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FINAL REPORT

R103: Virtual weigh-in-motion and Queensland freight movement study (2019/20)

ARRB Project No.: 015302

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SUMMARY

Road network information is critical for allowing the Queensland Department of Transport and Main Roads (TMR) to efficiently manage their network. As a result, TMR has invested in traffic counters, weigh–in-motion (WIM) sites and automatic number plate recognition (ANPR) sites to quantify the traffic on the network. While these sites provide invaluable information, they only provide information at a point on the network. In order to provide greater visibility of the loading of the network the concept of Virtual WIM (V-WIM) has been explored in this report. V-WIM builds on existing data sources to extrapolate the information collected from WIM sites across a broader area of the network. The primary use-case for V-WIM is for the asset management of roads and bridges through better understanding road freight movements and the loads imparted on the infrastructure.

This report documents the scoping study that included:

1. a review of existing data collection technology and locations
2. the feasibility of developing V-WIM
3. a review of data types and sources
4. a proposed framework for developing the V-WIM concept
5. recommendations on methods for the network extrapolation.

The study found that a V-WIM system is feasible and that a modular approach would allow the system to be implemented sooner while scoping the potential of further advancements that will improve the accuracy of the system.

A V-WIM framework has been proposed that comprises three modules. All modules apply network allocation and extrapolation techniques to build the V-WIM network. Module 1 uses data from WIM sites (mass tables) and classifiers. Module 2 is based on ANPR data and Module 3 uses truck telematics (GPS and OBM).

The relevant data, research and software packages which exist to support the implementation of module 1 of the framework were outlined. It is recommended that segment-based ordinary kriging allocation be used and for spatial prediction segment-based regression kriging. Point data was identified as suitable for the initial stages as it provides a base level of information that can be further improved.

A five-step process was proposed for building the V-WIM network from these data sources:

- WIM (derived data tables)
- traffic count data
- a road network comprising road links.

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1 INTRODUCTION

Information on the weight of a heavy vehicle is a critical requirement for road managers. This information is particularly useful when managing the impacts on pavement wear and structures. The ability to measure the weight, number of axles and axle spacings of a heavy vehicle provides more certainty that the loads imparted by these vehicles will remain within the design limits of the pavements. This information can also assist with planning, road maintenance and heavy vehicle access.

Weigh-in-motion (WIM) devices are designed to capture and record the weight of individual axle groups as they drive over the measurement device. This information can be used to determine the vehicle configuration as well as the gross vehicle mass (GVM) or gross combination mass (GCM). WIM stations are capable of measuring vehicles traveling at traffic speed and are already located throughout the Queensland road network, providing Queensland Department of Transport and Main Roads (TMR) with information on axle group mass, heavy vehicle classifications and counts. The WIM sites are typically located on major freight routes and corridors of strategic importance, providing useful data on the local freight task.

The term Virtual WIM (V-WIM) refers to the concept of using other data sources to extrapolate the information collected from WIM sites across a broader area of the road network. Data sources that are potentially suitable for building a V-WIM network include vehicle registrations via automatic number plate recognition (ANPR), freight routes, truck telematics, traffic counters that identify individual heavy vehicles and probe data (with heavy vehicle identification).

V-WIM should not be confused with on-board mass monitoring (OBMM). OBMM is where the heavy vehicle itself is fitted with on-board scales which measure the weight over an axle group. The primary purpose of OBMM is for fleet managers and operators to have visibility on their loads to assist with managing their operations and to avoid overloading axle groups. The majority of the heavy vehicle fleet is not fitted with OBMM, and the data has typically not been available to road managers.

However, the National Telematics Framework administered by Transport Certification Australia (TCA) provides a digital platform for facilitating access to road managers under operator consent, with the common use case being making access decisions for restricted access heavy vehicles. V-WIM provides an alternative means for obtaining the visibility that such a platform provides, but one which does not require fitting all heavy vehicles with on-board scales and gaining operator consent to share with road managers. The methods for extrapolating WIM data for building a V-WIM network will vary depending on the source data.

1.1 PROJECT SCOPE

The scope of this project is to determine the feasibility of building a V-WIM network across the Queensland state-controlled road network as well as the usefulness of V-WIM for understanding heavy vehicle loads on pavements and structures.

2 METHOD

The project method comprised the following tasks:

1. Review the current WIM locations, data and TMR requirements.
2. Take into consideration Queensland road network connectivity, monitoring sites, structure locations and key freight routes.
3. Investigate other data sets that can augment the existing WIM data.
4. Propose a V-WIM approach for Queensland within a final report on the project's findings.

2.1 GUIDING PRINCIPLES

This project was designed to be an exploratory project into data and analytical techniques for developing the V-WIM concept. The project brief was purposely broad to allow the project to focus on the datasets and methods that were found to be most suitable for the V-WIM. Following the commencement of the project, a workshop was held in which the TMR project team provided the guiding principles for the project. These can be summarised with the two key statements below:

'to make better use of the traffic data TMR already has'

and

'to create tools to allow better analytical capability for the Department'

2.2 APPLICATIONS

These two guiding statements help frame the requirements for applications that could suit a number of different TMR departments and work groups. The potential applications include:

- Asset management
  - supporting asset management with the additional information on heavy vehicle mass and volumes, particularly for pavement and structures
- Infrastructure planning
  - prioritising based on the value of the network, remaining life and heavy vehicle masses and volumes
- Pavement design
  - pavement design standards can be better informed with known loading on the network
- Structures
  - accurate loading information to develop bridge designs and maintenance
- Compliance and enforcement
  - insights for targeted enforcement of load limits
- Heavy vehicle access
  - management of heavy vehicle access to protect vulnerable infrastructure
- Freight and productivity
  - identification of freight routes, corridors and origin destination.

V-WIM will provide information on the heavy vehicle masses for a series of network links rather just a single point location. This is expected to reduce the need to make assumptions on loading for each of the identified use cases. In the process of developing a V-WIM network, the information derived from the WIM data will be in more usable form that can be easily queried without expert knowledge.

2.3 ROAD NETWORK

The priority for this project was the state road network, however it is worth noting that TMR has a 'one network' view and there is potential to expand the methods investigated for state roads to local roads.

The development of a V-WIM model focused on providing network-wide information rather than detailed information about select corridors, individual roads or locations. In this way, this project differs from the approach taken in the NACoE S26 project, which has linkages with this project, but has a focus on detailed and specific locations relating to the loading of structures.

