preferred option, with other factors needing to be taken into consideration – often a sampling frame cannot be 'perfect' and the limitations need to be considered in the analysis and interpretation of the results.

- The sample selection can only be as good as the sampling frame (including how up to date it is), the size of sample may be restricted due to additional implementation costs and other forms of non-sampling bias may be introduced (such as the advance notice of inspections allowing for maintenance to be conducted).
- Newly registered vehicles may be missed from the sampling frame and recently de-registered vehicles will be included. Changes of vehicle ownership may also not be reflected in the sampling frame. These issues can be mitigated (although not eliminated) by conducting the sampling and inspections with minimal time delay compared to the date of the registration details data extract – it must be accepted that this may not be too short a period of time, with different jurisdictions being involved in data provision and the time taken to process the data and draw the sample, make contact with the owner and conduct the inspection.
- Registered locations may not be the same as the 'usual' location of the vehicle.
- Vehicle type classifications in the sampling frame may not exactly match the classifications desired for the survey.
- For some analysis and reporting purposes, having the sample more representative of the number of km travelled may be preferable – this cannot be achieved in this methodology.

Key points relevant to a present-for-inspection methodology are provided in Table 11.

Table 11. Key points relevant to a roadside intercept inspection methodology.

Present-for-inspection Methodology	
Issue:	Sampling is undertaken from a comprehensive list of in-scope vehicles. The list should be complete, up to date, accurate and include contact details as well as relevant vehicle details for each vehicle. The list (or the sampling frame) will need to be compiled and will likely be generated via an amalgamation of each state's vehicle registration records.
Advantage or Disadvantage:	Advantage, but the quality of the sampling frame will only be as up-to-date and current as the data that feeds into it. The disadvantage is the need to generate the sampling frame and the knowledge that it will not be 100% perfect, including that the current location of any vehicle will not be known and may not be similar to the registered location.
Mitigation:	Not applicable, although obtaining the most up to date and comprehensive list possible will aid with improved quality.
Importance	High.

Present-for-inspection Methodology	
Issue:	Owners of the sampled vehicles will be contacted to set up an inspection time at an inspection location. This creates logistical issues for both parties that need to be considered for implementation. These logistical issues could be extensive including administrative time in setting up and monitoring inspection appointments and interfering with operator operations and scheduling. Conversely, in some circumstances, conducting an inspection by appointment could be less disruptive to operations. In particular, disruptions to passenger vehicles (such as buses and coaches) and emergency service vehicles may not be suitable for road side inspection.
Advantage or Disadvantage:	The logistical issues are primarily a disadvantage, but for some circumstances (such as passenger vehicles) the advantages of minimal disruption to passengers outweigh the disadvantages.
Mitigation:	-
Importance	High
Issue:	The sample selected will be more representative of the vehicles registered in the area rather than travelling in the area.
Advantage or Disadvantage:	Either, depending on the particular analysis. . If analysis is focussed on a vehicle's place of registration it is an advantage due to the increased representativeness, but if analysis is focussed on vehicles travelling in a region, it is a disadvantage due to the reduced representativeness
Mitigation:	Weighting can overcome the issues.
Importance	High, although with weighting, the analytical impact is low.
Issue:	The sample will include registered vehicles that do not typically get driven.
Advantage or Disadvantage:	Overall, this is likely to be an advantage in terms of the sample representativeness, but there could be other reasons for a vehicle not being driven such as the owner knowing it is unroadworthy (having major or minor defects) and it being under maintenance or self-imposed layoff until the defects are fixed.
Mitigation:	-
Importance	High.
Issue:	Vehicle owners and operators knowing in advance that their vehicles are to be inspected provides the opportunity for the vehicles to have maintenance undertaken on them prior to the inspection, possibly leading to biased inspection results. The extent of this bias cannot be estimated, but the level of defects found in this situation would presumably form a *lower limit* on the estimate of the true level of defects.
Advantage or Disadvantage:	Major disadvantage as it provides opportunities for vehicles to have maintenance undertaken on them prior to the inspection, possibly leading to biased inspection results.
Mitigation:	Minimise the time between contact being made with the owner and the inspection taking place.
Importance	High.

Present-for-inspection Methodology	
Issue:	Sampling from a list can be very targeted – each vehicle on the frame can be assigned to its specific stratum (for example, region by vehicle type) and the number of vehicles required to be inspected from each stratum can be completely randomly sampled from the list. Stratification variables could include other data such as age of vehicle (or year of manufacture) or any other information routinely collected on vehicle registers (although other sampling considerations may preclude this level of detail from being the preferred stratification).
Advantage or Disadvantage:	Advantage as the sampling can be made to very representative of the population, although it must be remembered that there will be discrepancies between a vehicle's listed place of registration and its current location.
Mitigation:	-
Importance	Medium to high.
Issue:	Except in situations where most registered addresses coincide with actual vehicle locations, sampling from a list can result in an extremely geographically disparate sample to be drawn, leading to higher than necessary cost of implementation.
Advantage or Disadvantage:	Disadvantage due to potentially unnecessarily high costs of implementation.
Mitigation:	Additional statistically valid sampling protocols could be put in place to alleviate such issues, but this would require analysis of the detailed sample frame itself.
Importance	Medium to high.
Issue:	Trailers can only be tested if attached to another vehicle. Consideration would need to be given to sampling trailers and prime movers together, creating additional logistic and sampling issues as well as losing representativeness of how the operators may actually couple the vehicles in practice.
Advantage or Disadvantage:	Disadvantage due to logistical and sampling issues.
Mitigation:	Could consider methods of sampling prime movers and trailers simultaneously, but would create many logistical issues for operators.
Importance	High for assessing trailers.

Present-for-inspection Methodology	
Issue:	It may be possible to exploit certain information available in the sample frame to obtain a more statistically efficient sample. For example, if there are correlations between the roadworthiness of vehicles within a single fleet or within a single manufacturer, there is the potential to undertake sophisticated sampling (such as cluster sampling) to target the sample appropriately to improve the precision of the overall estimates of defects. While introducing statistical efficiencies, it also introduces complexities that must be taken into account in the analysis stages to mitigate against biases that this can introduce without careful weighting of the survey results.
Advantage or Disadvantage:	Advantage, although unless there is prior knowledge regarding the relative performance of fleets in terms of roadworthiness, it is unlikely that significant advantages could be generated, particularly in the baseline survey. Also, such targeting could be seen as being non-random or representative (despite this being untrue from a statistical perspective, *provided that the appropriate weighting has been undertaken)*, leading to claims that the survey results are not valid and users losing confidence in the survey results and findings – this is a disadvantage, albeit not a statistical disadvantage.
Mitigation:	User education, including clear and concise reporting could help convince users that exploiting such sampling methods appropriately is not inappropriate or bias generating.
Importance	Low to medium for the baseline survey, may be more potential for advantages in latter surveys.
Issue:	Many commercial vehicles, particularly those in large fleets, may be fitted with GPS tracking devices. If the information from such devices could be accessed, it might be possible to develop a list based sampling procedure that can also use knowledge of where the vehicle is. This is not considered feasible for the current report, but may be something worth considering for future surveys.
Advantage or Disadvantage:	Potential advantage but many implementation issues would still need to be worked out, including how to complement this survey with a survey of vehicles not fitted out in this manner. Obtaining the information may also be problematic even if it is technically available.
Mitigation:	-
Importance	Low

4.2.1 Implementation

Implementation methodologies with bias mitigation strategies include:

- The registration databases for each jurisdiction form the obvious basis for a list based sampling procedure. In general, the accounting and revenue applications of these databases means that they are likely to be quite accurate in terms of vehicle type and owner.
- Stratification according to ownership, vehicle type or manufacturer, information normally in such databases, would be both straightforward and efficient. However for commercial vehicles the place where they are normally kept will not be known, and where they are operating during a particular sampling period

would be less known again. Sampling based on place of registration is likely to be the best geographical stratification possible.

- There is the *potential*, once more detailed vehicle ownership information is known following inspection of registration lists, that the sampling could involve more sophisticated techniques to minimise the total number of vehicles inspected for any single owner, allowing for great representation of owners to be included in the overall sample.
- Once sampled, owners will be sent letters requesting them to book in an inspection.
- Inspections should be set up to take place as soon as practical, to minimise the time available for maintenance to be undertaken.

5. Proposed Sampling Methodology

Data Analysis Australia proposes a three component sampling methodology for this survey, with the implementation details discussed in this section and the corresponding sample sizes discussed in Section 6. This recommendation has considered the points and issues discussed in the earlier sections balancing competing priorities, pros and cons. All maintain statistical integrity and attempt to leverage off the relative advantages of each methodology where it is appropriate to apply it. The three recommended components are:

4. A large scale roadside intercept survey for rigid trucks, articulated vehicles and B-Doubles (including road trains).
5. A present-for-inspection survey for buses, coaches and plant heavy vehicles.
6. A complementary present-for-inspection survey for vehicles in-scope of the roadside intercept scheme.

All survey components are based on a stratified sampling plan, with geographic region and vehicle class forming the basis of each stratum classification. When undertaking the sampling and inspections, it is important to collect and maintain all appropriate information that may be used in the weighting and analysis. For all survey components, weighting of the survey results is required to maintain an unbiased and representative set of findings (see Section 2.2.3).

5.1 Large Scale Roadside Intercept Surveys for Rigid Trucks, Articulated Trucks and B-Doubles (including Road Trains)

Roadside intercept surveys are deemed the most appropriate for these classes of vehicle for a number of reasons, including the logistics and extent of disruptive impact on both vehicle owners/operators and inspectors, being able to take advantage of the immediate nature of the inspection (hence not allowing any opportunity for maintenance) and providing a potentially useful weighting towards vehicles that are more heavily used.

Although sample counts have been determined based on place of vehicle owners postcode and the sampling is taking place on the road (and hence where the vehicle is currently travelling), all in-scope vehicles passing the inspection point must be sampled (for example, even if the inspection is taking place in Western Australia, vehicles registered in any state or territory can be sampled). This doesn't mean that all vehicles will be *randomly selected*, but they must all have the *chance* of being randomly selected. Failure to do so could result in biases.

