Australasian Transport Research Forum 2017 Proceedings
27 – 29 November 2017, Auckland, New Zealand
Publication website: http://www.atrf.info

Economic benefits of Smart Motorway applications

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Abstract

Smart Motorways (also known as managed motorways) increase mainline throughput and network productivity, prevent traffic flow breakdowns and increase travel time reliability. By managing the traffic flow speed differentials are reduced which in turn lowers road crashes. Smart Motorways can consequently manage incidents and reduce associated vehicle delays. Other advantages include the ability to collect real time traffic information and provide it to users to assist them in mode choice in pre-trip planning, route choice before entering the motorway or diversion decision if the motorway is highly congested or an incident has occurred. While a Smart Motorway will generate economic benefits, many economic appraisers have found it challenging to quantify the benefits due to lack of published methodologies and evidence. This paper presents the potential benefits of Smart Motorway applications extracted from the managed motorway benefit database that the authors established in practical economic appraisals of managed motorway projects. The benefit database is based on 96 project case studies of international managed motorways, Intelligent Transport Systems (ITS) and active transport managements. The estimated benefits and benefit-cost ratios from two economic appraisal projects in Australia are presented to provide interested readers a range of economic benefits of Smart Motorways.

1 Introduction

The M4 Smart Motorway[1], West Gate Freeway managed motorway[2] and Bruce Highway Managed Motorway[3] are three examples of Smart Motorways that Australian road agencies are implementing or planning, and further Smart Motorway projects are in the pipeline. As Smart Motorways are relatively new, there is generally a lack of guidance and proven methodology for estimating the economic benefits. An economic appraisal as part of the project business case is required to demonstrate the project justification and value for money. The objective of this paper is to share research into the economic appraisal of Smart Motorways undertaken in Australian jurisdictions.

2 Smart Motorway technologies

The Smart Motorway, also known as managed motorway, is a form of road network management that optimises the traffic flows on a motorway's mainline and arterial roads. It detects and responds to traffic incidents. It also collects and provides real-time traveller information and provides data for performance monitoring and evaluations. The whole system is also broadly referred to as an Intelligent Transport System (ITS). The Smart Motorway generally includes a combination of the following technologies:

[1] http://www.rms.nsw.gov.au/projects/sydney-west/m4/

[2]https://www.vicroads.vic.gov.au/planning-and-projects/melbourne-road-projects/west-gate-freeway-managed-motorway-project

[3] https://www.tmr.qld.gov.au/Projects/Name/B/Bruce-Highway-Managed-Motorway-Project

- **Coordinated ramp metering**: Control the traffic entering a motorway by means of traffic signals on the entry ramps and to optimise the traffic throughput and travel speed in mainline.
- **Lane use management systems (LUMS)**: Allocate and manage the available road space through display of variable speed limits (VSL) and lane control signals (LCS). Speed limits and lane status are varied in response to changing road and traffic conditions.
- **All-lane running (ALR):** An operational strategy where all lanes on a carriageway are used as running lanes on a full-time basis (i.e. there is no emergency lane). LUMS is deployed to enable safe operation of routes where there is no emergency lane (i.e. all lanes are trafficked) on a part-time or full-time basis. Such operations can provide significant capacity improvement without the need for motorway widening.
- **Part-time emergency lane running (ELR):** The emergency lane is used for traffic in peak-hours only as a means of capacity increase or incident management.
- **Variable message signs (VMS).** Used either on mainline, or arterial roads or both. Provides traveller information as well as a means of incident management. Diverts traffic from entering the motorway when traffic conditions on the motorway are congested.
- **Variable speed limits (VSL)**: Either side-mounted or integrated within a lane use management system (LUMS). Provides safety enhancement and incident management.
- **CCTV cameras for traffic surveillance.** They monitor operations as well as assist in lane use and incident management. Separate cameras are generally required for mainline monitoring and monitoring of the ramp signalling. They are a useful tool in congestion management, including assessment of congestion on arterial road approaches to the motorway. CCTV is used for monitoring of ramp queues and fine tuning the ramp signals' operations. They are also used to identify driver behaviour and operational issues such as incidents and planned events, while CCTV images are shared with key incident and emergency management partners.

3 What are the benefits of Smart Motorways?

The key benefit of Smart Motorways is to provide increased capacity and improve travel time in peak hours. "*An unmanaged motorway performs at its worst when it is needed the most, i.e. at peak times when demand is highest, and can reduce the performance of the wider network as well*" (Austroads 2016, p5). Smart Motorways also generate benefits through road safety and incident management.

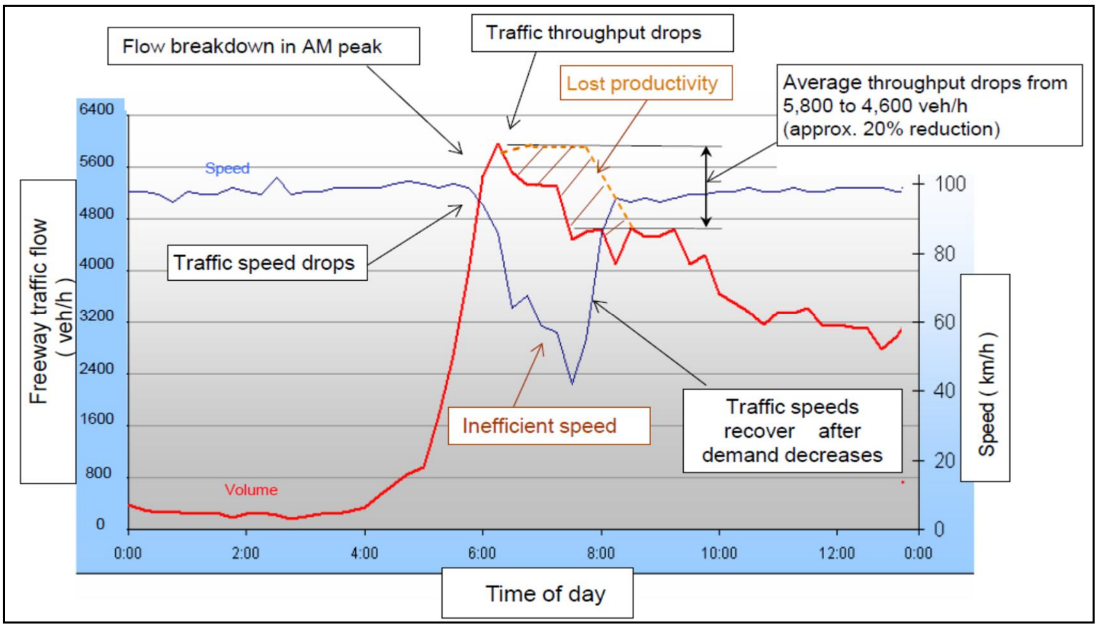
3.1 Increased throughput and productivity on mainline

