TRAILER MONITORING INTEROPERABILITY IN AUSTRALIA

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ABSTRACT

Transport Certification Australia (TCA) has identified the future need of a trailer interoperability system in Australia to support a range of regulatory telematics applications. Currently, drivers manually self declare trailers and other parameters of interest to regulators. A range of trailer monitoring devices are already in the market but many systems are stand alone. Trailer interoperability relates to the system able to identify an attached prime mover and trailer combination. The proposed trailer interoperability system is based on a back-office interoperability solution which permits interoperability between any certified in-vehicle unit and trailer-mounted monitoring devices. This paper reports on the current progress of this project in Australia.

KEY WORDS

trailer interoperability, Intelligent Access Program, trailer monitoring, mass monitoring

1. **BACKGROUND**

Transport Certification Australia Ltd (TCA, www.tca.gov.au) is an organisation which develops and administers the Intelligent Access Program (IAP) in Australia. The IAP is a voluntary program which provides heavy vehicles with access, or improved access, to the Australian road network in return for monitoring of compliance with specific access conditions through the use of in-vehicle tracking devices. TCA has identified that trailer monitoring will be required in the future as part of the process of heavy vehicle monitoring. In order to perform trailer monitoring, interoperability must be achieved, so that connected prime mover and trailer(s) will be able to provide information about the whole vehicle.

In order to address the requirements for trailer interoperability, TCA commissioned a study on the industry capability of implementing the trailer monitoring system (1). This study investigated both the current capability and capability under development. Following the capability study, a range of technical options to achieve trailer interoperability were identified, and a back-office option was recommended (2).

A feasibility project plan was subsequently approved. This project aimed to investigate the technical feasibility, business structure and operational requirements for such a trailer interoperability system.

2. CAPABILITY AND OPTIONS FOR TRAILER INTEROPERABILITY

2.1 Industry Capability

Discussions with various telematics experts in Europe and the USA showed that trailer monitoring was uncommon in both of these regions, and trailer interoperability was even less common due to the fact that most trailers are dedicated to their prime movers (1). On the other hand, it is common practice in Australia for one transport operator's prime mover to tow trailers from numerous other operators and suppliers (3). Therefore, trailer interoperability will be essential in Australia.

Currently, drivers use a manual input device to record the presence of attached trailers together with other trailer data as required by regulators, transport operators or customers. Automatic identification of trailers to a prime mover will potentially yield considerable benefits to transport operators in time savings and to regulators in increased reliability of the information recorded.

After a series of discussions and investigation with different telematics suppliers, current trailer monitoring technologies were classified into three categories:

1. Autonomous solution which is self powered, and able to operate localisation (GPS) and communication without assistance from the prime mover.
2. Tethered solution which requires physical connection to the prime mover for power supply and is able to perform localisation and communication.
3. Roadside checking solution which utilises roadside infrastructures to track vehicles that passing through via dedicated short range communication (DSRC).

Possible players in trailer monitoring were also identified in the study. Table 1 summarises the possible players and their roles.

Table 1: Trailer monitoring players and their roles

Player	Role
Sensor provider	Provide sensors which collect low level data about the vehicle
Service provider	Provide trailer monitoring services
Operator	Own vehicles/trailers and provide transport services
Customer	Own freights and purchase transport service
Network provider	Provide telecommunication networks
Regulator	Regulate and enforce non-compliance

Based on the capability study, four solution models were proposed (1,3). The implementation of each model is quite distinct, and the main difference between models is the way data is collected or logged. These four solution models are:

1. Master-slave
   In a master-slave system, the prime mover has the in-vehicle unit (IVU) which acts as an intelligent unit for the system. Sensors located in each part of the vehicle collect data and transmit to the IVU via a bus (wire or wireless). The IVU then transmits all the information collected to the service provider via mobile phone networks or satellite networks. The differentiating features in this model are the protocols and interfaces of the communication bus.

2. Stand-alone
   In a stand-alone system, the prime mover has the IVU, and the trailers are also equipped with a trailer monitoring device (TMD) which is also an intelligent unit. No communication between IVU and TMD is required. Instead, each IVU and TMD collects and transmits data to the associated service provider individually via mobile or satellite communication networks. The information is then assembled into information about the whole vehicle by correlating information such and speed and location to identify the combination. The service provider then reports to operators and regulators.