Without further information, it can only be assumed that there is a reasonable correlation between vehicles being registered within a state and travelling within that same state (for at least part of their trip) and hence it is assumed to form a good basis for sampling. In this regard, for implementation purposes, the sampling itself will be based on counts of vehicle type by *sampling location*, rather than the vehicle type by *registration location.* For analysis and weighting, the resultant counts by *registration location* should be used. Recommending sample sizes that are on the conservative side (that is, targeting higher precision than may be minimally acceptable) is a mitigation strategy against the limitations of this methodological approach.

To obtain a representative sample whose results can be generalised to the population that the sample selection is undertaken *randomly*, without propensity for inspectors to select vehicles (either consciously or sub-consciously) based on their perceived likelihood of them being roadworthy or not. For example, if a vehicle is visually seen to be defective and hence pulled over for inspection when it otherwise would not be, this would introduce a bias. A recommended method of enforcing this random selection is to provide instructions to inspectors as follows: "Select a particular in-scope vehicle as it approaches the inspection point. This vehicle is *not* to be sampled. Instead, the *next* in scope vehicle passing the inspection point is to be selected for inspection. If this vehicle is determined to be out of scope, has already been inspected under the sampling exercise or if the quota for that vehicle type has already been filled, sample he next vehicle for inspection instead."

If there are issues with difficult to fill sample sizes, refinements to this can be put in place, such as those discussed in Section 5.1.1.

When determining the sample sizes, it has been assumed that within a vehicle type and within a region, the selection of vehicles to be selected is reasonably random. It is difficult to achieve sampling perfection in a survey of this type, however, we strongly recommend steps be taken to maximise the randomness and representativeness of the sampling. These steps include:

- Sampling each vehicle type at a **range of locations** in a region.
- It should be noted that the best effort should be made to include as many different inspection points as feasible – **a minimum of at least one from every stratification region and other region as best as possible**. It is expected that different vehicle types may be more or less likely to be found in different regions, so an appropriate spread must be obtained **including rural and remote areas**;
- Minimising time spent at sampling locations that have, for example, a strong **bias** towards or away from a particular transport operator;

- Sampling over a **number of weeks, days of the week and times of day**. We understand that there may be some concern that interstate vehicles may be more prevalent on the roads at night – if so, it may be necessary to use time of day vehicle count data to guide the sampling quotas for time of day;
- Attempting to achieve **surprise** for at least a component of the sampling and not sampling too many vehicles before moving to another location – the aim must be that there is no strategy by which a vehicle can eliminate the possibility of being sampled;
- Inspectors doing their best to **minimise opportunities for drivers to stop and 'wait out' or divert their route from the inspection points**, for example, turning the inspection zones 'on and off' at regular intervals (a strategy that we understand is currently employed); and
- **Training staff** to use processes that will reduce their subconscious subjectivity when sampling. For example a rule of the form "randomly select a vehicle and then sample the one that follows it" can provide a discipline to avoid some subjectivity.

It is recommended that vehicle types flagged for inclusion in the second survey component (Present-for-inspection for buses, coaches and plant heavy vehicles) are *not* sampled if they happen to pass by an inspection point. This is to maintain as much consistency with the documented sampling plan as possible as per best practice, but in this case, if there is good reason to sample such vehicles, this would not adversely affect the survey results.

No vehicle should be sampled twice under this regime. After selecting a vehicle, but prior to inspecting it, the inspector should refer to a live database (if possible) to determine whether that vehicle has already been inspected as part of the baseline survey. Should this not be feasible, all inspected vehicles should be given a 'proof of inspection' card which can be shown to inspectors as evidence.

5.1.1 'Difficult to Fill' Stratum Sample Sizes

It is recognised that some stratum's sample sizes may be difficult or even impossible to fill due simply to the nature of the vehicles passing the inspection points not being constrained in any way to match the makeup of the population frame. Some vehicle types are also less prevalent than others and as a consequence will simply be more difficult to capture based on pure random selection. It is often necessary to 'target' the difficult to fill strata from early on in the sampling process rather than waiting until all other sample sizes have been achieved and then waiting for only the remaining vehicle types to pass the inspection point.

If likely difficult to fill stratum sample sizes are identified in advance or in the early stages of sampling, an approach such as the following would provide suitable statistical integrity, although the details would need to be resolved:

- Count the next x (say, 5 as an example) vehicles passing. If any of them are in the 'difficult to fill stratum', sample them, otherwise sample the x^{th} (in the example case, the 5^{th}) vehicle, irrespective of its type.

5.1.2 Additional Considerations for Trailers

Trailers can only be inspected as part of an assembly (that is, when attached to prime mover). As such, trailers are to be sampled and inspected via this roadside intercept survey component, but there are no specific sample size requirements and trailers are not to be individually sampled as such. Instead, any trailer attached to a sampled and inspected prime mover will be inspected and its details recorded. In this regard, trailers may be sampled more than once where they are attached to different prime movers. This multiple sampling does have an effect on statistical efficiency but this is small and cannot be avoided.

5.1.3 Additional Considerations for Road Trains

Road trains are in scope of the survey and must be inspected. The population data available in setting the sample sizes in this report provided road train counts as part of B-Double, and thus did not enable specific sample sizes to be set for road trains, although the determination of sample sizes for B-Double included consideration of this need. In considering this, it was decided that the sample size for the B-Double class would be split into separate B-Double and road train samples and relevant decisions on sample sizes were made on the side of conservatism (that is, selecting sufficient sample sizes to ensure adequate coverage for both road trains and B-Doubles). In taking this approach, there will be a need to consider appropriate application of weighting methodologies to account for the apportioning of single vehicle class sample into two sets sample sizes.

Although sufficient sample sizes for each of the road train and B-Double classes have been ensured to enable appropriate analysis, the individual survey precisions for B-Doubles and road trains will inevitably be reduced. Having considered the above caveats and associated trade-off in the statistical efficiency and optimality, this approach has been considered the most appropriate by the NHVR.

5.2 Present-For-Inspection Survey for Buses, Coaches and Plant Heavy Vehicles

For all vehicles being sampled using the present-for-inspection methodology, it is statistically ideal (and hence recommended) to randomly sample the required sample sizes from the list. It is recommended that inspections be booked in as soon as feasibly possible to minimise opportunities for owners to undertake maintenance in preparation for the inspection, however it will not be possible to prevent this completely. The sample sizes should be sampled based on place of registration. As there is legislation requiring requested inspections to take place, non response should not be a major concern for this survey. However, there may be some sampled vehicles that cannot be inspected due to changes of ownership or registration status in the intervening time, or other owners who simply cannot be contacted and appointments made within the inspection timeframe.

As such, it is recommended that a slight oversampling of vehicles be selected to allow for this ‘drop out’[7] and ensure that the prescribed sample sizes can be achieved. The extent of oversampling will be determined by expected rates of ‘drop out’ and should be applied as a percentage increase to the sample. Ideally the rate of oversampling would be estimated based on experience. In the absence of this experience, an oversampling rate of 5% may be appropriate – this is lower than usual rates put in place to account for non-response due to the mandatory nature of the inspections, but it must be acknowledged that this is a judgement estimate. It is important to ensure that *all* sampled units are followed up as much as possible to maximise the chance of the inspection taking place, as taking the naïve approach of stopping inspections once the initial sample size has been achieved may introduce biases (if the easy to inspect vehicles have different propensities to be roadworthy and/or have defects).

A recommended approach for randomly sampling from a list is as follows:

- Assign every vehicle in the list to its appropriate stratum.
- Randomly order the vehicles within each stratum (for example, using the =RAND() function in Excel, assign a random number to each vehicle, save the random number using the ‘Paste Special as values’ option and then sort vehicles within each stratum in ascending order of random number).
- Sample the top *n* vehicles in the randomly sorted list, where *n* is the required sample size for that stratum, *including the top up sample to allow for drop out*.

There may be limitations to the naïve random sampling approach, including generating an impractically geographic sample or sampling some vehicles for which it is practically infeasible to request them to present at an operating inspection facility. More subtly, there may be limits placed on how many, or what proportion of vehicles a single owner or operator can be asked to present for inspection before it is considered too burdensome.

In the first and last case, it is possible to undertake a form of cluster sampling, either first selecting geographical clusters for sampling and then selecting individual vehicles, or first selecting owners for sampling and then selecting individual vehicles. Care would need to be taken in developing the precise details of these methodologies to ensure that biases aren’t introduced, *unless they are biases that can be corrected for in the weighting and analysis.* In the second case (where it is practically infeasible to request presentation at a facility) such vehicles must be flagged as having no chance for being included in the survey – this will introduce a bias that cannot be corrected for weighting, but will ideally be of a small amount (if the impact was large, it would probably relate to feasibility of being able to create a suitable inspection opportunity).

[7] Note that there is no need to build in a corresponding oversampling to roadside intercept surveys, as by their very design, they continue until sample sizes have been met.

5.2.1 Additional Considerations for Buses and Coaches

Due to the impact and inconvenience for passengers in conducting a roadside intercept inspection, these classes of vehicle should be inspected using the present-for-inspection method.

As buses and coaches are considered as two separate vehicle classes and there is interest in separately analysing and interpreting the results for each class, ideally the two classes could be sampled as separate strata, with individual sample sizes calculated. With the data available for the current sampling design, this is not possible, due to the population data combining these two classes. Refinement may be able to be undertaken once the detailed registration lists are available for sampling. This could be achieved if the registration data classifies these vehicles into classes (the ideal scenario) or if it is possible to classify at least some of the vehicles based on desktop research (for example, the vehicle types may be known or can be determined for certain owners based on their business). If this is the case, it is likely that each vehicle will be classified as bus, coach or unknown. It will be important to sample from all *three* categories (including the unknown category) to avoid introducing biases.