3 NETWORK ALLOCATION METHODS

The foundation of the V-WIM concept is to extend data collected at a single location across a wider section of the road network. Several allocation methods were reviewed in order to identify the most suitable and effective method. Two common methods were identified as potentially suitable, these were:

1. Kriging based methods – interpolating the unknown regions based on known points
2. Network flow – modelling traffic flow across an edge-node network.

3.1 KRIGING-BASED METHODS

Kriging interpolation is a geostatistical technique for estimating unknown data based on their location relative to known sources. This method was originally developed for gold exploration and is commonly used across many different areas in which spatial interpolation of data is required. It uses a method based on inverse distance correlation to interpolate unknown data. There are many documented applications of the kriging-based method for traffic volume allocation, in particular extrapolating or predicting annual average daily traffic (AADT) traffic counts.

Lugo Serrato & Cochet (2014) examined using Kriging for Mexico's Federal Highway Association network and determined that it can be used to develop a continuous traffic count layer from point data sources.

Kriging interpolation has three main types that vary depending on the global mean, that is the mean value of measurement (i.e. traffic count) across the network:

- Simple
  - where global mean is known
- Ordinary
  - where global mean is not known
- Universal
  - uses trends to estimate global means.

As a result of these conditions, ordinary and universal kriging methods are typically best suited to traffic modelling.

Within these three broad types of kriging many different applications and methods have been developed. Of interest to the V-WIM application are those that use network distance rather than Euclidean distance (straight line distance) which allows spatial interpolation to function better on networks such as a road network. Segment based kriging described in Song et al. (2018) has been developed to utilise network distance along road segments and include segment attribute information in the models. The inclusion of attribution information in the prediction process allows road attributes such as road class and road width to act as weighting variables. This means that the process does not only use distance when predicting a value. For example, a minor road segment located close to a major highway counter will have a different value to a major highway segment the same distance away. This was shown by Song et al. to greatly increase the accuracy of the model to predict traffic counts and heavy vehicle proportions on the Western Australian road network. It is acknowledged that this method performs best with a dense network of sensors, which is not available in this instance, however, based on the results of this previous study this approach was identified to be the best option.

3.2 NETWORK FLOW

The other network allocation methods investigated for this project considered traffic using node-edge networks rather than line interpolation. There are two approaches used which are: network-in-network and network-node-connectivity.

The published examples of network-in-network models were used to interpolate traffic volume, however, they required a different form of input data. One example is given in Hackl and Adey (2019) which uses origin-destination data, along with a network graph to allocate traffic volume using a macroscopic traffic flow model.

This type of traffic allocation could be added as a separate module should origin-destination (OD) data become available to improve the accuracy of current estimates.

Network node connectivity is used to assess the reliability and route choice for a road network. A more connected node or network enables more diverse travel choice, a less connected node would allow less travel choice. It is likely that a less connected network could be more easily modelled so the connectivity may provide an indication of the ability of a model to predict the flow. However, there do not seem to be existing models that use network node connectivity to allocate traffic volumes.

4 TRAFFIC DATA SYSTEMS

A review of the traffic count data sources was conducted. This review included WIM but also covered other technologies, the additional data they provide and their ability to enhance the extrapolation method.

4.1 WEIGH-IN-MOTION

Weigh-in-motion is a term used to describe a number of different technologies that allow the mass of a vehicle axle group to be measured while the vehicle is still moving.

The following information is provided by WIM devices:

- axle group mass
- number of axles
- number of axle groups.

This basic information can be used to determine the vehicle type, class and GVM or GCM. This data is most commonly used for asset management purposes but is also useful for compliance and enforcement.

WIM sites are typically more expensive to install than counter and classifier sites, as a result there is a limited number on a network. The data obtained from WIM sites is often used to create tables of typical loads for various vehicle classifications so that loading information can be approximated at locations on the network.

WIM data offers the potential to provide greater value when combined with other data sources. These sources can include:

- counters
- basic classifiers
- detailed classifiers
- ANPR
- vehicle telematics.

4.2 COUNTERS AND CLASSIFIERS

Traffic counters and classifiers can also refer to a range of different technologies that provide vastly different datasets. The first key classification of this technology is if the site is temporary or permanent.

4.2.1 TEMPORARY COUNTERS

Temporary classifiers counts are typically collected using tube counters for a period of 1–2 weeks. These can produce detailed data for individual vehicles including:

- vehicle speed
- axle spacing
- axle configuration
- headway to other vehicles.

4.2.2 PERMANENT CLASSIFIERS

The three main types of permanent classifiers in order of data detail are:

- loop detectors
- piezo detectors

- infra-red beam detectors.

Loop detectors can typically only be used to measure speed and volume and at best only allow for broad categories of vehicle classification.

The piezo and infra-red technologies provide a more detailed dataset, similar to the tube counters listed above so include the following for individual vehicles:

- vehicle speed
- axle spacing
- axle configuration
- headway to other vehicles.

4.2.3 DATA AGGREGATION (SUMMARY) COUNTERS

Data aggregation or summary counters save on data storage and transmission, where the raw data collected by various detectors is aggregated into a simpler form. The aggregation methods preserve the generalised information about a traffic fleet by providing a count and speed summary of vehicles typically using time and vehicle classification bins. This data is still helpful for asset management using load tables but may not allow sufficient details regarding vehicle classification (by axle configuration) to allow vehicle tracking as discussed in Section 6.1.1. An example of the type of data output from summary counters is provided in Table 4.1.

Table 4.1: Example of data from a summary traffic counter

Time	Vehicle class	Number vehicles
2020-03-29 09:00	1	53
2020-03-29 09:00	2	10
2020-03-29 09:00	3	5
2020-03-29 09:15	1	49
2020-03-29 09:15	2	12
2020-03-29 09:15	3	6

4.3 AUTOMATIC NUMBER PLATE RECOGNITION

Number plate recognition technologies utilise cameras mounted on gantries or poles that provide a clear view of the front or back of vehicles along with optical character recognition software to record a vehicle observation in a machine-readable format. This allows a vehicle to be uniquely identified and with appropriate linkages it can also attach vehicle specific information to the observation such as GVM and vehicle classification.

ANPR provides a very rich dataset however typically a network will only have a small number of sites. Some uses for the data include:

- speed enforcement
- driver fatigue monitoring
- point-to-point vehicle tracing.