3. Roadside checking
   In this model, each prime mover and trailer is equipped with a passive Radio Frequency Identification Device (RFID) which collects data from on board sensors, and uploads the information to the roadside checking stations as the vehicle passes by. The checking stations assemble information about the whole vehicle and communicate this to the regulator.

4. Manual
   In this model, the information on the trailer is gathered by either the driver or the operator and provided to the regulator. This model includes the existing IAP self-declaration function.

2.2 Implementation Option

Following the capability study, six options were shortlisted for further assessment. Jurisdictional, regulator, industry and other common requirements were also identified, and an effectiveness rating was given to each of the shortlisted options against each requirement. A financial analysis then estimated the costs of each implementation option, including non-recurring cost, recurring cost and industry size. With the evaluated effectiveness ratings and costs, a costs per effectiveness ratio was calculated for each shortlisted option with different industry size. The option of a stand-alone model, with interoperability being achieved in the back office, appeared to be most effective for all of the industry sizes analysed, and was recommended as the preferred option for trailer interoperability (2, 3). In this option, each service provider collects information about the part of the vehicle that is under its monitoring, and sends it to a common back-office which assesses all information and assembles prime mover – trailer(s) combinations. Figure 1 shows the map for this option.

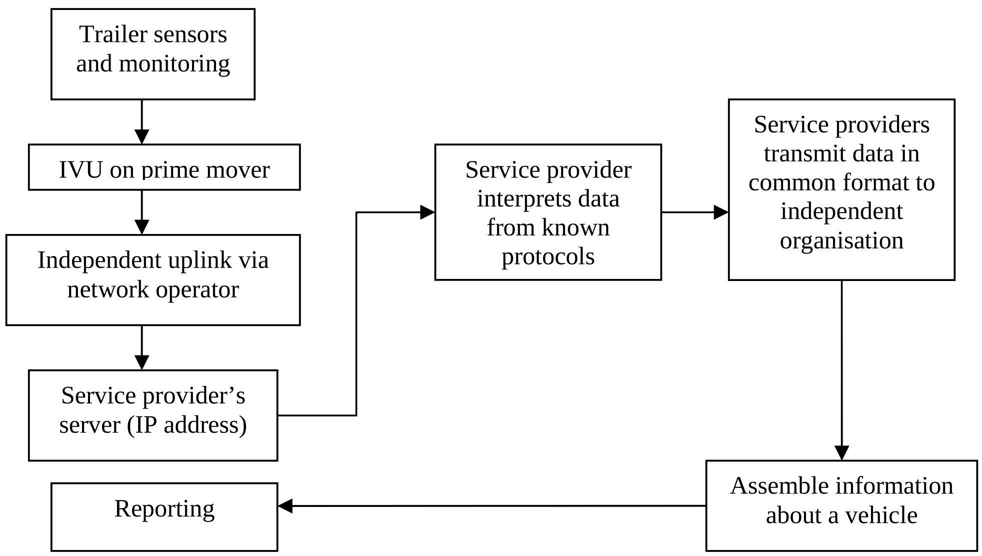


Figure 1: Option map for option 2D

3. FEASIBILITY STUDY FOR PREFERRED OPTION

The feasibility study encompassed assessment of three key areas for back-office interoperability; operations, business structure and technical feasibility (Figure 2).