5.3 Complementary Present-for-Inspection Survey for Vehicles In-Scope of Roadside Intercept Scheme

One of the major disadvantages of the roadside intercept scheme is that some in-scope vehicles will not have a chance of being sampled due to not travelling on the roads at all, rarely, not during the inspection periods (for example vehicles used for seasonal work only) or travelling, but not travelling via networks that may reasonably be considered to include inspection points (for example, travelling only short distances between neighbouring properties). To mitigate against this, a complementary present-for-inspection survey should be undertaken. From an analytical perspective it also enables validation of the results from the main survey (as it is undertaking what is essentially the same survey but using a very different implementation approach, and hence can highlight any sensitivities or differences, at a high level).

The compatibility of the results will always be questioned because of the notice being given before inspection and consequently the roadside component must be large enough to stand alone. This dictates a smaller sample size for the third component, but one large enough to enable comparative analysis and provide meaningful results in its own right. Data Analysis Australia recommends a minimum sample size of 400 nationally (to complement the roadside component of many thousands), being the smallest sized sample that would indicate whether nationally across classes there is any systematic issue between the populations covered in the intercept survey compared to the present-for-inspection survey. This sample size is not sufficient to enable stratum level comparisons, but that level of detail is not an intended outcome of this recommended survey component.

The sample size of 400 should be allocated to the individual strata to match the same proportions as in the roadside survey component. That is, if a particular stratum had

4% of the total roadside sample size, it should also have 4% of the complementary present-for-inspection sample size.

There will be some limits on just how this survey component can be used. While it is a fill-in for the less travelled (or infrequently used) vehicles, it could also be used to explore a specific vehicle type to some extent. For example, if there is a vehicle type that is known to be missing from the roadside intercept surveys (such as seasonal vehicles) additional sample *or* a portion of the existing sample can be targeted to those vehicle types. The details of these latter options would need to considered on a bespoke basis, but in essence, if there is a particular type of vehicle for which there is particular interest (eg seasonal usage vehicles which may be known to be undersampled in the roadside survey) *and if* these types of vehicles were identifiable in the sampling frame, these could be targeted in choosing the random samples.

This methodology could also be applied to meet any quotas that were not met in the roadside component, but this should be seen as a last resort. In this case, the 'make-up sample' for the quotas are additional to the 400.

This survey should be undertaken in the same way as the present-for-inspection survey for buses, coaches and plant heavy vehicles with the sample being drawn in the same way, but restricted to a different set of vehicle classifications.

Vehicles should not be sampled twice in the two survey components – it is unlikely that this will occur for too many vehicles by random chance, but if a vehicle is sampled twice, only its first inspection should take place.

Not only is this survey important for maintaining and achieving a fully representative sample of vehicles, maximising the chance of a vehicle being given a chance of selection, it may also provide insights into the differences of those vehicles who travel more or less frequently, or those who have had advance notification of the inspection compared to those who have not. To make full use of this survey, complementary information such as kilometres travelled by the vehicle, locations of travel etc should be collected for all survey components, to the extent feasible.

6. Proposed Sample Sizes

In considering the determination of sample size it is necessary to trade off between the ideal – that would almost certainly dictate a sample size well in excess of what is achievable – and the practical, both in terms of cost and the burden placed upon road users. In this survey (as with almost all others) a combination of statistical principles with informed judgment must be applied.

The sample sizes need to balance achieving good performance when considering vehicle types and good performance when considering regions. It is also necessary to recognise that when considering just one category – say rigid trucks – the sample size required is not substantially influenced by the category population size. Hence ideally one might have the same sample for buses as for plant, even though the population sizes are very different. However, when the same data is used to consider a region, one wants to have the sample in some sense reflective of that region, and that will mean not having the sample sizes too disproportionate to the population sizes.

A key challenge in defining the population size was how to address the discrepancies of the vehicle classifications used in the raw data and those required in the survey. The heavy vehicle population data provided counts of rigid trucks, prime movers and trailers, however, how these units are assembled and configured determines the vehicle classification and the data itself is not sufficient to make appropriate apportion to the vehicle types, namely separating road trains from the B-Double population.

Given the limitation with the population data, it has been deemed that the most practical approach is to apportion the B-Double sample into separate B-Double and road train samples using approximate proportions. To assist with deriving the proportions of road trains and B-Doubles, Data Analysis Australia was provided with vehicle monitoring records for Victoria and Queensland, containing counts of motor vehicles passing through inspection sites in those states.

The vehicle monitoring data from Victoria presented counts of vehicle classes that combined the types of vehicles which we require individual counts, therefore was unable to provide useful information for estimating the proportions of vehicle types.

The vehicle monitoring data from Queensland provided separate counts for B-Doubles and road trains, allowing calculation of the proportions. The vehicle counts were summed over each district and the proportion of the three vehicle types were calculated for each district. Table 12 shows the total counts and proportions of each vehicle by districts. The assignment of metropolitan and non-metropolitan classification to the district was based solely on the geographical location of the districts.

Table 12. District level proportions of B-Doubles and road trains for Queensland.

District	Total B-Double	Total Road Train	Proportion B-Double	Proportion Road Train
Metropolitan				
Metropolitan	15,566	1,031	93.79%	6.21%
North Coast	5,532	495	91.79%	8.21%
South Coast	12,015	305	97.52%	2.48%
Wide Bay/Burnett	13,938	721	95.08%	4.92%
Non-metropolitan				
Central West	215	973	18.10%	81.90%
Darling Downs	27,456	9,911	73.48%	26.52%
Far North	546	178	75.41%	24.59%
Fitzroy	16,880	3,422	83.14%	16.86%
Mackay/Whitsunday	13,000	1,162	91.79%	8.21%
North West	230	1,812	11.26%	88.74%
Northern	6,601	1,690	79.62%	20.38%
South West	2,029	4,341	31.85%	68.15%

The variability in the proportion between the vehicle types must be taken into account when implementing these proportions to derive sample size.

It can also be seen that the district level proportions can vary significantly due to the difference in the size of the overall counts, for example the proportion of road trains in non-metropolitan districts tends to be much higher for districts with small vehicle counts. Simply averaging these proportions will lead to inappropriate proportions, including the risk of overestimating the road train sample, and consequently underestimating the B-Double sample, at a state and national level, therefore proportions at metropolitan and non-metropolitan level should be used.

Table 13. Relative proportions of B-Doubles and road trains by Metropolitan and Non-metropolitan areas based on the Queensland Vehicle Monitoring data.

	Proportion – B-Double	Proportion – Road Train
Metropolitan	94.86%	5.14%
Non-metropolitan	74.03%	25.97%

The above proportions will be used as a guide to apportion the overall B-Double sample into separate road train and B-Double samples but the exact proportions should not be taken as 'the truth' as they are simplified figures based on aggregated data from a single state only and over a limited time period[8]. By necessity, this will result in some strata being oversampled compared to others, but this can be accounted for during the weighting stage. It *may* also result in some strata being oversampled to an extent of making their sample sizes difficult to achieve in practice but this cannot be determined until the sampling takes place. If, after investing appropriate effort, the required number of road trains cannot be sampled for a particular stratum for this reason, additional B-Double inspections should take place instead.

These caveats demonstrate the risks of setting sample sizes based on the approximated proportions. Therefore, necessary adjustment and balancing of the sample sizes will be undertaken to the extent feasible in order to ensure that the final sample will be representative and unbiased to enable meaningful analysis to take place.

As discussed in section 5.2.1, the distinction between buses and coaches were also not available from the population data. It was deemed appropriate to sample these two classes together, with a combined sample count for these vehicle types being presented in the sample size tables. It is possible to apply quotas to each type of vehicle during the sampling stage if desired, to ensure a minimum count of each type.

Two recommended sampling options are proposed in the following sections, with each prioritising different elements.

[8] The data collection period was approximately 3 weeks, which may result in some bias in the vehicle counts, as there may be seasonal patterns in the traffic of certain vehicle types.

6.1 Preliminary Sample Size for First Recommended Sample Option

In deriving the proposed sample counts for the National Heavy Vehicle Baseline Survey we first generated *preliminary* sample counts based on combinations of the potential defect rate and individual subgroup (strata) precisions. These sample counts were then adjusted to a *base* sample size (Section 6.2) and then a *recommended* sample size (Section 6.3), keeping in mind the necessary balance between performance and representativeness.

After considering the relative population sizes and implementation issues and constraints, it was deemed appropriate to stratify based on a metropolitan/non-metropolitan breakdown, with the exception of ACT, which was treated as a single geographic unit.

In recommending sample sizes for the baseline survey, a somewhat conservative approach has been taken, with larger sample sizes (i.e. higher precision targets) than might be used in later surveys, for the following reasons:

- It is likely that the baseline survey may be used for a number of years as the benchmark against which improvements are measured. The greater use of the baseline survey means that it makes sense to give it greater resources.
- The baseline survey will uncover a number of issues in the vehicle fleet, in the nature of defects and in the methodology itself that will enable the optimising of future surveys.

Presented in Table 14 overleaf is the preliminary scenario derived from the conservative estimate of the expected defect rate (50%) and reasonably high precision within each stratum (±8.5%).

Table 14. Preliminary sample size with estimated 50% prevalence and ±8.5% precision for each stratum.