4.4 VEHICLE TELEMATICS

Telematics refers to a broad set of technologies that are generally used to keep track of the status of a vehicle while it is on the road. Pervasive across the heavy vehicle industry, telematics devices are used primarily for fleet management. Installed individually in each vehicle, these systems can allow the location, speed and mass to be monitored at any time from a central location. The data is sampled at regular intervals depending on the system. These can be every second or more commonly at 30-second or one-minute intervals and in some cases at 5-minute intervals.

Truck telematics can typically provide the following data:

- vehicle make and model
- GPS coordinates and heading
- vehicle speed
- vehicle mass.

This type of data is ideal for the assessment and management of heavy vehicle access restriction compliance. The combination of vehicle location and attributes such as gross combination mass mean that truck movements can be cross-checked against the restricted access network – yielding cases where operators have not been following access rules or permit conditions. With a large enough sample of telematics data, problematic areas could be identified paving the way for the development of appropriate treatments.

5 DATA SOURCES

5.1 TMR TRAFFIC DATA COLLECTION SITES

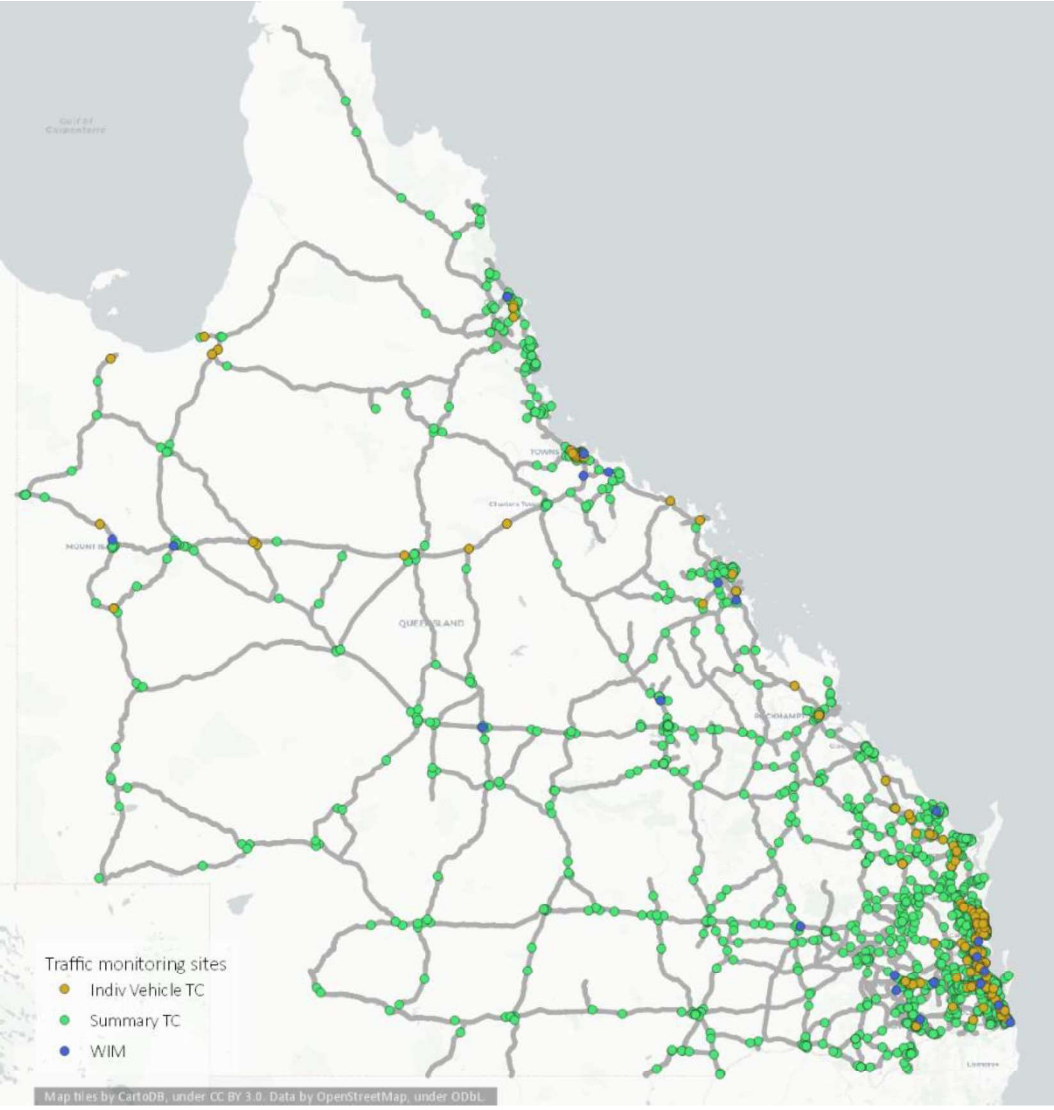
TMR has a large network of traffic counters and classifiers which includes a number of WIM and ANPR sites. The data provided by TRM contained 2008 counter sites. Table 5.1 shows the majority of these sites (1831) are Summary Traffic Counter sites which provide 15-minute bins of vehicle counts by Austroads classification. The remaining 177 sites (including 22 WIM sites) provide individual vehicle information including axle spacing and vehicle classification. It should be noted that not all these sites are active, which further reduces the availability of WIM data for extrapolation.

Table 5.1: Breakdown of traffic counter sites in Queensland by type

Site type	Number of sites	Proportion of sites
Individual vehicle traffic counter	155	8%
Summary traffic counters	1831	91%
WIM	22	1%
Total	**2008**	**100%**

The location of these sites is shown in Figure 5.1.