It has been observed that motorway flow can break down very rapidly when the demand approaches the capacity of the road. The resulting congestion can last for many hours, or even the whole day (Austroads 2016, p5).

Motorway traffic flow breakdown usually creates significant reductions in throughput and vehicle speeds which can result in substantial increases in travel time. During the period of flow breakdown, lane occupancy (density) rises as a result of reduced headway on the motorway. The reduction in throughput results in underutilisation of a high-value asset and lost productivity. The lost productivity is illustrated in Figure 1.

After a traffic flow breakdown occurs at a bottleneck, the subsequent congestion results in slow speeds at that location and a loss of throughput, i.e. capacity flow is only achieved for a relatively short time. The symptoms may be localised and remain at or near the bottleneck, or more usually, the congestion creates a moving queue with a shock wave that travels upstream from the initial location of flow breakdown to affect the performance of an extended length of the motorway.

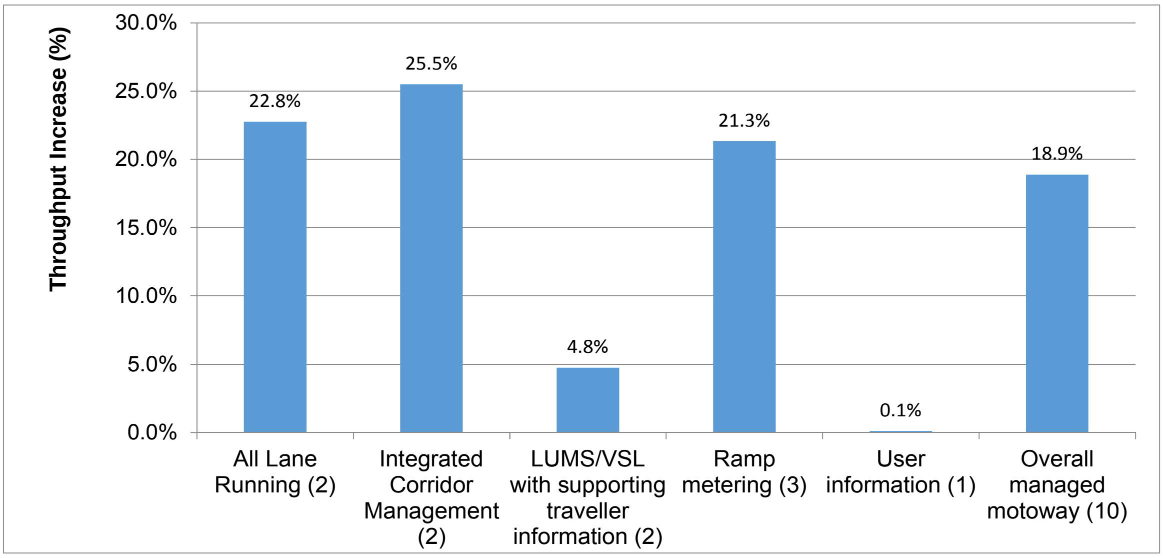
Figure 1: Lost productivity of motorway traffic breakdown



Source: Austroads 2016, p36

A Smart Motorway can reduce the incidence of traffic flow breakdowns through coordinated ramp metering and lane use management. Figure 2 shows the potential throughput increase by Smart Motorways based on 10 case studies.

Figure 2: Throughput increase due to Smart Motorways



Source: 10 case studies in Australia, USA, UK, Germany and Netherland. Number in bracket indicates the number of studies for a particular application. The reference of case studies is provided in Appendix 1.

Figure 2 shows that integrated corridor management, typically including LUMS, VSL, Ramp metering and traveller information, is most effective in increasing motorway throughput by

25.5%. All lane running increases throughput by 22.8% as the additional shoulder lane is putting into the use. Ramp metering increases the throughput by 21.3% by controlling traffic flow on the mainline and preventing traffic breakdowns. LUMS/VSL can also marginally increase throughput by 4.8%. User information barely changes the throughput. Overall, Smart Motorway technologies can increase throughput by an average of 18.9%. If more than one Smart Motorway applications were used, the maximal effects could be capped by the Integrated Corridor Management.