State	Region	Rigid Truck	Articulated	B-Double	Bus/Coach	Plant	Total
NSW	Metropolitan	133	130	126	130	123	**642**
NSW	Non-Metropolitan	133	131	129	129	126	**648**
	NSW Total	**266**	**261**	**255**	**259**	**249**	**1,290**
VIC	Metropolitan	133	131	128	130	129	**651**
VIC	Non-Metropolitan	132	131	129	128	130	**650**
	VIC Total	**265**	**262**	**257**	**258**	**259**	**1,301**
QLD	Metropolitan	132	130	128	130	123	**643**
QLD	Non-Metropolitan	133	130	130	128	122	**643**
	QLD Total	**265**	**260**	**258**	**258**	**245**	**1,286**
SA	Metropolitan	132	123	122	126	128	**631**
SA	Non-Metropolitan	131	128	125	116	128	**628**
	SA Total	**263**	**251**	**247**	**242**	**256**	**1,259**
WA	Metropolitan	132	129	128	129	131	**649**
WA	Non-Metropolitan	132	128	128	123	131	**642**
	WA Total	**264**	**257**	**256**	**252**	**262**	**1,291**
NT	Darwin	127	80	108	104	112	**531**
NT	Other	124	60	95	99	102	**480**
	NT Total	**251**	**140**	**203**	**203**	**214**	**1,011**
ACT	ACT	124	67	26	108	84	**409**
	ACT Total	**124**	**67**	**26**	**108**	**84**	**409**
TAS	Major Cities	130	112	68	121	65	**496**
TAS	Other	125	106	82	102	36	**451**
	TAS Total	**255**	**218**	**150**	**223**	**101**	**947**
TOTAL		**1,953**	**1,716**	**1,652**	**1,803**	**1,670**	**8,794**

Table 15 shows the percentages of the vehicle population covered by the above sample size. The percentage figures indicate that the distributions of samples in metropolitan and non-metropolitan regions are balanced for the majority of subgroups. Obvious exceptions are for Bus/Coach vehicle type where the sampled proportion is always higher in non-metropolitan areas, with notable magnitudes for South Australia, Western Australia and Tasmania. This is understandable as we would expect higher number of buses and coaches to be in service within the metropolitan area. An excessively high coverage of B-Double in ACT is a result of very small population count (32) in that stratum.

There are other notable discrepancies between the population coverage, which are observed more frequently in the smaller state and territories, for example plant heavy vehicle coverage in Tasmania. This is a natural result of stratified sampling – smaller stratum (in this case, smaller states/territories and vehicle types with smaller population counts) will usually be sampled at a higher rate to generate reasonable precision for their stratum estimates.

Table 15. Percentages of population covered by the preliminary sample size.

State	Region	Rigid Truck	Articulated	B-Double	Bus/Coach	Plant
NSW	Metropolitan	0.28%	2.33%	5.54%	2.15%	**7.27%**
NSW	Non-Metropolitan	0.32%	1.76%	2.77%	2.99%	**4.87%**
	NSW Total	**0.30%**	**2.00%**	**3.68%**	**2.50%**	**5.82%**
VIC	Metropolitan	0.27%	1.82%	3.45%	2.51%	**3.27%**
VIC	Non-Metropolitan	0.35%	1.37%	2.99%	3.66%	**2.53%**
	VIC Total	**0.31%**	**1.56%**	**3.20%**	**2.98%**	**2.85%**
QLD	Metropolitan	0.37%	2.37%	3.47%	2.26%	**7.27%**
QLD	Non-Metropolitan	0.30%	2.12%	2.02%	3.78%	**7.99%**
	QLD Total	**0.33%**	**2.24%**	**2.55%**	**2.82%**	**7.61%**
SA	Metropolitan	0.95%	7.43%	7.98%	5.53%	**3.82%**
SA	Non-Metropolitan	1.15%	3.94%	5.58%	12.93%	**3.83%**
	SA Total	**1.04%**	**5.12%**	**6.56%**	**7.62%**	**3.83%**
WA	Metropolitan	0.41%	3.10%	3.33%	2.83%	**1.76%**
WA	Non-Metropolitan	0.49%	3.59%	3.43%	7.39%	**1.52%**
	WA Total	**0.44%**	**3.33%**	**3.38%**	**4.05%**	**1.63%**
NT	Darwin	4.07%	40.40%	18.52%	21.71%	**16.02%**
NT	Other	6.81%	54.55%	28.61%	25.32%	**23.13%**
	NT Total	**5.08%**	**45.45%**	**22.19%**	**23.33%**	**18.77%**
ACT	ACT	6.39%	49.63%	81.25%	18.40%	**36.68%**
	ACT Total	**6.39%**	**49.63%**	**81.25%**	**18.40%**	**36.68%**
TAS	Major Cities	1.82%	15.41%	48.57%	8.81%	**50.39%**
TAS	Other	5.70%	19.81%	37.79%	22.82%	**73.47%**
	TAS Total	**2.73%**	**17.27%**	**42.02%**	**12.25%**	**56.74%**
Nationwide percentage of population sampled		**0.55%**	**3.08%**	**4.38%**	**4.42%**	**4.09%**

The preliminary sample size was derived so as to achieve a pre-defined precision (±8.5%) within each stratum (State-Region by Vehicle types). Table 16 to Table 18 show the precisions at various aggregate levels – namely vehicle types, states and combination of state and vehicle types. The tabulated precision figures should provide an idea of the magnitude of precision that can be expected at the aggregate level, and some indication of the allowable extent to which the individual precisions could be relaxed (the aggregate level will always have improved precision, due to the effective adding of sample sizes).

Table 16. Vehicle Type level precision of the preliminary sample size.

Vehicle Type	Precision
Rigid Truck	1.49%
Articulated	1.48%
B-Double	1.37%
Bus/Coach	1.40%
Plant	1.54%

Table 17. State level precision of the preliminary sample size.

State	Precision
NEW SOUTH WALES	2.22%
VICTORIA	2.25%
QUEENSLAND	2.44%
SOUTH AUSTRALIA	1.98%
WESTERN AUSTRALIA	2.22%
NORTHERN TERRITORY	1.82%
AUSTRALIAN CAPITAL TERRITORY	2.49%
TASMANIA	2.36%

Table 18. State by vehicle type precision of the preliminary sample size.

State	Rigid Truck	Articulated	B-Double	Bus/Coach	Plant
NSW	3.00%	3.03%	3.17%	3.05%	3.07%
VIC	3.03%	3.03%	3.01%	3.06%	3.02%
QLD	3.02%	3.01%	3.11%	3.10%	3.01%
SA	3.02%	3.15%	3.06%	3.25%	3.00%
WA	3.02%	3.01%	3.01%	3.30%	3.01%
NT	3.11%	3.09%	3.10%	3.02%	3.07%
ACT	4.26%	4.25%	4.16%	4.26%	4.25%
TAS	3.40%	3.04%	3.07%	3.34%	3.25%

6.2 Base Sample Size for First Recommended Sample Option

Using the preliminary sample size as a starting point, Data Analysis Australia considered the following factors in making adjustments to derive base sample sizes:

- Rounding each of the preliminary stratum sample sizes, giving an overall sample size of 8,680 and maintaining this overall sample size as it appears reasonable and should be targeted.
- The breakdown of the states and territories (except for ACT) into two subgroups appears to give practically achievable sample counts. Therefore we recommend the implementation of this regional structure for the development of the sample counts.

- The individual subgroup precision of ±8.5% yielded high precision at the aggregated level, indicating that this could be relaxed to some extent via reduction of required sample counts for some strata.
- While the distributions of samples across metropolitan and non-metropolitan area appear reasonable for the larger states, adjustments reflecting the balance in requirements could be made to the sample counts for the smaller states and territories.
- The smaller states are perhaps being slightly oversampled relative to the larger states – while generating the same levels of precision for the smaller states as larger states could be the target, improved overall sampling efficiency could be obtained by reallocating some of the sample to the larger states.
- The rigid trucks in particular are sampled at a low rate compared to the other vehicle types, due to their much larger population. The effect on overall sampling efficiency, in addition to the need to ensure that adequate road trains are captured in the sample without being able to set sample sizes based on population data suggests that rigid trucks in the more populated states would benefit from having their sample sizes increased.

Taking these factors into account, the adjustments made were:

- For all vehicle types except rigid trucks, reduce the sample size in the smaller states and territories (South Australia, Tasmania, ACT and Northern Territory) by accepting a lower target precision rate for each individual stratum (±10%).
- Calculating the overall reduction in sample size that this generates (650).
- Assign these 650 units to the rigid truck sample size counts (excluding ACT and NT which were already being sampled at a high rate). Do this assignment proportional to the rigid truck population size in each stratum. The reallocation to the rigid trucks strata is due to their proportionately high population count compared to the other vehicle types.

This approach maintains a high degree of focus on maintaining individual stratum precision levels, with some additional sampling for the particularly high population strata. The advantage of choosing an approach that maintains a focus on individual stratum precision levels is that it enables analysis of all strata to be considered with similar levels of precision. That is, the results for, say, plant vehicles in South Australia will have a similar level of precision as, say, articulated vehicles in Victoria. The disadvantage of this approach is that strata with smaller population counts can be sampled at a much higher rate than strata with large population counts, leading to less natural representativeness in the sample, leading to higher variability in weights which adversely impacts on overall statistical efficiency.

The base sample size figures are presented in Table 19.

Table 19. Base sample size with estimated 50% prevalence and ±8.5% precision for each stratum.

State	Region	Rigid Truck	Articulated	B-Double	Bus/Coach	Plant	Total
NSW	Metropolitan	200	140	120	130	120	**710**
NSW	Non-Metropolitan	200	140	130	130	120	**720**
	NSW Total	**400**	**280**	**250**	**260**	**240**	**1,430**
VIC	Metropolitan	200	140	130	130	130	**730**
VIC	Non-Metropolitan	200	140	130	130	130	**730**
	VIC Total	**400**	**280**	**260**	**260**	**260**	**1,460**
QLD	Metropolitan	200	140	130	130	120	**720**
QLD	Non-Metropolitan	200	140	130	130	120	**720**
	QLD Total	**400**	**280**	**260**	**260**	**240**	**1,440**
SA	Metropolitan	160	90	90	90	90	**520**
SA	Non-Metropolitan	150	90	90	80	90	**500**
	SA Total	**310**	**180**	**180**	**170**	**180**	**1,020**
WA	Metropolitan	190	130	130	130	130	**710**
WA	Non-Metropolitan	180	130	130	120	130	**690**
	WA Total	**370**	**260**	**260**	**250**	**260**	**1,400**
NT	Darwin	120	60	80	80	80	**420**
NT	Other	120	50	70	70	80	**390**
	NT Total	**240**	**110**	**150**	**150**	**160**	**810**
ACT	ACT	120	50	20	80	70	**340**
	ACT Total	**120**	**50**	**20**	**80**	**70**	**340**
TAS	Major Cities	140	80	50	90	50	**410**
TAS	Other	120	80	60	80	30	**370**
	TAS Total	**260**	**160**	**110**	**170**	**80**	**780**
TOTAL		**2,500**	**1,600**	**1,490**	**1,600**	**1,490**	**8,680**

6.3 Final Sample Size for First Recommended Sample Option

The base sample size does not address the issue of road train sample sizes, which is addressed in the derivation of recommended sample sizes by taking the base B-Double sample size and apportioning it to separate road train and B-Double sample sizes.