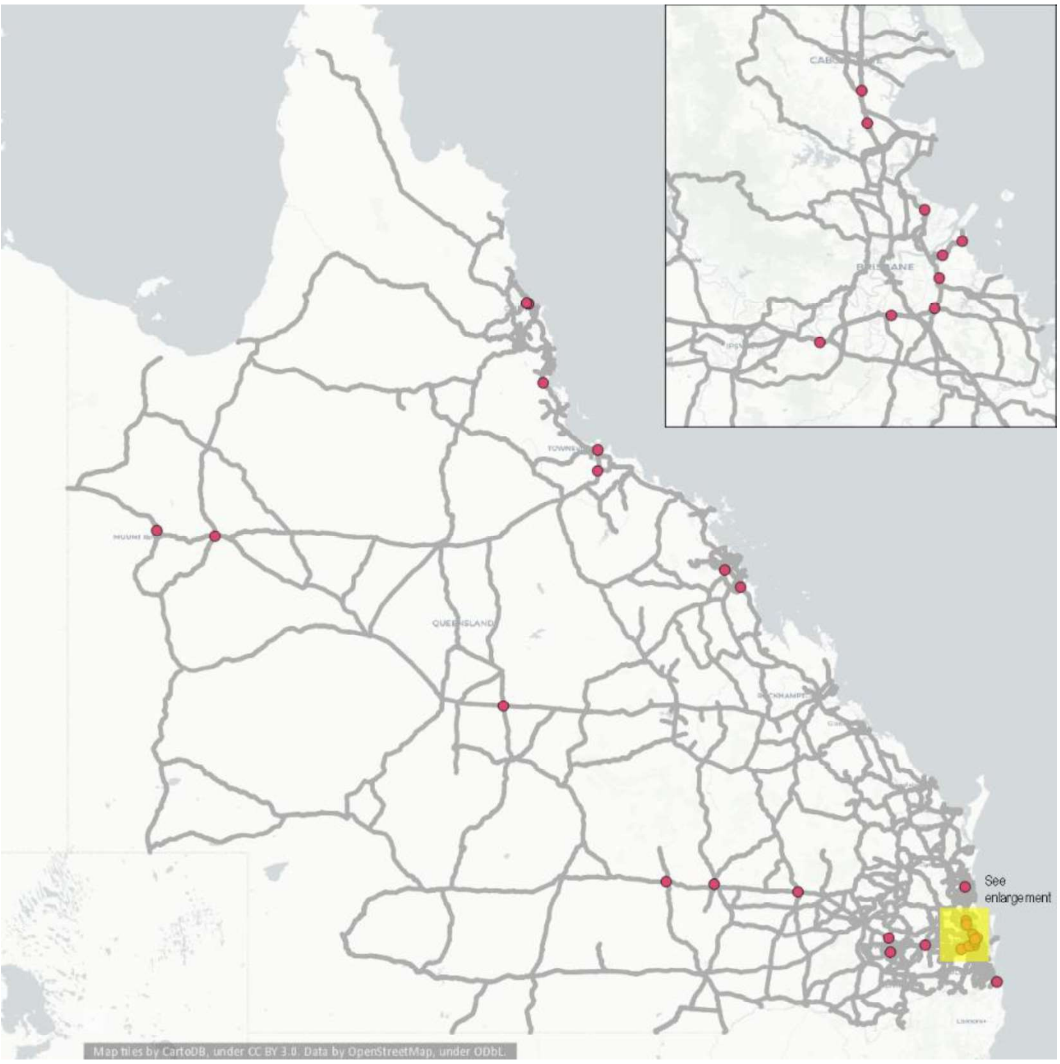
Figure 5.1 TMR traffic counter locations



Source: Data supplied by TMR

The traffic counter network is also supplemented by 27 ANPR sites which allows a record to be linked to the registration database for classification and compliance. It also provides point-to-point tracking of vehicles on the network. Figure 5.2 shows the location of TMR's ANPR sites.

Figure 5.2 TMR ANPR locations



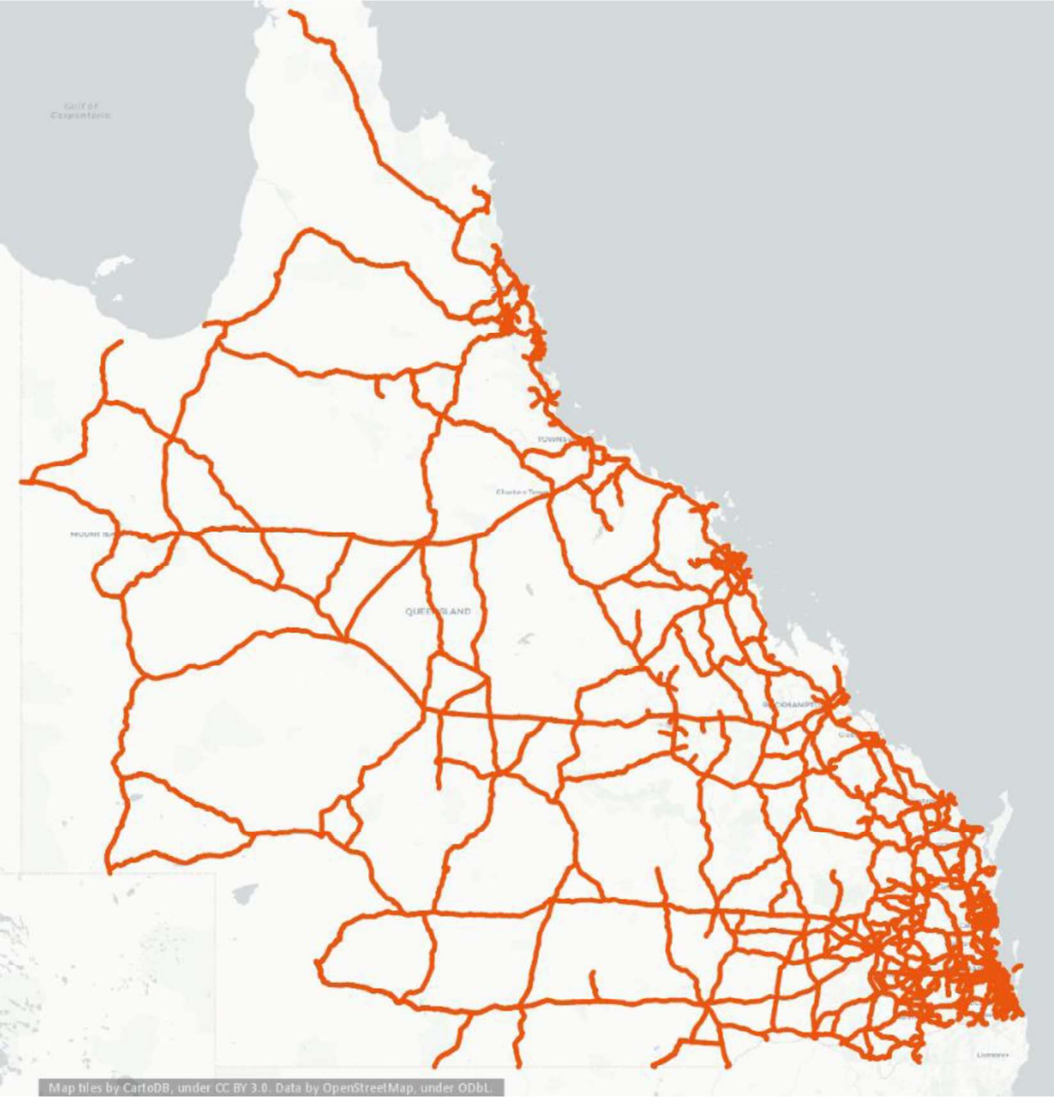
Source: Data supplied by TMR

5.2 ROAD NETWORK

In addition to network data provided by TMR the state-controlled road centrelines data was sourced from the Queensland Government (2020a) open data portal. This dataset provides a network connected at nodes but includes very little attribute information (e.g. no road class information) which may assist network extrapolation techniques in Section 6.2. Additional attribute information is available from other data layers including TMR datasets and third-party commercial datasets, which, if available, could be used to identify key freight routes and the location of structures assisting with the effectiveness of a V-WIM network.