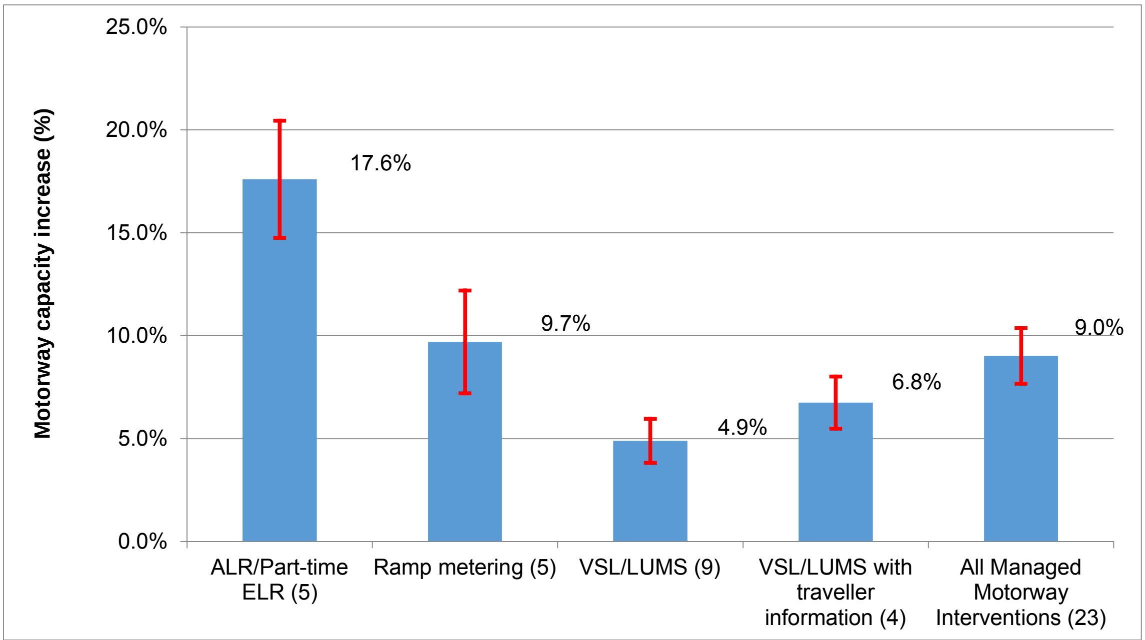
3.2 Capacity increase

Smart Motorway applications can increase operational capacity (the actual real-time capacity for a road segment). The real time capacity can vary depending on prevailing roadway, traffic and control conditions such as the percentage of heavy vehicles, driver population (passive or aggressive driving, familiar or unfamiliar with road), road geometry, road surface, time-of-day, weather and light. The theoretical capacity for a road segment is an average capacity estimate over a period.

The managed motorway will control the motorway traffic demand such that the mainline operates at near capacity, but not at the point of flow breakdown. It aims to achieve the evenly distributed flow of on–ramp traffic onto the mainline by dispersing on–ramp platoons. The mainline traffic volume is controlled so that the traffic breakdowns are prevented and traffic flow is optimised. Congestion reduction and higher travel speed compared to non-smart motorway condition will lead to travel time savings. The estimate of congestion relief and travel time savings will typically rely on traffic modelling outputs on mainline vehicle hours travelled (VHT) in the base case and Smart Motorway case. That said, the accuracy of traffic modelling determines the accuracy of benefit estimate. The role of traffic modelling in calculating economic benefits is discussed in Section 4.2.

An ALR/ELR will increase the capacity by adding an extra traffic lane. A managed motorway with coordinated ramp signals has the ability to maintain optimal density and capacity by managing the carriageway occupancy and minimising flow breakdown. Based on a review of 23 studies, the observed capacity increase of Smart Motorways is presented in Figure 3.

Figure 3: Capacity increase due to Smart Motorway applications



Source: 23 case studies in Australia, USA, UK, Germany and Netherland. Number in bracket indicates the number of case studies. Red bars represent the Standard Errors. The reference of case studies is provided in Appendix 1.

It shows that ALR/Part-time ELR can increase motorway capacity by 17.6% by providing an additional traffic lane. Ramp metering can increase the capacity by 9.7% by optimising traffic flow on mainline. VSL/LUMS with traveller information can increase capacity by 6.8% by regulating travel speed. VSL/LUMS without traveller information can also marginally increase capacity by 4.9%. Overall, Smart Motorway applications can increase motorway capacity by 9%.

3.3 Crash reduction benefit

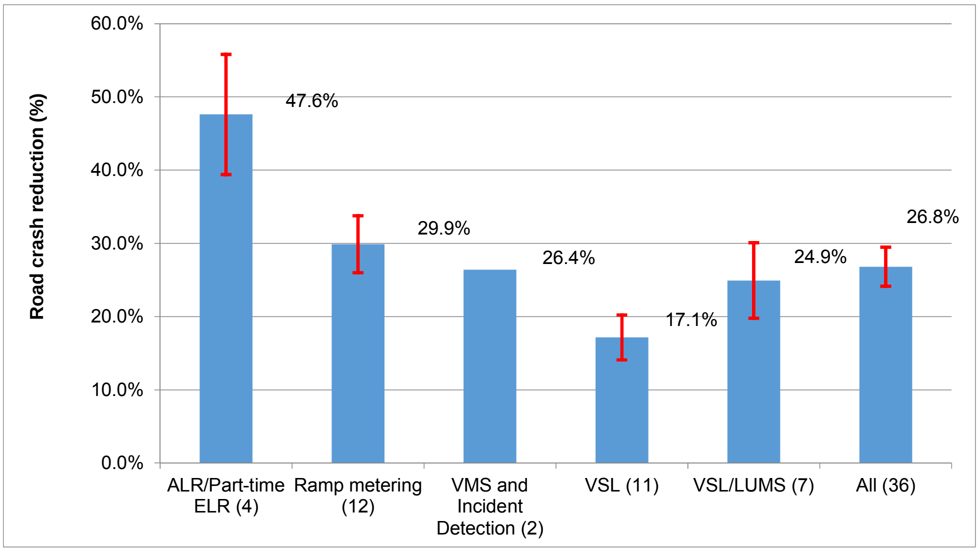
A Smart Motorway improves road safety in two ways – it reduces the crash occurrence and also decreases the severity if crashes do happen. By reducing severity, fatal crashes can become injury crashes and injury crashes become property damage only.