The overall principles in these decisions were:

- Keeping as much consistency as possible with the original sampling design, as this is a modification to it for ensuring sufficient road trains will be sampled;
- Setting sample sizes for road trains based on both the vehicle proportion information and judgement, balancing the requirements of ensuring minimum sample sizes available for analysis and interpretation while still being achievable in terms of sampling proportions; and

- Sample sizes for road trains being taken as a subset of the B-Double sample sizes, based on proportions. To maintain appropriate overall sampling balance, the road train sample, while only being *applied* to the non-metropolitan areas was topped up by transferring some of the metropolitan B-Double sample. Thus, the sum of B-Doubles and Road Trains within each state in the recommended sampling option matches the B-Double sample sizes in the *base* sampling table.

This results in the recommended sample sizes provided in Table 20.

Table 20. Recommended sample size focusing on maintaining individual precision levels.

State	Region	Rigid Truck	Articulated	B-Double	Road Train	Bus / Coach	Plant	Total
NSW	Metropolitan	200	140	95	0	130	120	685
NSW	Non-Metropolitan	200	140	95	60	130	120	745
	NSW Total	400	280	190	60	260	240	1,430
VIC	Metropolitan	200	140	105	0	130	130	705
VIC	Non-Metropolitan	200	140	95	60	130	130	755
	VIC Total	400	280	200	60	260	260	1,460
QLD	Metropolitan	200	140	105	0	130	120	695
QLD	Non-Metropolitan	200	140	95	60	130	120	745
	QLD Total	400	280	200	60	260	240	1,440
SA	Metropolitan	160	90	75	0	90	90	505
SA	Non-Metropolitan	150	90	65	40	80	90	515
	SA Total	310	180	140	40	170	180	1,020
WA	Metropolitan	190	130	115	0	130	130	695
WA	Non-Metropolitan	180	130	95	50	120	130	705
	WA Total	370	260	210	50	250	260	1,400
NT	Darwin	120	60	80	0	80	80	420
NT	Other	120	50	50	20	70	80	390
	NT Total	240	110	130	20	150	160	810
ACT	ACT	120	50	20	0	80	70	340
	ACT Total	120	50	20	0	80	70	340
TAS	Major Cities	140	80	50	0	90	50	410
TAS	Other	120	80	60	0	80	30	370
	TAS Total	260	160	110	0	170	80	780
TOTAL		**2,500**	**1,600**	**1,200**	**290**	**1,600**	**1,490**	**8,680**

6.4 Preliminary Sample Size for Second Recommended Sample Option

The second recommended sample option is based on an alternative *preliminary* sample design, obtained by taking the total sample size of the first option's preliminary sample (8,680) and allocating it in the following manner:

- Calculate the square root of the population size for each stratum.
- Assign the overall original preliminary sample size to each stratum based on its proportion using the square roots calculated in the first step.
- Round the raw sample size to clean figures.

This approach focuses on achieving a more balanced proportional representation of the sample compared to the population, at the expense of the precision level of some of the smaller stratum. Often sample sizes are based on simple proportional allocation, but this often results in the smaller stratum having samples sizes that are too low for meaningful analysis and the larger strata having unnecessarily high sample sizes. Allocation proportional to the square root provides a balance between the two, and is often used in practice.

The advantage of choosing an approach that maintains a more balanced proportional representation of the sample compared to the population is that there will be less variability in the weights, which positively impacts on overall statistical efficiency. The disadvantage of this approach is that larger strata result in far more precise estimates than smaller strata, reducing the inferences that can be made regarding the smaller strata.

Due to the differences in the methodologies used to arrive at the preliminary sample sizes for the first and second recommended sample options, the intervening 'base' sample size calculation is not needed for the second recommended sample option. Instead, the preliminary sample sizes presented in Table 21 only need the adjustment for road trains to be incorporated in transitioning to the *final* sample sizes for this option, as presented in Section 6.5.

Table 21. Preliminary sample size focusing on balanced individual stratum sizes.

State	Region	Rigid Truck	Articulated	B-Double	Bus/Coach	Plant	Total
NSW	Metropolitan	380	130	85	135	70	**800**
NSW	Non-Metropolitan	360	150	120	115	90	**835**
	NSW Total	**740**	**280**	**205**	**250**	**160**	**1,635**
VIC	Metropolitan	390	150	105	125	110	**880**
VIC	Non-Metropolitan	340	170	115	105	120	**850**
	VIC Total	**730**	**320**	**220**	**230**	**230**	**1,730**
QLD	Metropolitan	330	130	105	135	70	**770**
QLD	Non-Metropolitan	370	135	140	100	70	**815**
	QLD Total	**700**	**265**	**245**	**235**	**140**	**1,585**
SA	Metropolitan	205	70	70	85	100	**530**
SA	Non-Metropolitan	185	100	85	50	100	**520**
	SA Total	**390**	**170**	**155**	**135**	**200**	**1,050**
WA	Metropolitan	315	115	110	120	150	**810**
WA	Non-Metropolitan	290	105	105	70	160	**730**
	WA Total	**605**	**220**	**215**	**190**	**310**	**1,540**
NT	Darwin	100	25	40	40	45	**250**
NT	Other	75	20	30	35	35	**195**
	NT Total	**175**	**45**	**70**	**75**	**80**	**445**
ACT	ACT	75	20	10	40	25	**170**
	ACT Total	**75**	**20**	**10**	**40**	**25**	**170**
TAS	Major Cities	150	45	20	65	20	**300**
TAS	Other	80	40	25	35	10	**190**
	TAS Total	**230**	**85**	**45**	**100**	**30**	**490**
TOTAL		**3,645**	**1,405**	**1,165**	**1,255**	**1,175**	**8,645**

Table 22. Percentages of population covered by the alternative preliminary sample sizes.

State	Region	Rigid Truck	Articulated	B-Double	Bus/Coach	Plant
NSW	Metropolitan	0.80%	2.33%	3.73%	2.23%	**4.14%**
NSW	Non-Metropolitan	0.85%	2.01%	2.58%	2.67%	**3.48%**
	NSW Total	**0.83%**	**2.15%**	**2.96%**	**2.41%**	**3.74%**
VIC	Metropolitan	0.79%	2.08%	2.83%	2.41%	**2.79%**
VIC	Non-Metropolitan	0.91%	1.77%	2.67%	3.00%	**2.34%**
	VIC Total	**0.84%**	**1.91%**	**2.74%**	**2.65%**	**2.53%**
QLD	Metropolitan	0.92%	2.37%	2.84%	2.35%	**4.13%**
QLD	Non-Metropolitan	0.83%	2.20%	2.18%	2.95%	**4.59%**
	QLD Total	**0.87%**	**2.28%**	**2.42%**	**2.57%**	**4.35%**
SA	Metropolitan	1.47%	4.23%	4.58%	3.73%	**2.99%**
SA	Non-Metropolitan	1.62%	3.08%	3.80%	5.57%	**2.99%**
	SA Total	**1.54%**	**3.47%**	**4.11%**	**4.25%**	**2.99%**
WA	Metropolitan	0.97%	2.77%	2.86%	2.64%	**2.02%**
WA	Non-Metropolitan	1.07%	2.94%	2.82%	4.20%	**1.86%**
	WA Total	**1.02%**	**2.85%**	**2.84%**	**3.06%**	**1.93%**
NT	Darwin	3.21%	12.63%	6.86%	8.35%	**6.44%**
NT	Other	4.12%	18.18%	9.04%	8.95%	**7.94%**
	NT Total	**3.54%**	**14.61%**	**7.65%**	**8.62%**	**7.02%**
ACT	ACT	3.86%	14.81%	31.25%	6.81%	**10.92%**
	ACT Total	**3.86%**	**14.81%**	**31.25%**	**6.81%**	**10.92%**
TAS	Major Cities	2.10%	6.19%	14.29%	4.73%	**15.50%**
TAS	Other	3.65%	7.48%	11.52%	7.83%	**20.41%**
	TAS Total	**2.47%**	**6.74%**	**12.61%**	**5.49%**	**16.85%**
TOTAL		**1.02%**	**2.52%**	**3.09%**	**3.07%**	**2.88%**

6.5 Final Sample Size for Second Recommended Sample Option

The final sample sizes were then processed in the same way as deriving the final sample sizes for the first recommended sample option. That is, a road train sample size is obtained by taking the B-Double sample size and apportioning it to separate road train and B-Double sample sizes[9].

Table 23. Recommended sample size focusing on balanced individual strata sizes.

State	Region	Rigid Truck	Articulated	B-Double	Road Train	Bus / Coach	Plant	Total
NSW	Metropolitan	380	130	60	0	135	70	770
NSW	Non-Metropolitan	360	150	85	60	115	90	865
	NSW Total	740	280	145	60	250	160	1,635
VIC	Metropolitan	390	150	75	0	125	110	850
VIC	Non-Metropolitan	340	170	85	60	105	120	880
	VIC Total	730	320	160	60	230	230	1,730
QLD	Metropolitan	330	130	80	0	135	70	745
QLD	Non-Metropolitan	370	135	105	60	100	70	840
	QLD Total	700	265	185	60	235	140	1,585
SA	Metropolitan	205	70	50	0	85	100	510
SA	Non-Metropolitan	185	100	65	40	50	100	540
	SA Total	390	170	115	40	135	200	1,050
WA	Metropolitan	315	115	85	0	120	150	785
WA	Non-Metropolitan	290	105	80	50	70	160	755
	WA Total	605	220	165	50	190	310	1,540
NT	Darwin	100	25	30	0	40	45	240
NT	Other	75	20	20	20	35	35	205
	NT Total	175	45	50	20	75	80	445
ACT	ACT	75	20	10	0	40	25	170
	ACT Total	75	20	10	0	40	25	170
TAS	Major Cities	150	45	20	0	65	20	300
TAS	Other	80	40	25	0	35	10	190
	TAS Total	230	85	45	0	100	30	490
TOTAL		**3,645**	**1,405**	**875**	**290**	**1,255**	**1,175**	**8,645**

[9] See Section 6.3 for more details.