The TMR road network is 35 879 km in length and is shown in Figure 5.3. The road network map is made up of 11 253 segments which generally break at major intersections as well as some mid-block locations.

Figure 5.3 Queensland state road network



Source: Open data portal: state-controlled roads (Queensland Government, 2020a)

5.3 BRIDGES

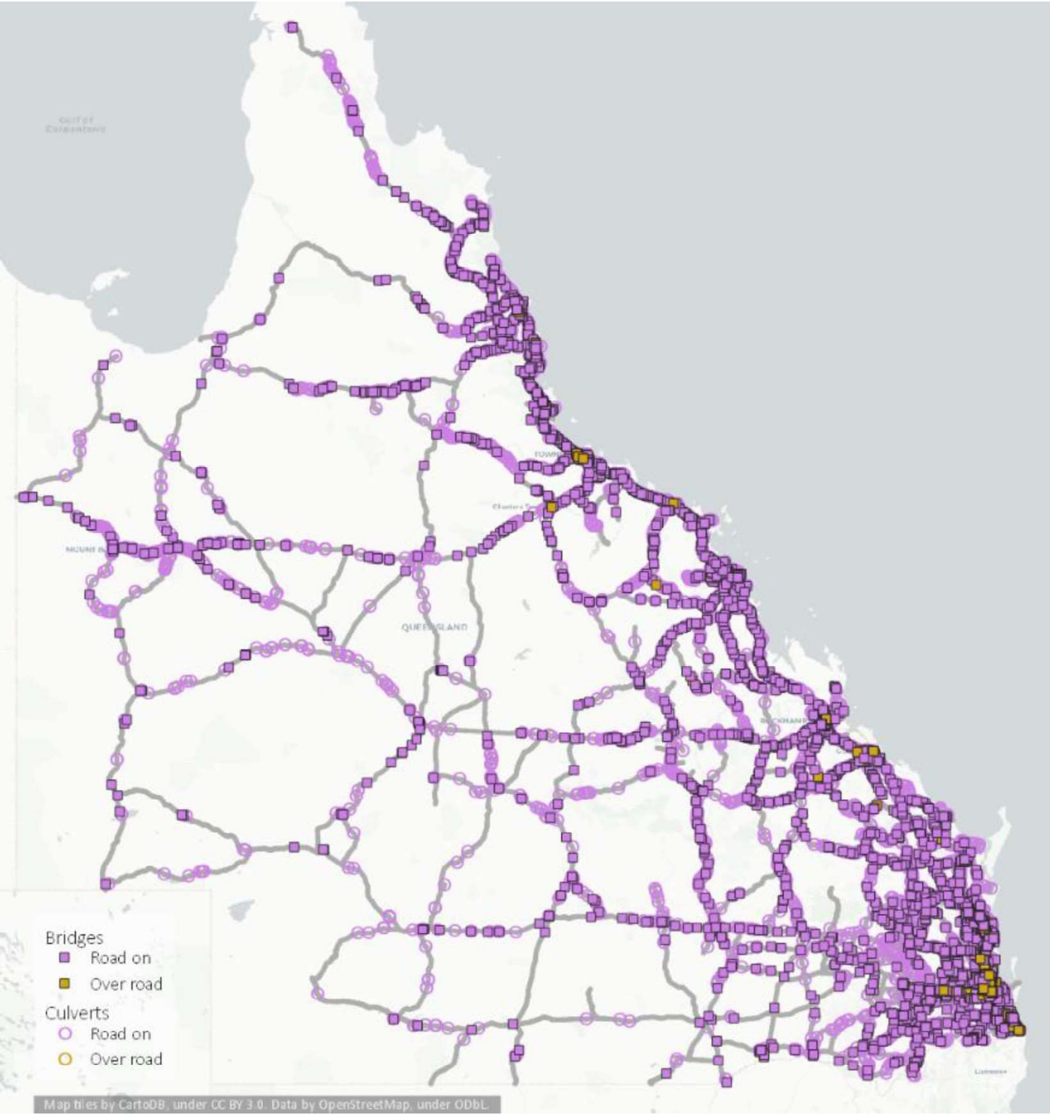
The location of bridges and culverts on the state road network was accessed as point data layers from the Queensland Government (2020b, 2020c) open data portal. This dataset includes all road bridges and overpasses for the entire Queensland road network as a line data layer. This dataset contained a total of 4080 bridges, of which a road passed over 3243. These bridges were the focus of this project. Table 5.2 shows the number of bridges by bridge type.

Table 5.2: Summary of bridges from the state network by construction type

Construction type	Road on bridge	Bridge over road
Arch	8	10
Box girder	36	50
Deck unit	2057	349
Girder/beam	1034	377
Slab	86	31
Special	22	20
Total	**3243**	**837**

Figure 5.4 shows the location of all bridges and culverts on the network.

Figure 5.4 Queensland state road network bridges and culverts



Source: Open data portal: state-controlled roads (Queensland Government, 2020a)

5.4 TELEMATICS AND ON-BOARD MASS

Vehicle telematics with on-board mass provides detailed information. It was not possible to source telematics and on-board mass data for this project for the reasons explained below.

Vehicle telematics data has some key limitations in relation to this use case. The first, and arguably least significant of these is that not all heavy vehicles are fitted with such a system. The insights provided by telematics will likely be concentrated on certain operators or locations. This is not necessarily an undesirable outcome, as the locations that are highly trafficked by heavy vehicles, such as the A-double route along the Warrego Highway between the Port of Brisbane and Toowoomba, will have a high volume of data to draw upon and produce more accurate results. However, such corridors are not representative of other corridors, especially those without the same level of heavy vehicle access. This highlights the importance of including other road attributes in the extrapolation process.

A major restriction is its availability. There are many different commercial telematics providers active in Australia, each providing their own unique fleet management products to operators. No universal telematics dataset exists for Australian vehicles. It is likely that each provider maintains uniquely formatted records that would require standardisation and consolidation of the different telematics data sources.