Safety is improved as a result of improved merging. Ramp metering disperses platoons of vehicles before they enter the motorway. Dispersed vehicles can more easily merge with less disruption to mainline traffic. This greatly reduces turbulence in the merge area which reduces the potential for incidents.

Improved safety through variable speed limits is achieved by reducing the speed differential between vehicles, minimising lane changing and braking caused by speed differentials, increasing time for drivers to react to changing conditions and reducing the severity of a crash if an impact does occur.

Studies, investigations and previous projects demonstrate the extent to which a managed motorway can reduce road crashes. A review of 36 studies in Australia, UK, Germany, Netherlands, New Zealand, USA and Japan has indicated a range of crash reduction rates as shown in Figure 4.

Figure 4: Road crash reduction of managed motorway technologies



Source: 36 case studies in Australia, USA, UK, Germany and Netherland. Number in bracket indicates the number of studies. Red bars represent the Standard Errors. The reference of case studies is provided in Appendix 1.

The reductions found in studies are:

- All Lane Running / Part-Time Emergency Lane Running can reduce road crashes by 47.5% on average. ALR/ELR can increase road capacity up to 25% and reduce vehicle speed differentials. ALR/ELR has the largest road safety effects presumably due to increased headways between vehicles and less stop/start conditions.

- Ramp Metering reduces crash by 29.9%, by improving traffic flow on the mainline and reducing stop-start unstable traffic conditions.
- VMS and incident detection reduce road crashes by 26.4%, by helping manage network demand and reducing congestion, and by providing road users with advance warning and greater certainty about upcoming traffic conditions. It particularly reduces rear-end crashes.
- VSL reduces crashes by 17.1% by reducing speed differentials between vehicles, minimising lane changing and braking and reducing the severity of a crash if an incident does occur. If combined with LUMS, the crash reduction can be increased to 24.9%.
- Overall, managed motorway technologies can reduce crashes by 26.8%.

  As demonstrated above, road crash reduction can be observed using the before and after intervention data. However for economic appraisals, as the after-intervention data is not available, the expected crash reduction must be estimated from similar measured interventions from other projects.

The crash rate in the base case should be established first. Historical crash statistics for past 5-10 years should be analysed to estimate the crash rate by severity, typically expressed as number of crashes per million vehicle kilometres travelled.

The crash reduction is unknown in the project case assessment period. The expected crash reduction must be obtained from similar Smart Motorway interventions, transferred to the project under the evaluation and projected to future years. Like any forecasting, there is always a level of uncertainty. One assumption pertaining to the benefit transfer is that there is sufficient similarity between projects in the base case crash rate, traffic volumes and driver behaviours.

3.4 More reliable journey time

The performance of the motorway is optimised by maintaining mainline flows at operational capacities during peak periods. The control of flows through ramp metering greatly reduces turbulence such that day-to-day traffic flows remain relatively constant, providing greater travel time reliability.

In Australia, there is no universally agreed travel time reliability model. In 2006 the National Guidelines for Transport System Management implicitly recommended the model developed in New Zealand. This model takes a very simple form of logistic relationship between the Standard Deviation (SD) of travel time and Volume Capacity Ratio (VCR) as follows:

$$SD_{Travel\ Time} = \frac{S - S_0}{1 + e^{b(VCR-1)}} \qquad (1)$$

Where *SD* is the Standard Deviation in travel time, *VCR* is the Volume Capacity Ratio, S, S_0 and b are parameters provided in ATC (2006, p.49). The model requires only knowledge of the volume capacity ratio for the road in question. However, in practical use, this model is very cumbersome. It requires traffic volumes for each road section and each approach of an intersection. For a network based model, there could be hundreds of road sections and intersections, that detailed information is rarely available from the traffic assignment. In addition, the formula requires 15-minute bin traffic modelling output to clearly identify the changes of reliability between the base case and the project case. Whilst this formula has merits in estimating reliability benefits for small scale interventions such as intersection upgrade, it has generally been disliked by practitioners. In fact, it is hard to find any practical use of this model in any large project.

A more common formula is taken from research in the UK. The UK model was originally developed as part of the 1993 London Congestion Charging study. Later on, more recent data was used to validate it but the model still takes the same form. The travel time variability was estimated from Origin-Destination matrix of travel time and distance in the form of:

$$SD_{ij} = 0.0018 \cdot T_{ij}^{2.02} \cdot D_{ij}^{-1.41} \qquad (2)$$

Where *SD* is the Standard Division of travel time, *T* is the travel time and *D* is distance between travel zones *i* and *j*. This model has been the preferred formula for use in Australia because the OD matrix is usually available from a strategic transport model normally applied in a large project thus there is reliable data to feed into the formula. Another advantage is that any prototype of reliability model can be re-used in different projects simply by replacing the OD matrix. This is an advantage as typically a consultancy project has a strict and tight deadline.