7. Future Survey Designs

This survey is intended as a point in time baseline survey, with the possibility of undertaking future surveys to measure the roadworthiness of the heavy vehicle fleet in the years to come. While the design for future surveys has not been specifically covered in this report, they have been considered in decisions and recommendations for the baseline survey, minimising the risk of implementing procedures that limit options and opportunities for future surveys.

A key point in this regard is that Data Analysis Australia proposes that future surveys follow essentially the same sampling and implementation methodology as the baseline survey, appropriately updated for new population data and to correct for any sampling biases that were identified to have occurred in the previous survey and that *can be corrected for*. Maintaining comparability in methodologies provides the best basis for comparisons between years, but any improvements that can be made, should be made. This is particularly relevant when moving from the baseline survey to the first subsequent survey – lessons learned from data that was not available before the baseline survey but was collected *in* the baseline survey can be used to optimise the sample. In particular, where there are identifiable strata in the baseline survey that have higher defect rates, subsequent surveys can make savings by over sampling such strata and under sampling other strata, for an overall reduction in sample size.

It is appropriate to point out that while such a set of surveys is, in some sense, longitudinal, if the same vehicles are not tracked over time in the various sampling years, it is not considered a longitudinal survey in the strict statistical sense. Instead, it is longitudinal in the sense that it is a repeated cross-sectional survey, with each cross-sectional survey being designed to provide the best estimates for that particular survey. This is particularly appropriate for this type of survey as:

- This approach provides the best possible sample for each individual year being surveyed, hence providing the best overall representation of the current state of heavy vehicle roadworthiness.
- It allows for incremental updates and iterative improvements to the sampling design for each survey.
- It accounts for changes in the population over time, via simple adjustments and recalibration of the sampling sizes each year based on updated population data and lessons learned from the previous surveys.
- There is not the need or desire to track changes in roadworthiness of a particular vehicle over time.
- It maintains the element of surprise to the inspections, which is particularly crucial for a context such as this – should vehicle owners know that particular vehicles are (or are not) going to be inspected in future surveys there would be higher incentives for them to maintain a higher level of roadworthiness of the vehicles known to be sampled.

8. Conclusions

This report proposes a sampling regime covering both sample sizes and implementation methodologies for a baseline survey to measure the roadworthiness of the national heavy vehicle fleet. The sampling regime includes both a roadside intercept survey component and a present-for-inspection list based sampling component.

The sample sizes have been recommended to be on the conservative side – that is, targeting a higher level of precision than may be strictly necessary – due to inherent uncertainties that exist the first time any survey is carried out for the first time and due to the extra emphasis that is likely to be placed on the baseline survey results for many years going forwards.

Numerous recommendations have been given regarding the sampling and implementation procedures to generate a robust and representative sample of vehicles, but certain details can only be prescribed once detailed logistical planning of the survey commences.

Appendix A. Glossary

Bias

The tendency of a sample statistic to systematically over- or under-estimate a population parameter. This typically results from the sample being non-representative of the population.

Census

A survey that obtains data from every member of a population, rather than just a sample of the population.

Cluster sampling

A sampling process where a number of related sample units are chosen together.

Cross-sectional survey

A survey conducted at a single point in time. It is possible to repeat a cross-sectional survey at different periods, reflecting a longitudinal design, however the sampling units of each survey are independent from sampling units of previous surveys (rather than specifically choosing the same units as in previous surveys).

Errors

The difference between the estimated value obtained from a sample and the true population value.

Independent

Two units are independent if the probability of choosing one unit to be in the sample does not affect the probability of the other unit being in the sample.

Longitudinal survey

A survey repeated over time where the same sampling units are re-sampled in subsequent surveys.

National Roadworthiness Baseline Survey (NRBS)

The first of potentially a series of surveys aimed at gathering sufficient information which will enable the assessment of roadworthiness of the fleet of heavy vehicles in Australia.

Normal distribution

A statistical distribution, also often referred to as the Gaussian distribution, or the ‘bell-shaped’ curve.

Population

The full set of units (in this case, heavy vehicles) that are of interest in a study.

Precision

The amount by which the survey results may have differed if a different random sample had have been chosen.

Prevalence

The percentage of the population with a particular feature or characteristic.

Quota

An allocation of a sample used to ensure a minimum count (or proportion) of units with a particular, often harder to capture, characteristic is obtained.

Representativeness

A conceptual measure of how well a sample reflects a population.

Sample

A subset of units surveyed from a population, enabling inferences to be made about the population.

Sample size

The number of units selected in the sample.

Sample survey

A study that obtains data from a subset of a population, rather than the full population, in order to estimate characteristics of the population.

Sampling Frame

A list of all eligible units to participate in the survey. Often referred to as the population data.

Sampling region

A subset area of the entire survey area which has a known population and which feeds into the sampling design, with a particular sample size required for each region.

SA4 (Statistical Area Level 4)

An ABS standard level of geography.

Simple random sample

A sample selection method whereby each unit of the population has an equal probability of selection and each unit in the sample is randomly selected in a statistically independent manner from the other units. In a stratified sampling design, simple random sampling is often applied within each stratum.

Statistical efficiency

A term used to compare the precision of an estimate obtained under one particular sampling regime compared to another. A higher level of statistical efficiency is achieved if an improved precision is obtained for a smaller sample size under one design than another design.

Stratified design

A sampling design whereby each unit (in this case, heavy vehicle) in the population is assigned to one and only one sub-group, with all of the sub-groups together forming the total population. Each sub-group is referred to as a stratum (plural strata) and each stratum has a sample size attached to it, as well as a methodology and means of obtaining the sample from that stratum.

Stratum (plural strata)

A subgroup of the population that is used in stratified survey designs (see definition). Each unit (in this case, heavy vehicle) in the population is assigned to one and only one stratum, with all of the strata together forming the total population. Each stratum has a sample size attached to it, as well as a methodology and means of obtaining the sample from that stratum.

Weight

A multiplier (or scaling factor) attached to each unit in the sample to scale it to the population. The multiplier represents how many units in the population each sample unit is representing, including itself. Weighting is needed for any sample survey, and particularly for those where the makeup of the sample doesn't match the makeup of the population in key ways.

Appendix B. Heavy Vehicle Classification Comparison

Table 24. Comparison of the heavy vehicle categories available in the Australian Bureau of Statistics 2015 Motor Vehicle Census, the Austroads classification and the desired breakdown for this survey.

Heavy Vehicle Code	Austroads classification	Classification for survey
Rigid - 2 axle - over 4.5 to 12T gvm	3	Rigid Truck
Rigid - 3 axle - over 4.5 to 16.5T gvm	4	Rigid Truck
Rigid - 4 axle - over 4.5 to 20T gvm	5	Rigid Truck
Rigid - 5 axle - over 4.5 to 20T gvm	5	Rigid Truck
Rigid - 2 axle - over 12T gvm	3	Rigid Truck
Rigid - 3 axle - over 16.5T gvm	4	Rigid Truck
Rigid - 4 axle - over 20T gvm	5	Rigid Truck
Rigid - 5 axle - over 20T gvm	5	Rigid Truck
Rigid/short comb - 2 axle - 6 axles max	6/7/8/9	Rigid Truck
Rigid/short comb - 3 axle - 6 axles max	6/7/8/9	Rigid Truck
Rigid/short comb - 4 axle - 6 axles max	6/7/8/9	Rigid Truck
Rigid/short comb - 5 axle - 6 axles max	6/7/8/9	Rigid Truck
Rigid/med comb - 2 axle - over 6 axles	10	Rigid Truck
Rigid/med comb - 3 axle - over 6 axles	10	Rigid Truck
Rigid/med comb - 4 axle - over 6 axles	10	Rigid Truck
Rigid/med comb - 5 axle - over 6 axles	10	Rigid Truck
Rigid/long comb - 2 axle	11 or 12	Rigid Truck
Rigid/long comb - 3 axle	11 or 12	Rigid Truck
Rigid/long comb - 4 axle	11 or 12	Rigid Truck
Rigid/long comb - 5 axle	11 or 12	Rigid Truck
Prime mover/short comb - 2 axle pm	8	Articulated
Prime mover/short comb - 3 axle pm	9	Articulated
Prime mover/short comb - 4 axle pm	9	Articulated
Prime mover/short comb - 5 axle pm	9	Articulated
Prime mover/med comb/B-double - 2 ax pm	10	B-Double
Prime mover/med comb/B-double - 3 ax pm	10	B-Double
Prime mover/med comb/B-double - 4 ax pm	10	B-Double
Prime mover/med comb/B-double - 5 ax pm	10	B-Double
Prime mover/long comb - 2 axle pm	11 or 12	Road Train
Prime mover/long comb - 3 axle pm	11 or 12	Road Train
Prime mover/long comb - 4 axle pm	11 or 12	Road Train
Prime mover/long comb - 5 axle pm	11 or 12	Road Train
Buses - 2 axle - over 4.5 to 12T gvm	3	Either Bus or Coach
Buses - 3 axle - over 4.5 to 12T gvm	4	Either Bus or Coach
Buses - 2 axle - over 12T gvm	3	Either Bus or Coach
Buses - 3 axle - over 12T gvm	4	Either Bus or Coach