As an extension of the previous limitation, the major concern regarding the use of telematics data is privacy. With access to this information, it would be possible to discern routes, trip timings and travel patterns. With the accompanying speed, mass and other attributes, it would be possible to see if an operator was abiding by road rules and regulations, or even what types of vehicles constitute their fleet. This is sensitive information, and it is unlikely that any operator or telematics provider would provide it in unedited form to an external third party, in particular a road manager and/or regulator.

Data sharing platforms such as the Department of Infrastructure, Transport and Regional Development and Communications' National Freight Data Hub or open data marketplaces such as the TCA's National Telematics Framework can provide means for accessing truck telematics data that has been standardised, de-identified and consolidated as a single national dataset.

The shortcomings and challenges of using telematics data should be acknowledged but not prohibit further investigation of the potential use of this dataset. However this is outside the scope of this project. This project has pursued data sources accessible and within the control of TMR.

5.5 DISTRIBUTION OF ASSETS AND DATA COLLECTION SITES

Queensland has an extensive network of traffic counter and ANPR sites which can greatly assist allocating traffic count and mass data onto the network. However, in many cases these sites provide insufficient detail, with the majority of these sites providing only summary traffic information. This lack of detail restricts the use of these sites for vehicle tracking and extrapolation purposes.

As part of the process of investigating the feasibility of these data sources, several of the datasets were joined to the road network to examine the distribution of counters and bridges across the road network.

A summary of the distribution of assets on the network is provided below. The total number of road sections:

- that pass over bridges: 2130 (18.9%)
- with traffic counters: 2089 (18.6%)
- with summary traffic counters: 2016 (17.9%)
- with WIM sites: 33 (0.3%)
- with an individual vehicle traffic counter:247 (2.2%)
- with a bridge and a traffic counter: 755 (6.7%).

This investigation found that there are more road segments with counters than counter sites. This is because it has been assumed that where a counter is located on a divided carriageway road it will be collecting data in both directions and will therefore match to two segments.

It is unlikely that a network-wide vehicle tracking system will be possible (even for unusual vehicles) due to limited distribution of WIM, ANPR and classifier traffic counter sites on the network. However, there were multiple corridors across the state where this could be considered on a smaller scale and combined with network-wide data. Any work invested in developing a small-scale model would help inform both the feasibility and method for a larger network approach.

6 PROPOSED FRAMEWORK

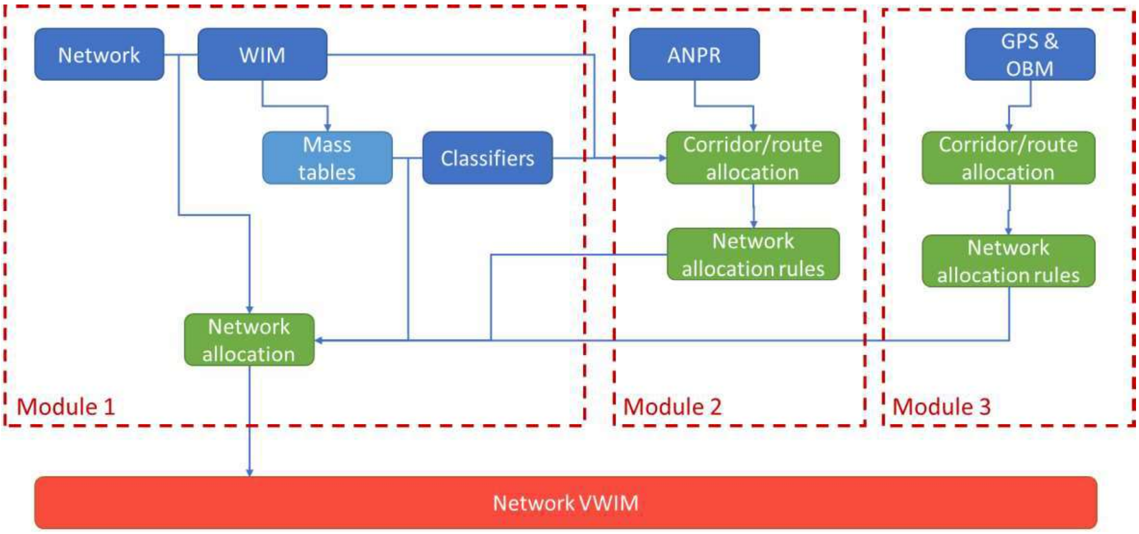
This project has links with NACOE project S26. A framework comprising three modules was proposed to guide progress and avoid duplicating work in both projects. Figure 6.1 shows the proposed framework and modules for developing network level V-WIM. All modules apply network allocation and extrapolation techniques to build the V-WIM network.

Module 1 uses data from WIM sites (mass tables) and classifiers.

Module 2 uses ANPR data.

Module 3 uses truck telematics (GPS and OBM).

Figure 6.1 Proposed framework and modules for developing network level V-WIM



This project focussed on developing a network wide V-WIM in Module 1 of the proposed framework. This was achieved by allocating from point data sources, but with the potential to accept inputs from other data sources (e.g. vehicle traces) in future stages of the project.

Additional modules could be added, for example utilising OD data sources or probe data to generate traffic counts on road segments. These datasets do not currently exist in a reliable format, however, even if these data sources are less reliable, they still have the potential to improve the data estimations generated in the earlier modules.

6.1 DATA TYPES

6.1.1 FIXED-POINT

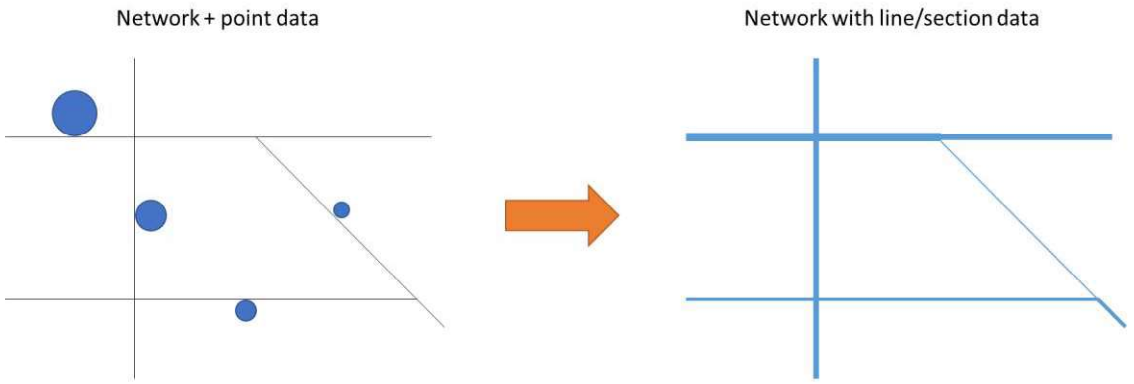
A fixed-point data source is one that provides a snapshot of a single location on the network. It includes data from a number of different technologies including:

- WIM sites
- permanent classifier sites
- tube counter locations (temporary)
- ANPR sites
- loop detectors.