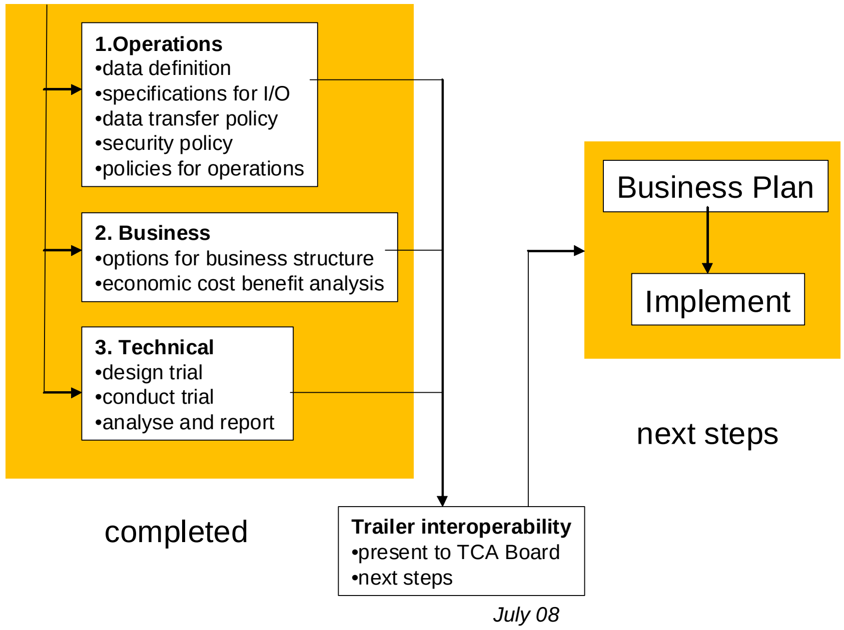


Figure 2: Trailer interoperability project phases (4)

3.1 Technical Feasibility

Two steps are required for a successful trailer matching process; allocation of the trailer(s) to the prime mover and sorting of the trailers in combination order. Position records are the primary inputs to the trailer matching process, and they are collected via GPS sensors.

Two main sources that could result in matching error were identified: the clock synchronization between the GPS records from the TMD and the IVU; and the GPS antenna placement on the trailer (5). The first source of error could be addressed by specifying the required time epoch to be at 0s and 30s for GPS data (IVU collects position records every 30s under IAP). The second error source was outside the scope of this project and would need to be addressed in future specifications for TMD.

The trailer matching process allocates a trailer to the closest prime mover. This could be done by performing the "nearest neighbour search" algorithm. Several searching algorithms were investigated (5):

- Linear scan: compute the distance from the trailer to every prime mover in the data base, keep tracking for the closest prime mover "so far".
- Kd-trees: iteratively bisect the search space into two regions containing half of the prime movers. Queries are performed via traversal of the tree from root to leaf by evaluating the query point after each split. The closest prime mover is then found at the end of the split process.
- Voronoi diagram: an advanced technique which subdivide geometric space into regions, according to which point is closest to the prime movers. A trailer falls within a partitioned region has the shortest distance to the prime mover that within the same region.

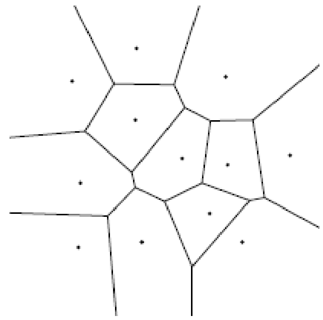


Figure 3: Voronoi diagram (5)

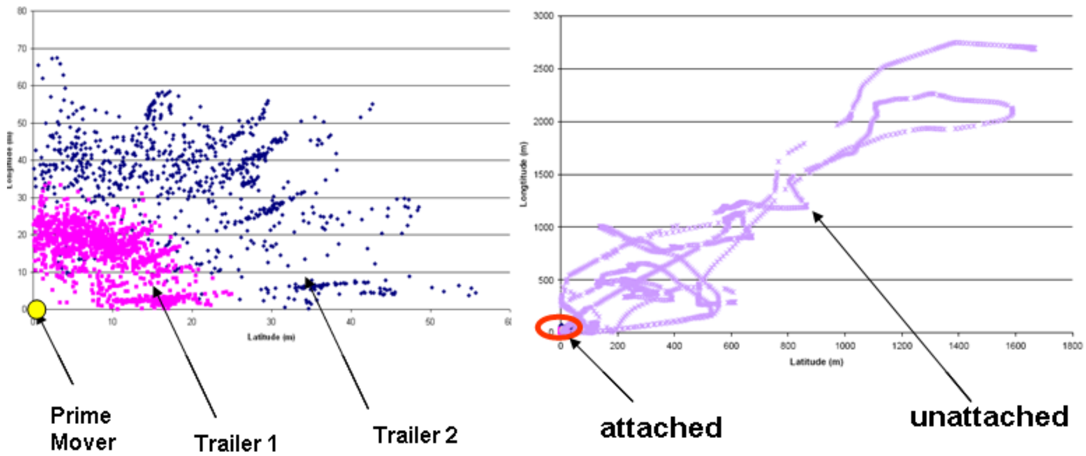
The linear scan algorithm is simple to implement, but its computational time increases exponentially with the number of trailers and prime movers, thus it is not practical for a large industry size. Both Kd-trees and Voronoi diagram algorithms were considered feasible for the trailer matching application in Australia. A Voronoi diagram based simulation was performed on a laptop, with the assumption that 20,000 prime movers and 30,000 trailers randomly located in a square of dimension 1000 × 1000km. The running time was found to be within 3s. This result will be different when running with different computers, but it is likely to be insignificant time in general.