Whilst this formula is popular amongst practitioners, Australian transport agencies are reluctant to endorse it. The main reason is that the model has not been calibrated to Australian traffic conditions. The equation was based on London traffic characteristics that may not be transferable to other cities. For example, the model assumes a constant average free flow speed of 44.5 km/hr. UK Department for Transport recommends that the model be calibrated to local conditions. To address this issue, the Working Group for the National Guidelines commissioned Deloitte and developed an interim model for Australian capital cities in the form of:

$$\Delta\sigma_{ij} = \frac{\alpha}{ft^{\beta}} \left(\mu_{ij2}^{\alpha+1} - \mu_{ij1}^{\alpha+1}\right) D_{ij}^{\delta} \qquad (3)$$

Where $\Delta\sigma_{ij}$ is the estimated Standard Deviation of travel time between locations *i* and *j, D* is the route distance, ft is the free flow travel time, μ is the average travel time and $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$ and $\boldsymbol{\delta}$ are model parameters that had been estimated for Australian capital cities. It is clear that this model takes the UK formula but calibrated with Australian traffic conditions. Parameters have been estimated for each Australian and New Zealand Capital Cities. Because the interim model has not been fully endorsed by the Working Group, it is recommended only for sensitivity testing within the economic appraisal. This means that the equation (1) is the only officially recommended reliability model for economic appraisals in Australia.

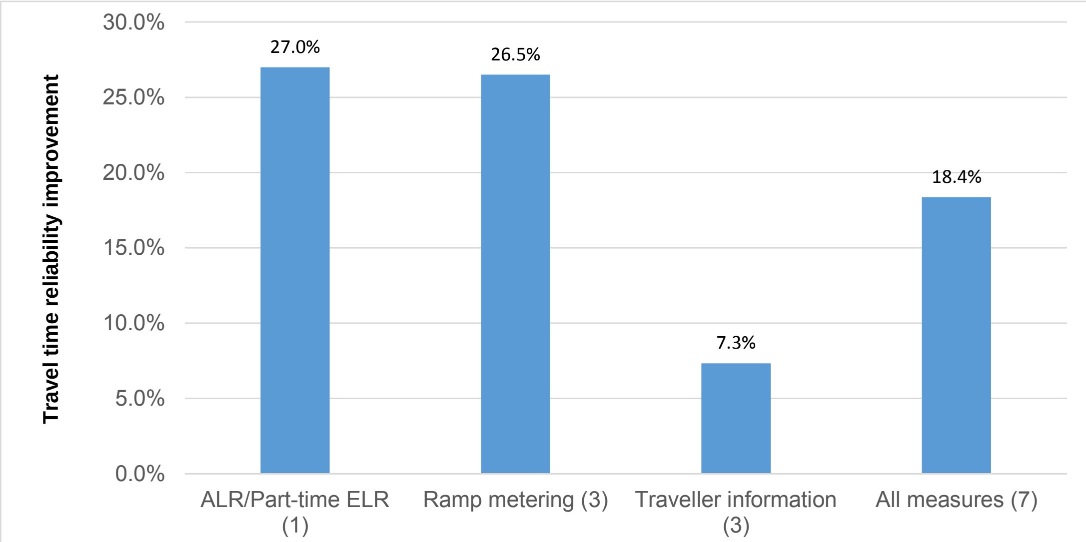
Australian States have tried to develop reliability models for specific purposes. NSW Roads and Maritime Services (RMS) had developed a model specifically applicable for motorways:

$$SD = \beta 1 * Delay^{\beta 2} * VCR^{\beta 3} \qquad (4)$$

Where *SD* is the Standard Deviation, *Delay* is the travel time delays estimated from the difference between actual travel time and estimated travel time at posted speed limit and the *VCR* is the volume capacity ratio.

While travel time reliability benefits can be estimated from the above models, there are a small number of studies indicating potential extent of reliability improvement as shown in Figure 5. The travel time reliability can be improved ranging from 7.3% to 27%.

Figure 5: Reliability improvement by Smart Motorway technologies

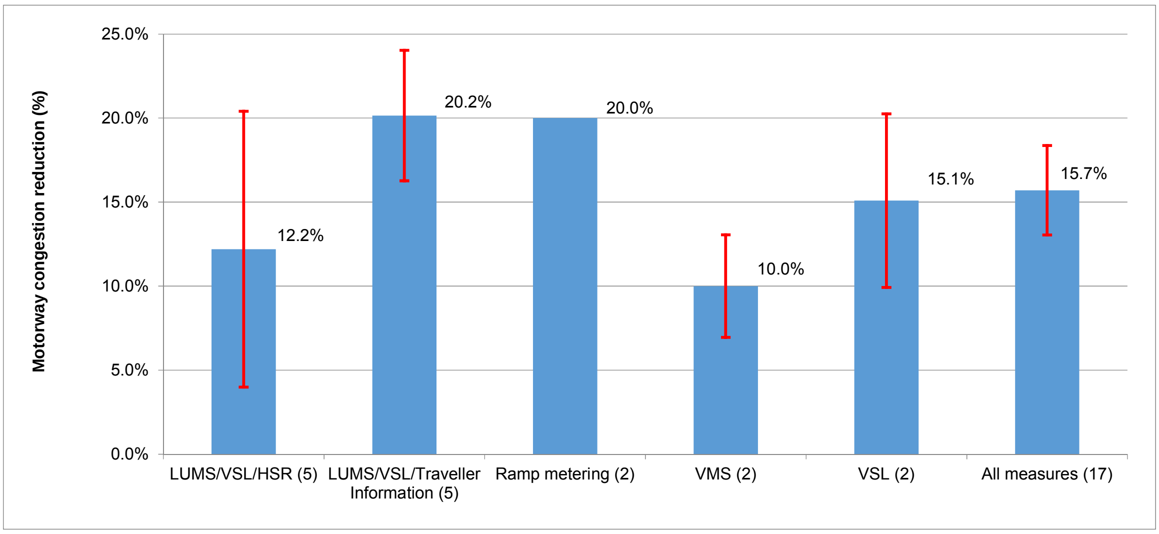


Source: 7 case studies in Australia, USA and UK. The reference of case studies is provided in Appendix 1.