One of the key benefits of fixed-point data is that it typically includes all vehicles passing that point rather than just a sample of vehicles, which makes these data sources a good measure of the 'truth' and suitable for the calibration of other data sources.

Figure 6.2 shows an example of what point traffic count data on a network might look like, with the centre of the circle indicating the site location and its size representing traffic volume, when converted to network segment volume.

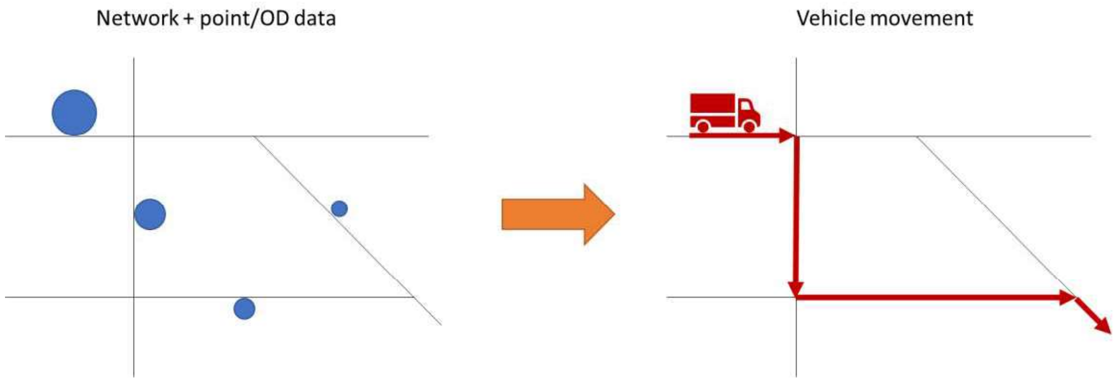
Figure 6.2 V-WIM point data converted to network section data (line thickness)



The process of generating network segment volume from point sources is typically called interpolation or extrapolation.

Figure 6.3 shows an example of converting point level data to vehicle trace or movements.

Figure 6.3 V-WIM point data converted to vehicle movements



Identifying vehicle movements from traffic count devices requires devices that measure axle spacing and then this is only likely to be possible for unique vehicle configurations. The process requires complex heuristic modelling to determine routes and therefore initial efforts should be focused on key routes with good data and vulnerable infrastructure such as bridges.

Despite these challenges it is considered worth pursuing because it will provide a greater level of detail on critical infrastructure, particularly for special purpose vehicles such as mobile cranes which often operate above typical mass limits. This approach could be pursued as part of the NACOE S26 project but is outside the scope of this project.

6.1.2 VEHICLE TRACE

Vehicle trace data is extremely rich, however, it often provides information on a small sample of the total population. Using a data source that is rich in information and localised, rather than representative of the traffic movements across the broader network can lead to biases. Even when combining different data sources, it is likely that this approach will produce biased results. For example, on-board mass may only be fitted to vehicles typically loaded to their mass limit in a given vehicle class. If many of the vehicles in that class are running below that mass limit (i.e. volume constrained vehicles) then an incorrect assumption may be made about the typical mass of that configuration. In addition, if unladen journeys are not included in the analysis then this will also lead to a misrepresentation of heavy vehicle movements and pavement loading.

Therefore, care needs to be taken when developing a method to incorporate vehicle trace data with existing data sources.

The two main uses of vehicle GPS trace data are to allocate the data directly to the network (Figure 6.4) or to develop origin destination data (Figure 6.5). Both data sets can be used to provide additional information into the V-WIM system, the option selected will be heavily reliant on the restrictions placed by the data provider and the frequency at which the data was recorded. The first option allows for better individual vehicle anonymisation and the second will work better with infrequent data logging.

Figure 6.4 V-WIM input using GPS trace data converted to network data

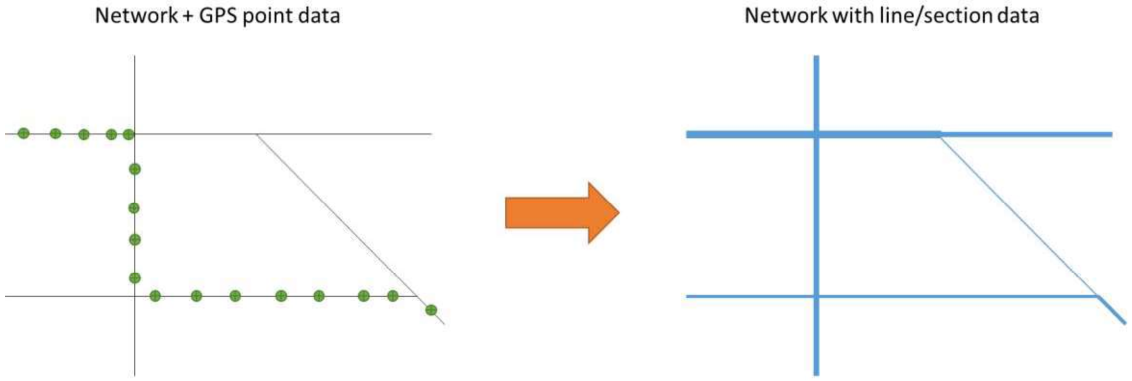
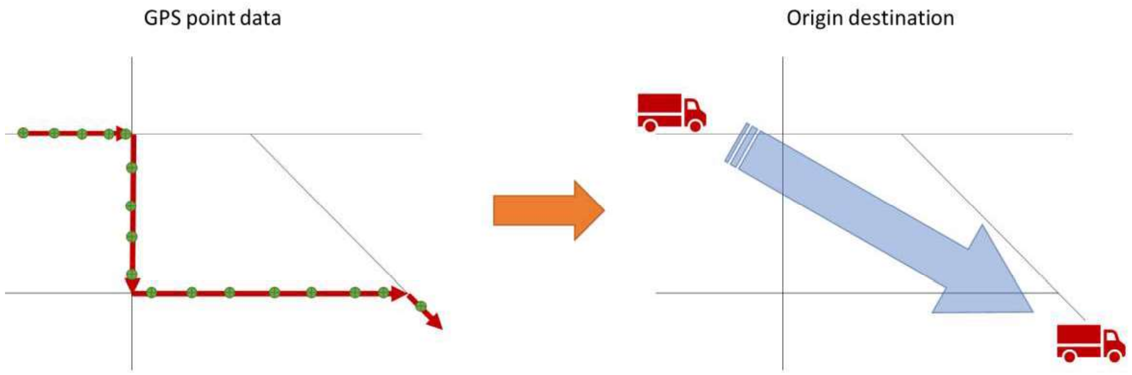