However, it was found that the closest prime mover would not always be the correct one that towing the trailer. For instance, if two road trains traveled side by side, a trailer may be closer to the prime mover which it is not physically attached to. Therefore, additional information has to be considered in order to produce a robust solution. The algorithm developed includes the following factors:

- recording all the nearest neighbours within a radius
- calculating relative heading of the TMD to the IVU to determine the direction of travel
- measuring average and standard deviation of IVU-TMD distance
- tracking IVUs over multiple epochs.

The solution tracks the candidate prime movers over multiple epochs to achieve more accurate position accuracy by averaging GPS random error. In addition, the behaviour of other prime movers (velocity, heading) may diverge from the target IVU over time. With these improvements, the solution algorithm was able to produce a reliability of 99.9% (5). Once the trailers that attached to the same prime mover were identified, the IVU-TMD distances can be used to sort out the combination order.

Field demonstration: In parallel with the development of the matching algorithm, TCA undertook a field demonstration for trailer matching. Three vehicles were driven on local roads in the Melbourne area, one following another, with minimal distance between each other to simulate a prime mover pulling two trailers. In another test, three cars were driven independently to simulate the case when the prime mover and trailers were not attached. Each car was equipped with a GPS receiver and data logger, and GPS position records were collected for analysis. Figure 4 (a) and (b) shows the attached and unattached trailers positions relative to the prime mover (6). It can be seen that an attached trailer will display a consistent and reasonable distance to the prime mover over time. Furthermore, the medians of the trailer-prime mover distances also provide the order of the combination.



(a): Attached trailers positions **(b): Attached and unattached trailers positions**

Figure 4 (6)

3.2 Operational Feasibility

A number of potential operational scenarios were identified through the discussion with the jurisdictions (7). This gives a guide for later work on defining the high-level business requirements for the system to ensure that the system specified is capable of covering both the common elements and the specific differences arising from these scenarios. The identified scenarios are:

- Replacement of manual declaration for Higher Mass Limits (HML)
- Incremental pricing
- Performance-Based Standards Combinations
- Quad-axle Semi-trailers and B-doubles
- High Productivity Freight Combinations/B-triples
- 40-40 Vehicles/Super-B-double
- Unescorted Low Loaders
- Specialty Trailers.

The scoping document also identified the roles and objectives of all key stakeholders. A context model of the trailer interoperability system with major information flows between relevant parties is illustrated in Figure 5. This model is based on the existing IAP Functional and Technical Specification, with additional information that relates to trailer interoperability.

The existing IAP and the scope of trailer interoperability also provided for the decomposed high-level functions for the system:

- Manage trailer monitoring device (TMD)
- Manage intelligent access conditions (IAC)
- Manage Combinations
- Manage TMD alarms
- Manage non-compliances.

Further decomposed functions and the business requirements were provided in the System Scoping Document (8).