3.5 Congestion reduction

Situations that could lead to heavy motorway congestion include insufficient control of ramp entry, excessive demand, incidents and major bottlenecks. The Smart Motorway has an important function in managing mainline and network congestion by controlling entry flows, preventing road incidents, diverting traffic and better managing incidents if they do occur. During a major incident or congestion, an area-wide response may be most effective to divert and disperse traffic across the network. In the long term, Smart Motorways are complementary to a range of demand and supply management measures that seek to manage urban congestion. The technologies enable road operators to get the most from the existing motorway infrastructure (i.e. ‘sweat the asset’). Figure 6 shows the potential motorway congestion reduction by Smart Motorway technologies ranging from 10% to 20.2%, with an overall congestion reduction in the order of 15.7%. These are observed congestion reduction from various jurisdictions.

Figure 6: Congestion reduction by Smart Motorway technologies



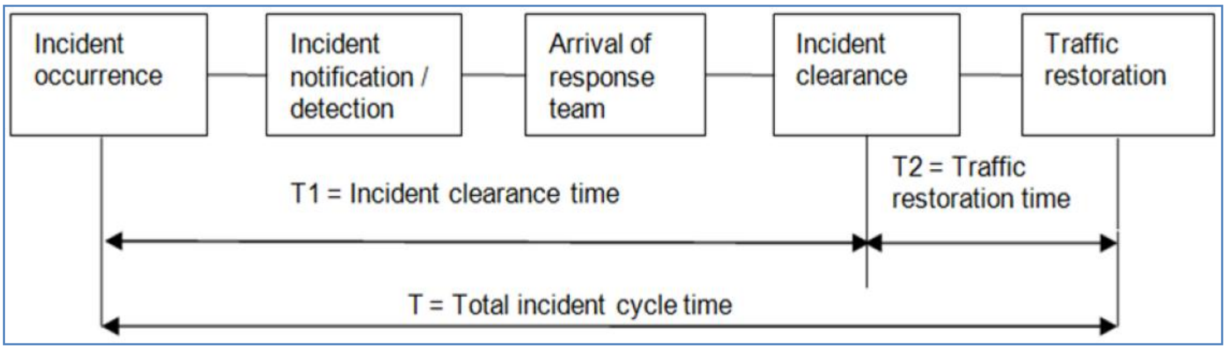
Source: 17 international case studies. Red bars represent the Standard Errors. The reference of case studies is provided in Appendix 1.

3.6 Reduced incident caused delays

International studies indicate that the share of non-recurrent congestion in urban areas can vary considerably from 14% to 64%, although this wide range of estimates may be attributable to differences in calculation methodologies and local conditions (Austroads 2016).

Incidents typically have been found to reduce the capacity of a section of road and increase the travel time of impacted vehicles. A typical traffic incident has five phases as illustrated in Figure . It starts with the incident occurrence. An incident notification / detection brings the incident to the attention of the traffic management authority who then alert the response team. The incident is then cleared with normal traffic flow restored.

Figure 7: Incident phases and total incident cycle time

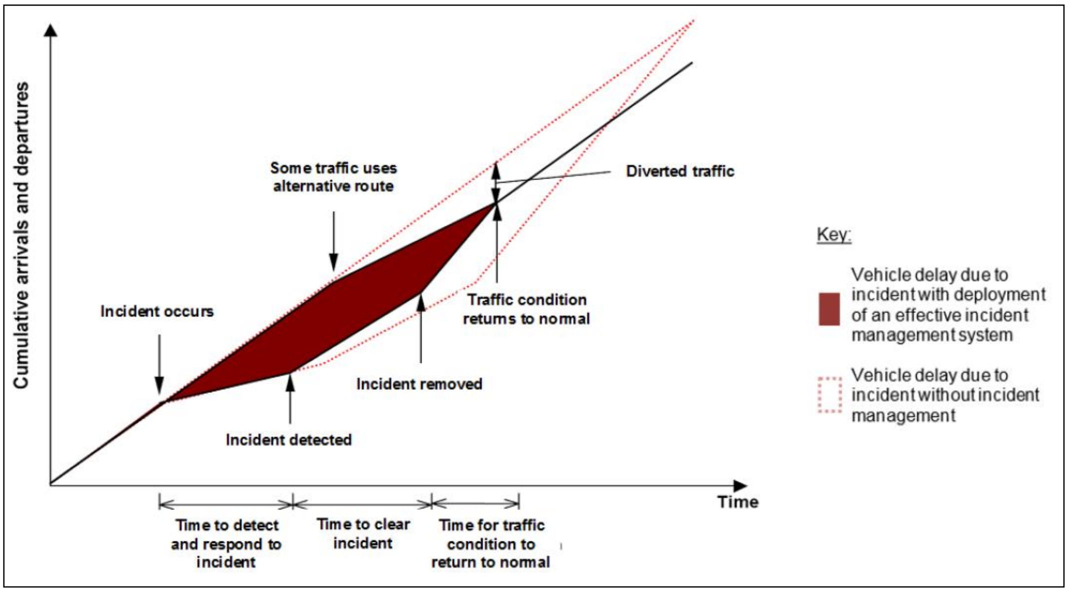


Source: ARRB conference paper 2014, Economic evaluation of travel time reliability in road project planning, a practitioner's perspective

Management of incidents in a timely manner reduces the amount of delay associated with each incident, and therefore improves the travel time on the motorway. Smart Motorway services can improve incident management through the use of CCTV, VMS, VSLS and LUMS systems, typically generating a 20 per cent reduction in incident response and clearance time[4]. This effect is illustrated in Figure 8, showing that, without Smart Motorway management, an incident takes longer to clear and more vehicles are impacted. With Smart Motorway management, there will be a quicker incident detection and response which effectively reduce incident delays. Traffic diversion is also an important factor for reducing incident delays. When an incident occurs, traveller real time information can divert traffic away from incident site ranging from 7% to 35% (Austroads 2016, p.203).