Figure 6.5 V-WIM input using GPS trace data converted to origin destination data



6.1.3 NEXT STEPS

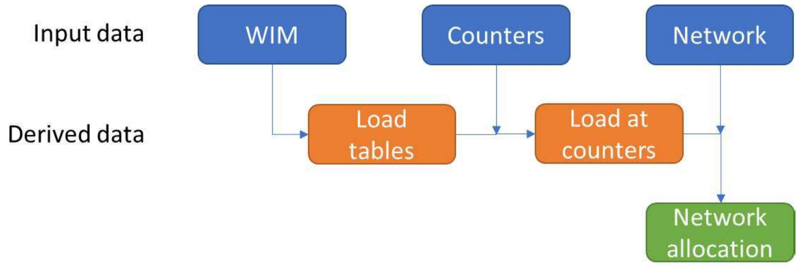
All data types identified as part of this project have the potential to provide additional information to a V-WIM system. As a first step and to remain within the scope of this project, only point data to network distribution will be considered. Point data was selected as it provides a base level of information that can be further improved with additional data sources in further iterations.

The proposed process to develop this data is to:

1. aggregate WIM data into load tables based on vehicle class and classify site by road and region type
2. allocate load table to counter sites
3. aggregate counter site data into load table categories
4. calculate totals for vehicle categories
5. apply network allocation.

Figure 6.6 shows the input data required for the module 1 process.

Figure 6.6 V-WIM module 1 process



The derived load tables could take the form of another metric that is best suited for the particular use case. For example, an asset management use case may require a metric of average mass per vehicle or average Equivalent Standard Axles (ESA) per vehicle. It is recommended that an initial implementation should use the simplest approach with average values before expanding to more complex data types.

6.2 NETWORK ALLOCATION

Network allocation is the process of taking the various forms of traffic data and attaching or distributingthem to a road network. When allocating point traffic data to a network, the most suitable technique was identified to be a spatial kriging method.

Many GIS packages include interpolation based on kriging methods however SK (Segment-based Ordinary Kriging and Segment-based Regression Kriging for Spatial Prediction) is an open source package for the R scripting language designed to allocate known traffic information onto an entire road network. The package was developed by researchers at Curtin University investigating the impact of heavy vehicles on road maintenance. Song et al. (2018) outline the methodology behind the SK package which also includes a test dataset based on Western Australian roads.

One of the advantages of this package is that it also uses additional weighting criteria to assist with traffic data predictions. These attributes (available from map data layers) may include:

- road class
- road width
- number of lanes
- freight network flag
- carriageway status
- remoteness.

These additional attributes will improve the model and allow for more accurate predictions about the distribution of the traffic data.

The data being distributed to the network is also not restricted to traffic volume data. Some other possibilities include:

- heavy vehicle volume
- volume by vehicle class
- tonnes of freight
- ESAs.

6.3 COMBINING DATA TYPES

Combining data sets with different samples, different data types and different biases is a field of statistics all of its own. While some transport examples exist, most of the best documented cases relate to large scale survey data such as census data and general household surveys, as well as other smaller data samples, including face-to-face interviews.

As outlined in section 6.1, the data types differ in geospatial format (point, line or network), information (location and/or mass) and confidence. Therefore, the best method for combining datasets will depend on the data type and intended purpose which may also relate to each other.

Improved results can be acheieved by combining datasets, such as updating load tables collected at a counter site with route-based mass data. If the load tables contain a single value per vehicle category such as mean gross mass the process of updating the mean is a simple equation. However, if the intended purpose is to calculate the total ESAs then a single mass value will not produce a good result because the relationship between ESAs and mass is not linear, and using the mean mass will underestimate the ESAs in a vehicle class (or axle group type). For this purpose, load tables containing a mass distribution for each vehicle category will more closely mirror reality and produce better estimates of ESA (and mass).

The method required for combining these distributions can largely be drawn from Bayesian statistics. For example updating a load distribution (prior distribution) with additional loading data (from which the likelihood distribution is derived) can be expressed as Equation 1.

$$P(\theta|data) = \frac{P(data|\theta) \times P(\theta)}{P(data)} \quad (1)$$

where

$P(\theta)$	=	Load table distribution (prior distribution)
$P(data\|\theta)$	=	New data distribution (likelihood distribution)
$P(\theta\|data)$	=	Combined distribution (posterior distribution)

The process of combining distributions is relatively simple when applied to gaussian or normal distributions, however it becomes significantly processor intensive if they are not. For irregular distributions simulation techniques such as Markov Chain Monte Carlo methods are required to combine them into the posterior distribution.

Other methods such as probabilistic record linkage (particularly in conjunction with imputation methods) and small-area estimation methods could also provide additional options. These techniques may prove more effective when combining network-wide traffic data sources after the network allocation stage.

There is no ‘one size fits all’ approach that can be applied to combining datasets, each case in the process will need to be developed based on data types and desired output, however the foundations for these methods is well documented in literature.

7 CONCLUSION

Implementing a V-WIM system for Queensland will have major benefits for road managers. Once data is available there will likely be use cases in other areas as well.

The proposed approach is to develop modules which can be combined at each stage of the project to provide better system-wide estimates. This allows the system to be implemented sooner while scoping the feasibility of further stages.

The relevant data, research and software packages to support the implementation of module 1 of the framework have been outlined.

Development and refinement of extrapolation techniques can be explored in future projects. It is recommended that the following methods be used:

- segment-based ordinary kriging

and for spatial prediction

- segment-based regression kriging.

Development of V-WIM requires sample data. Point data was identified as suitable for the initial stages as it provides a base level of information that can be further improved.

A five-step process was proposed for building a V-WIM network from these data sources:

- WIM (derived data tables)
- traffic count data
- a road network comprising road links.

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