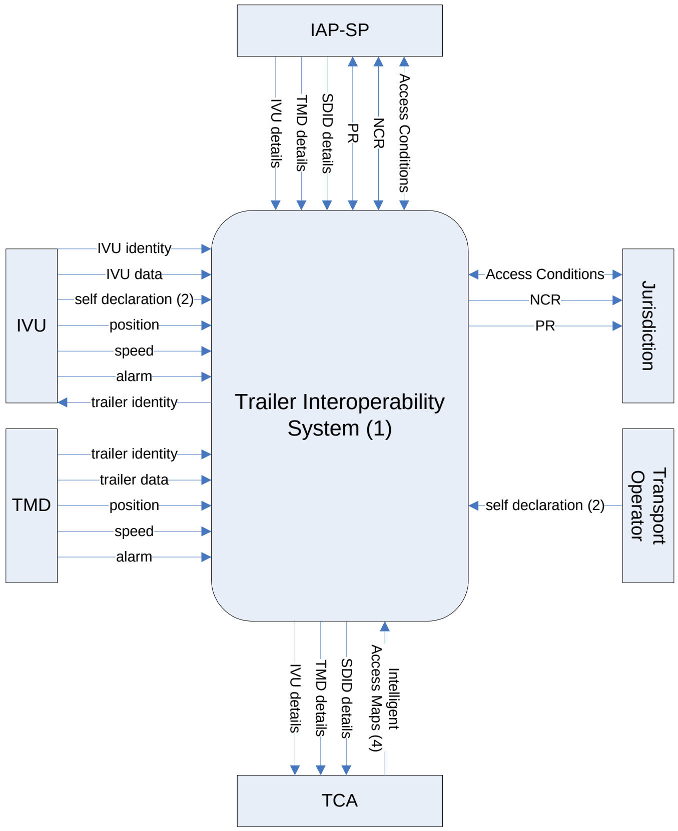


Figure 5: Major information flows for trailer interoperability system (8)

Note:

1. The "Trailer Interoperability System" incorporates all the components necessary to implement the system, including IAP service Provider (IAP-SP) and separate back-office systems.
2. Self-declarations include details of configuration and total combination mass. They may be Transport Operator and IAP-SP.
3. Intelligent Access Maps are provided by TCA directly to IAP-SPs via a path outside of the scope of the Trailer Interoperability System. The data flow indicated on the diagram is to record the likelihood that TCA will also need to provide these maps to any back-office system.

After the interviews with industry and jurisdictions, on-board mass-monitoring (OBM) was identified as a major opportunity for IAP, especially when coupled to trailer interoperability. The mass of vehicles is the major concern of the jurisdictions, particularly for asset protection. Therefore, it will affect the access conditions for heavy vehicles. A robust on-board mass-monitoring process requires explicit mass information about the vehicle combination, more specifically, each axle group. Hence, trailer interoperability and on-board mass-monitoring together will provide a possible solution to automate and transmit mass data for each part of the vehicle combination.

Road user charging was identified as another key opportunity for trailer interoperability in the future, especially if linked to on-board mass-monitoring. With trailer interoperability, more precise charging schemes could be implemented.

3.3 Costs-Benefit Analysis

In order to assess the economic feasibility of a back-office solution for trailer interoperability, an economic costs and benefits analysis for government and commercial operators was undertaken (9).

The analysis separated the impacts of trailer interoperability into first and second order impacts. The first-order impacts assumed that by replacing manual data entering with automatic recording in trailer interoperability, benefits were generated from time saving and reliability gain. Some key assumptions were made for the analysis:

- Present value of the cost of TMD – $7,000/vehicle
- Present value of the cost of on-board mass-monitoring (OBM) – $7,000/vehicle
- Present value of the cost of back-office – $170,000
- Time saving with TMD – 10mins/week/vehicle
- Time saving with OBM – 20mins/week/vehicle
- Number of vehicles – 3,000

Based on the above assumptions, benefits and costs associated with different items were calculated and presented in Figure 6. In these items, time saving, TMD cost and OBM cost are relevant to transport operators; reliability gain is relevant to government; back-office cost could be relevant to either or both transport operators and government, depending on the way it is established. Trailer interoperability is feasible in the cases where the net social benefits, which is the combination of transport operators and government benefits, are positive.