[4] RTA (2009) New South Wales Managed Motorways Business Case & ARRB 2014, p.7

Figure 8: Incident phases and total incident cycle time



Source: Austroads 2016, p. 6

For the purposes of economic appraisal, the methodology of estimating incident management savings follows four steps:

(A)	*Incident Cycle Time (Min)*	=	*Incident Response and Clearance Time (Min)*	+	*Traffic Restoration Time (Min)*				
(B)	*Number of vehicles impacted*	=	*Capacity reduction based on number of lanes*	x	*Traffic flow in incident direction lanes*	x	*Incident Cycle Time*		
(C)	*Average Delay Time*	=	*Incident cycle time*	x	*Delay factor*				
(D)	*Incident Management Cost*	=	*Average delay of each vehicle*	x	*Number of vehicles Impacted*	x	*Number of Incidents*	x	*Value of Travel Time*

The incident cycle time includes both incident clearance time and traffic restoration time. The NSW Transport Management Centre's incident data shows that the average incident response and clearance time is 40 min[5]. Traffic restoration time will depend on arrival flow, road capacity and the availability of a diversion route. The restoration time will also depend on the incident response and clearance time. The longer the clearance time, the more traffic builds up at the crash site. The incident and queen analysis indicates that the traffic restoration time is around 60 per cent of the incident clearance time however it varies with road capacity, traffic flow, and availability of traffic diversion routes and real time traffic information.

3.7 Vehicle operating cost savings

Vehicle operating cost (VOC) includes the cost for fuel, oil, tyre, vehicle repair, vehicle maintenance and depreciation. Smart Motorway improves traffic flow and travel speed, which can either increase or decrease the vehicle operating cost. The ATAP National Guidelines provide VOC models for interrupted stop-start traffic flows, uninterrupted urban

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[5] Wang, Economic evaluation of travel time reliability in road project planning, a practitioner's perspective, ARRB conference 2014. RMS economics team advised the incident response and clearance time 0.6 hours (36 mins), close to the 40 mins used in the economic appraisal.

free-flow and uninterrupted rural traffic flow that can be used for estimating VOC savings across various road and traffic conditions.

3.8 Reduced environmental external cost

Environmental parameters presented in Austroads guidelines are the unit cost per VKT for passenger vehicles or tonne-kilometre travelled for freight vehicles. For the Managed Motorway implementation where the network VKT and freight throughput are not expected to change significantly from the base case, the environmental impact cannot be fully assessed. To address this, the environmental impact is assessed by firstly estimating the fuel consumption, then converting the fuel consumption to emissions and finally applying a price on those emissions.

3.9 Congestion reduction from broad road network

Smart Motorways provide integration with arterial road operations to optimise the performance of the overall road network (motorway and other arterial roads). By diverting traffic away from arterial and local roads or attracting traffic to the smart motorway, it reduces network congestion. However, ramp metering can have a negative impact on the arterial road network. To make the best use of total road network, the motorway will typically be given priority over the arterial roads, the negative impacts on the arterial roads should be managed to achieve a net overall gain to all road users (VicRoads 2015). The effect can only be estimated by use of a wide area traffic model. In some projects, the induced traffic is estimated and included in the project case. The induced traffic reduces the overall benefit in the project case as more traffic is added on the road network. The benefit of existing road users is reduced. The benefit of the induced users is assumed the half of the existing users.

Typically, the benefit of real time information is acknowledged in economic approach but not estimated due to lack of reliable data. The real time information may enhance customer satisfaction, reduce driver stress / frustration.

4 How the benefits can be estimated

4.1 Estimate methodology

Improvements of motorway throughput, capacity and congestion will be reflected in value of travel time savings. In economic appraisals, the following benefits are typically presented:

- Value of travel time savings (VTTS)
- Value of travel time reliability (VTTR)
- Road crash reduction benefit
- Incident management benefit
- Vehicle Operating Cost (VOC) savings
- Environmental externality reduction benefit
- Broad road network congestion reduction benefit

The estimating methodology for motorway existing, diverted and induced trips are summarised in Table 1.

Table 1: Benefit estimation methodology

Benefit type	Existing trips	Diverted trips	Induced trips
VTTS	VHT reduction x VOT Traffic modelling output	VHT reduction x VOT Traffic modelling output	Rule of Half
Reliability benefit	Reliability models Traffic modelling outputs in volume , capacity, distance and travel time	Reliability models Traffic modelling outputs in volume , capacity, distance and travel time	Rule of Half
Road crash reduction benefit	Historical crashes by severity x crash reduction Meta-analysis approach to estimate the expected crash reduction	Historical crashes by severity x crash reduction Meta-analysis approach to estimate the expected crash reduction	Net disbenefit based on crash rate per MVKT
Incident management benefit	Average delay x Number of vehicle impacted Based on average incident response and clearance with and without SM Number of road crashes avoided	Average delay x Number of vehicle impacted Based on average incident response and clearance with and without SM Number of road crashes avoided	Net disbenefit based on crash rate per MVKT
VOC savings	VOC models Stop-start urban model Uninterrupted urban freeway model Uninterrupted rural highway model Using inputs from traffic modelling and road design parameters (smoothness, gradient and curvature)	VOC models Stop-start urban model Uninterrupted urban freeway model Uninterrupted rural highway model Using inputs from traffic modelling and road design parameters (smoothness, gradient and curvature)	Net disbenefit
Environmental externality	Emission price approach: External cost = Fuel consumption x emission conversion factor x emission price	Emission price approach: External cost = Fuel consumption x emission conversion factor x emission price	Net disbenefit
Road Network Congestion	N/A	Parameter method Congestion cost per vkt	N/A – assuming induced trips will use motorway

4.2 Role of traffic modelling

Traffic modelling is typically undertaken for the base case and Smart Motorway options. It should estimate the existing, diverted and induced trips. Traffic diversion from road network to Smart Motorway is required for estimating congestion reduction benefits in the wider road network. The Rule of Half is generally applied for benefit estimation of induced trips.