Heavy Vehicle Code	Austroads classification	Classification for survey
Buses - 4 axle - over 12T gvm	4	Either Bus or Coach
Buses/artic - 3 axle - over 4.5T gvm	4	Bus
Buses/artic - 4 axle - over 4.5T gvm	5	Bus
Special purpose vehicle - type 1	NA	Plant
Special purpose vehicle - type 1 - 1 ax	NA	Plant
Special purpose vehicle - type 1 - 2 ax	NA	Plant
Special purpose vehicle - type 1 - 3 ax	NA	Plant
Special purpose vehicle - type 1 - 4 ax	NA	Plant
Special purpose vehicle - type 1 - 5 ax	NA	Plant
Special purpose vehicle - type 1 - 6 ax	NA	Plant
Special purpose vehicle - type 1 - 7 ax	NA	Plant
Special purpose vehicle - type 1 - 8 ax	NA	Plant
Special purpose vehicle - type 2 - 1ax	NA	Plant
Special purpose vehicle - type 2 - 2 ax	NA	Plant
Special purpose vehicle - type 2 - 3 ax	NA	Plant
Special purpose vehicle - type 2 - 4 ax	NA	Plant
Special purpose vehicle - type 2 - 5 ax	NA	Plant
Special purpose vehicle - type 2 - 6 ax	NA	Plant
Special purpose vehicle - type 2 - 7 ax	NA	Plant
Special purpose vehicle - type 2 - 8 ax	NA	Plant
Special purpose vehicle - type 2 - 6 ax	NA	Plant
Heavy Trailers - 1 axle	NA	
Heavy Trailers - 2 axle	NA	
Heavy Trailers - 3 axle	NA	
Heavy Trailers - 4 axle	NA	
Heavy Trailers - 5 axle	NA	
Heavy Trailers - 6 axle	NA	
Heavy Trailers - 7 axle	NA	
Heavy Trailers - 8 axle	NA	
Heavy Trailers - 9 axle	NA	
Trailers - 1 axle	NA	
Trailers - 2 axle	NA	
Trailers - 3 axle	NA	
Trailers - 4 axle	NA	
Trailers - 5 axle	NA	
Trailers - 6 axle	NA	
Trailers - 7 axle	NA	
Trailers - 8 axle	NA	
Trailers - 9 axle	NA	
Other Special purpose vehicle - 1 ax	NA	Plant
Other Special purpose vehicle- 2 ax	NA	Plant

Heavy Vehicle Code	Austroads classification	Classification for survey
Other Special purpose vehicle- 3 ax	NA	Plant
Other Special purpose vehicle- 4 ax	NA	Plant
Other Special purpose vehicle- 5 ax	NA	Plant
Other Special purpose vehicle- 6 ax	NA	Plant
Other Special purpose vehicle- 7 ax	NA	Plant
Other Special purpose vehicle- 8 ax	NA	Plant
Other Special purpose vehicle- 9 ax	NA	Plant
Truck Special Vehicle	NA	Plant
Truck Special Vehicle - 1axle	NA	Plant
Truck Special Vehicle - 2axle	NA	Plant
Truck Special Vehicle - 3axle	NA	Plant
Truck Special Vehicle - 4axle	NA	Plant
Truck Special Vehicle - 5axle	NA	Plant
Truck Special Vehicle - 6axle	NA	Plant
Truck Special Vehicle - 7axle	NA	Plant
Truck Special Vehicle - 8axle	NA	Plant
Plant Special Vehicle	NA	Plant
Plant Special Vehicle - 1 axle	NA	Plant
Plant Special Vehicle - 2 axle	NA	Plant
Plant Special Vehicle - 3 axle	NA	Plant
Plant Special Vehicle - 4 axle	NA	Plant
Plant Special Vehicle - 5 axle	NA	Plant
Plant Special Vehicle - 6 axle	NA	Plant

Appendix C. Maps of Heavy Vehicle Counts

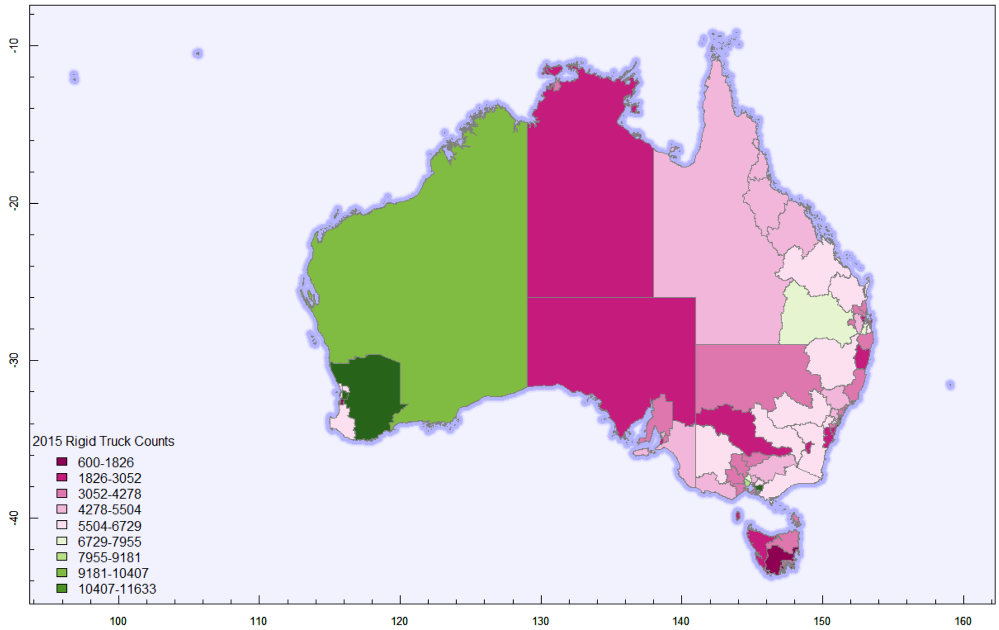


Figure 4. Rigid Truck counts at SA4 regional level derived from the ABS 2015 Motor Vehicle Census postcode of owner.

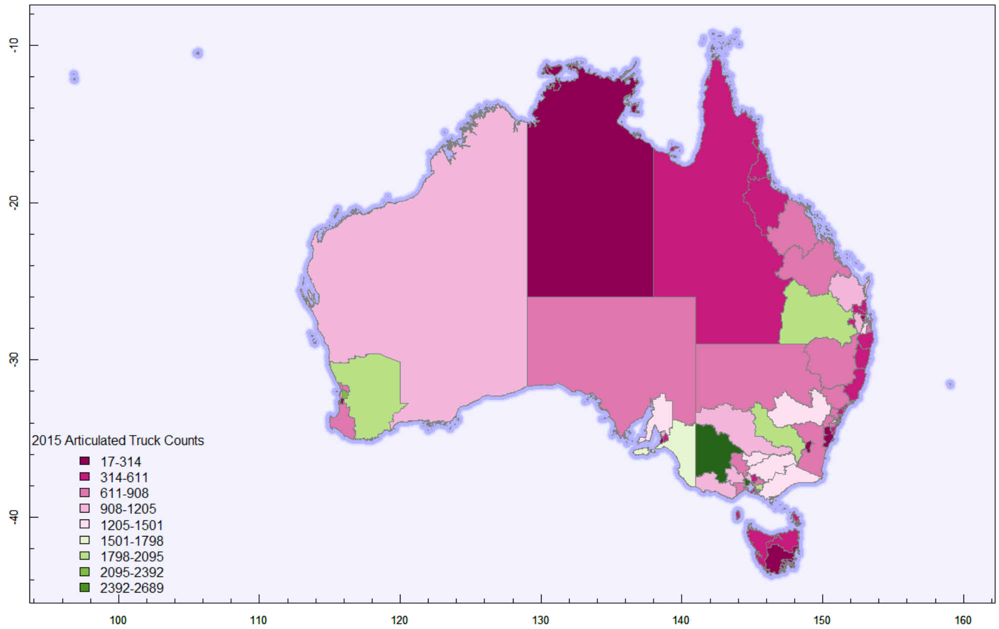


Figure 5. Articulated Truck counts at SA4 regional level derived from the ABS 2015 Motor Vehicle Census postcode of owner.

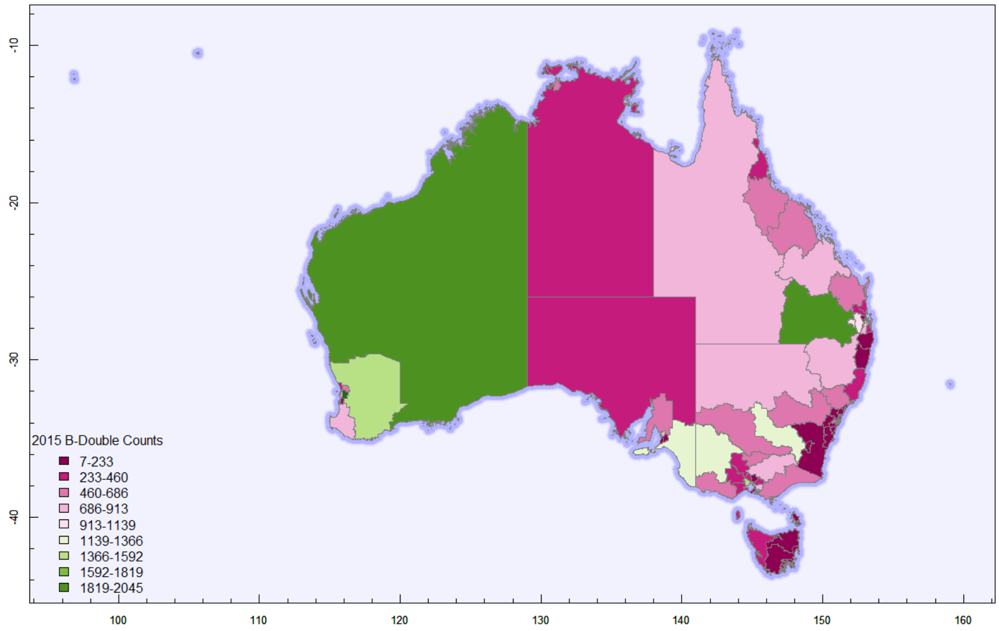


Figure 6. B-Double Truck counts at SA4 regional level derived from the ABS 2015 Motor Vehicle Census postcode of owner.