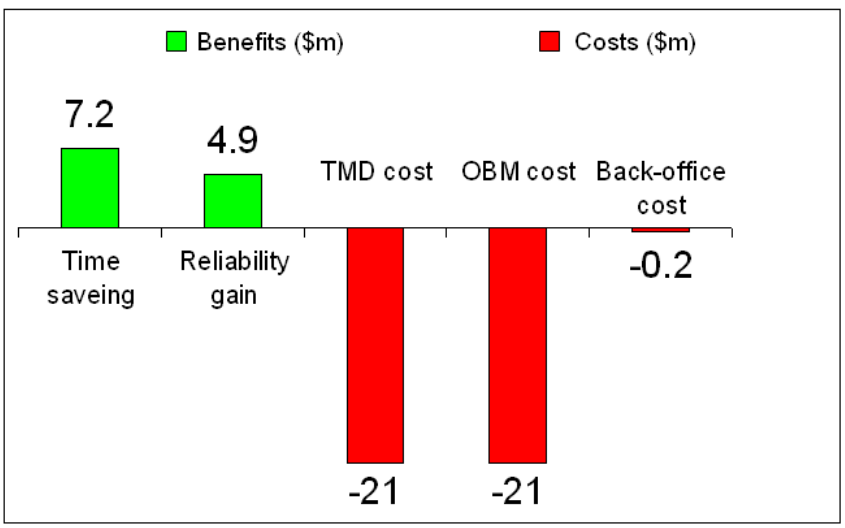


Figure 6: Benefits and costs for different items in trailer interoperability

The economic impacts of trailer interoperability are largely dependent on the equipment already installed on trailers, and the equipment that need to be installed. Six possible analysis cases were identified, and the net social benefits associated with each case is summarised in Table 2. The feasible cases appear to be those which have either or both TMD and OBM previously installed on trailer. It is clear that existing on-board equipment has the most sensitive impacts on this analysis. Given that the costs of installing on-board devices greatly outweigh the benefits it brings upon itself, no overall benefit could be generated unless these devices come along with the trailers when purchased.

Table 2: Impacts of trailer interoperability by analysis case

	Net benefit ($m)	**Net benefit per vehicle ($)**
Neither TMD nor OBM previously installed, Transport Operators install TMDs to save 10mins/week/vehicle	-9.1	-3,000
Neither TMD nor OBM previously installed, Transport Operators install both TMDs and OBMs to save 30mins/week/vehicle	-15.7	-5,200
TMD is previously installed, transport operators save 10mins/week/vehicle	11.9	4,000
TMD is previously installed, transport operators install OBMs to save 30mins/week/vehicle	5.3	1,800
OBM is previously installed, transport operators install TMDs to save 30mins/week/vehicle (1)	5.3	1,800
Both TMD and OBM are previously installed, transport operators save 30mins/week/vehicle	26.3	8,800

Note:
1. In a back-office solution to trailer interoperability, OBM is not able to work alone without TMD.

In addition to the first-order analysis, a second-order impact of trailer interoperability found that the benefits created by trailer interoperability would lower the effective price of the IAP, so making it more attractive and increasing take-up of IAP.

4. SUMMARY

With the intention of adding future value to the current Intelligent Access Program (IAP), Transport Certification Australia (TCA) has investigated a solution enabling interoperable trailer monitoring.

It was found that trailer matching could be achieved by solving the “nearest neighbour problem”. To significantly reduce the complexity of the problem, GPS position records collected by IVUs and TMDs should be synchronised. A number of algorithms were investigated, namely linear scan, Kd-trees and Voronoi diagram. To compromise errors introduced by environmental and practical issues, a few improvements were added into the full algorithm, including comparison of IVU and TMD headings, measuring average and standard deviation of IVU-TMD distance, and tracking possible combinations over time. The solution algorithm was able to produced a reliability of over 99.9%, and a computational time of a few seconds for 30,000 trailers and 20,000 prime movers on a normal laptop. A TCA demonstration also illustrated the capability of allocating trailers to the attached prime movers via GPS position records.

An operational feasibility study was also undertaken. A system scoping document was produced to address and examine the operational issues related to the implementation of a trailer interoperability system. The scoping document identified eight potential operational scenarios of trailer interoperability in Australia, major information flows between all relevant parties, and the high-level functions of the system as well as the business requirements.

A cost-benefits analysis on the back-office trailer interoperability system was commissioned. The analysis assumed that primary benefits were generated from driver time saving and reliability gain; costs were resulted from installation of TMD and OBM, and establishment of the back office. Six possible analysis cases were examined and the estimated net benefits ranged from -$15.7 m to $26.3 m, or -$5,200 to $8,800 per vehicle. The results showed that the costs of the on-board equipment were the most cost sensitive factor. The analysis also identified a second-order benefit generated by increase in the take-up of IAP.

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