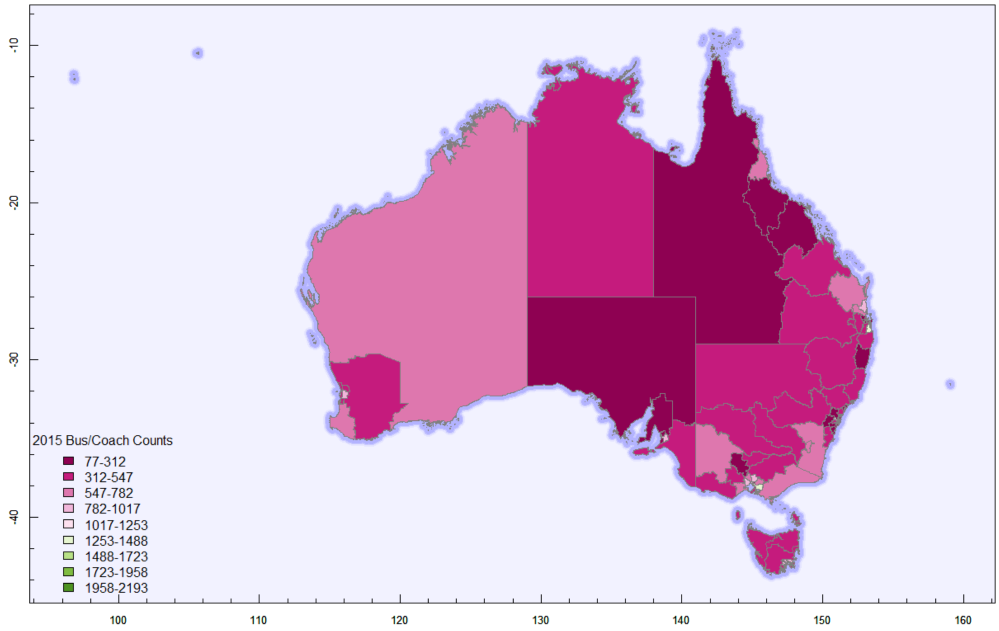


Figure 7. Bus/Coach counts at SA4 regional level derived from the ABS 2015 Motor Vehicle Census postcode of owner.

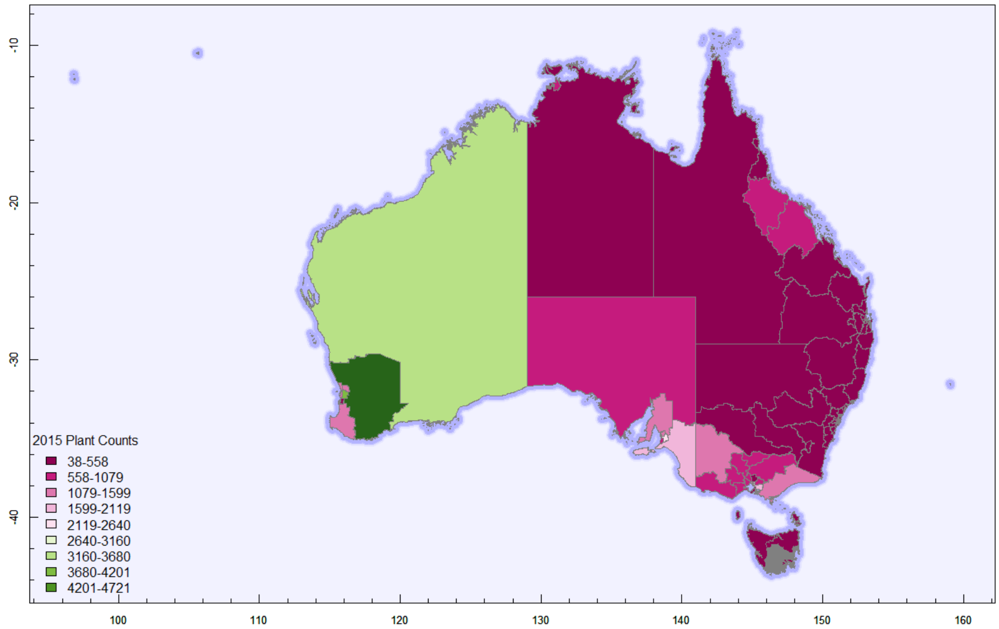


Figure 8. Plant counts at SA4 regional level derived from the ABS 2015 Motor Vehicle Census postcode of owner.

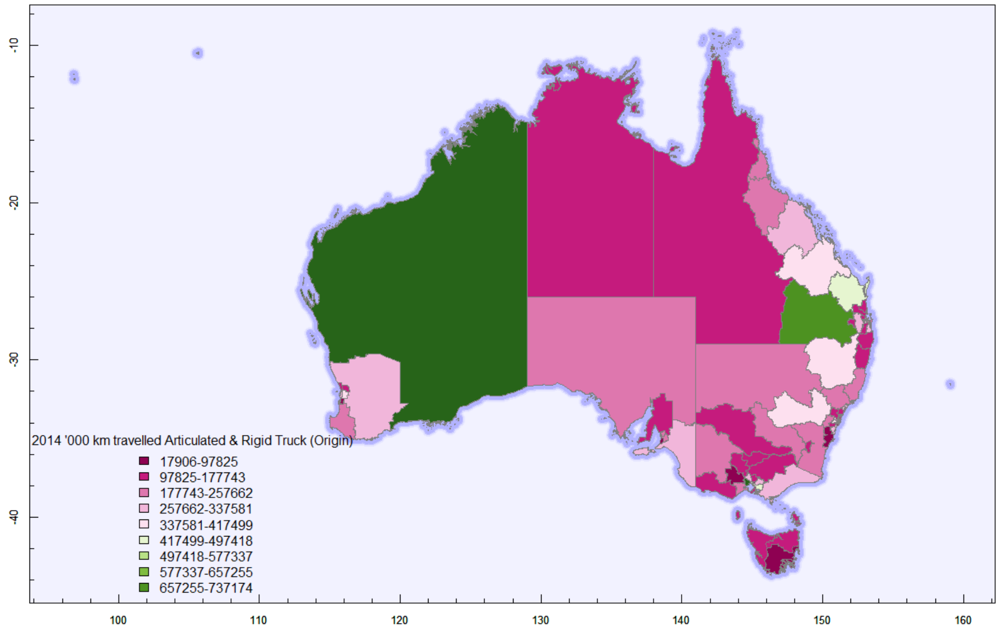


Figure 9. Total kilometres travelled for articulated and rigid trucks from the origin of trip at SA4 regional level from the ABS Road Freight Movement Survey.

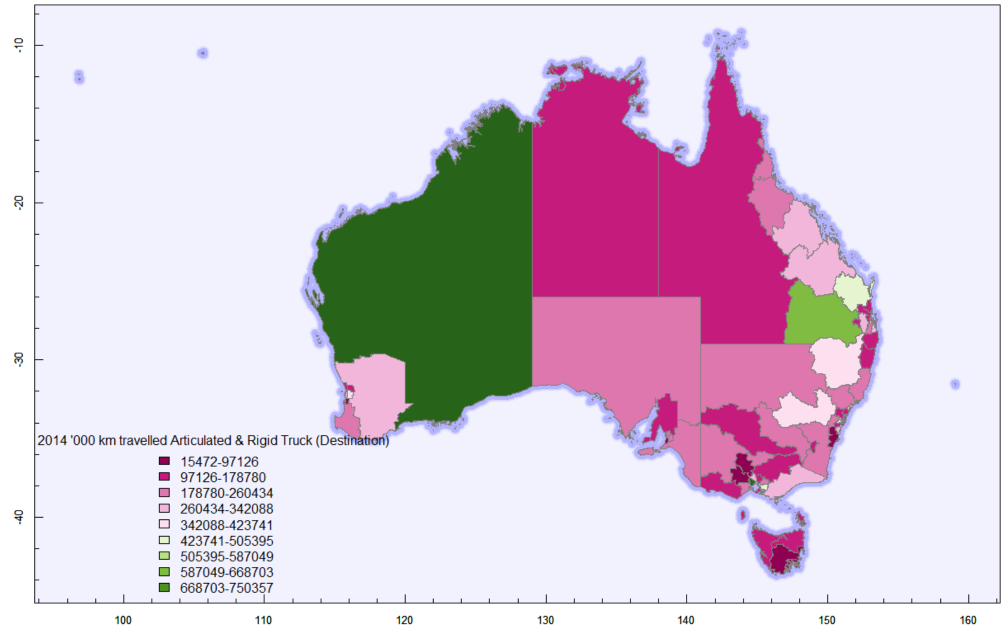


Figure 10. Total kilometres travelled for articulated and rigid trucks from the destination of trip at SA4 regional level from the ABS Road Freight Movement Survey.

Appendix D. Queensland Vehicle Monitoring Data

Table 25. Example records of the Queensland Vehicle Monitoring data. AADT stands for Annual Average Daily Traffic.

REGION	RSECT_ ID	ROAD_NAME	ROAD_SECTION_ NAME	TDIST_ START	TDIST_ END	SITE_ID	AADT	RIGID	ARTICULATED	ROAD_TRAIN (includes B-Doubles)	B_DOUBLE
Central West District	13D	LANDSBOROUGH HIGHWAY	BLACKALL - BARCALDINE	0	103.6	70003	480	46	26	70	11
Central West District	13D	LANDSBOROUGH HIGHWAY	BLACKALL - BARCALDINE	103.6	106.16	70186	791	90	34	68	11
Central West District	13E	LANDSBOROUGH HIGHWAY	BARCALDINE - LONGREACH	0	83.25	70005	735	48	32	72	12
Central West District	13E	LANDSBOROUGH HIGHWAY	BARCALDINE - LONGREACH	83.25	105.56	70185	929	111	45	75	13
…	…	…	…	…	…	…	…	…	…	…	…
Metropolitan District	900	EVERTON PARK - ALBANY CREEK ROAD	EVERTON PARK - ALBANY CREEK ROAD	0	2.57	136159	38000	1813	239	38	38
Metropolitan District	900	EVERTON PARK - ALBANY CREEK ROAD	EVERTON PARK - ALBANY CREEK ROAD	2.57	3.29	136173	31701	1148	95	0	
…	…	…	…	…	…	…	…	…	…	…	…