The outputs of the traffic modelling should include vehicle kilometres travelled (VKT) and VHT for mainline on the motorway and on the wider road network. For the mainline, the modelling should generate the volume, travel speed, volume capacity ratio in the base case and Smart Motorway case. For the broader network, some models can estimate the average speed in the catchment area. Travel times from origin to destination can be extracted from traffic models from which an average speed can be calculated!

An important aspect is modelling the coordinated ramp metering that controls entering traffic to maintain the traffic flow just below its capacity of the mainline. Vehicle queue time and number of vehicle stops at ramp should be modelled. Vehicle stop attracts additional vehicle operating cost. For example, a single stop for a B-Double may consume 0.80 litre of fuel used during decelerating and accelerating. If there is insufficient storage in ramp, the vehicle could queue back to other road section, affecting the broad road network performance. An intersection based modelling may be warranted for ramp metering. Microsimulation models would be required for ramp metering and local impacts.

One limitation of traffic modelling is that it cannot effectively model road capacity increase on mainline due to Smart Motorway technologies. Road capacity is an input to the traffic model not an output. The traffic models are unable to dynamically model road capacity. The capacity increase has to be determined based on other researches and as an input to traffic models. Additionally, traffic simulation models have the capability to provide an assessment in terms of travel time reliability. However, this is seldom produced for economic appraisal.

4.3 Observation on costing

The scope of costing will obviously include Smart Motorway field devices (ramp signals, LUMS signs, VMS, CCTV and vehicle detectors). Costs will also need to include for additional elements such as:

- Communications systems that provide secure network connectivity from the central ITS control system and servers in the TMC to the ITS field devices
- Smart Motorways typically require installation of a high-quality, high-capacity optical fibre backbone along the length of the motorway corridor, with sufficient capacity to meet current and future requirements
- Provision of a power supply includes electrical cables and associated conduits/ducts, pits, chambers, equipment footings, site earthworks, earthing system, and switchboards
- Civil works required for mainline and ramp storage
- Traffic Management Centre

Communication systems, power supply and TMC may have other shared functions beyond Smart Motorway operations. In economic appraisal, a proportion of costs attributable to Smart Motorway operation are included.

The ITS assets usually have short economic life between 10-20 years, while economic appraisal is typically undertaken for 30 years. The upgrade cost at the end of economic life should be included either in CAPEX or OPEX.

5 Application and conclusion

Smart Motorways can generate singular significant benefits by increasing motorway throughput, motorway capacity, improving road safety, travel time reliability and mitigating road congestion. Table 2 presents the benefit estimates of two recent projects[6]. On average, the value of travel time savings is the largest benefit, representing 69% of the total benefit, followed by road safety benefits (18%), travel time reliability (9%) and congestion reduction (4%). Depending on project, other benefits may be included. One such benefit is the maintenance cost reduction on arterial and local roads as traffic is diverted to motorway (the motorway maintenance cost has been included in the project cost thus the marginal maintenance cost reduction on arterial road is a net saving). One project includes civil and

[6] The project names are withheld due to client confidentiality.

structure works on ramp which has longer economic life and residue value at the end of the evaluation period.

Table 2: Likely percentages of benefits

Benefit type	Project 1	Project 2	Average
VTTS	80.2%	57.0%	69%
VTTR	14.0%	4.1%	9%
Road safety	7.9%	27.4%	18%
Incident management		3.0%	1%
Congestion reduction		8.0%	4%
VOC savings	-1.7%	-0.1%	-1%
Environmental benefit	-2.5%	-0.1%	-1%
Arterial road maintenance savings	2.1%		2%
Residue value		0.7%	1%
Total	100.0%	100.0%	100%
BCR	4.60	4.35	4.48

The benefits estimated from two recent projects are moderate in comparison to BCRs cited in BITRE (2017, p.4), where it had been reported that the BCR is more than 10 for a traffic signal coordination, ramp metering, between 5-10 for variable speed limits and 1 for variable message boards. It is worth noting that both VOC savings and environmental externalities generate net dis-benefits. This is because Smart Motorway has increased travel speed on mainline. Typical, VOC and fuel consumption is at the lowest when travel speed is around 60 – 70 km/h. Beyond this, fuel consumption per kilometre travelled will increase that results in negative VOC savings and environmental impacts.

The experience of practical economic appraisals has identified some areas for further research and studies. While Smart Motorway improves traffic flow on mainlines, there can be negative impacts on ramp queue and vehicle stops on entry. Current modelling approaches tend to ignore these effects which will overstate the benefit. Road crash reduction rates are largely based on overseas studies which may be problematic in transferring the result to Australia. Post completion review should be undertaken to collect real project based evidence on crash reduction, capacity increase and productivity improvements to compare with modelled forecasts.

Acknowledgement

We thank two anonymous reviewers appointed by ATRF conference organiser for their insightful comments that have materially improved the paper.

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VicRoads (2015) Managed motorways framework: network optimisation & operations rationale and technical requirements, VicRoads, Kew, Vic.

Appendix 1: Smart motorway economic benefit database

A database that contains 96 economic benefit items has been established by Authors. The benefit is related to motorway productivity, capacity, safety, reliability, congestion reduction, traffic incident response and traffic diversion. The benefit database was sourced by the following studies:

- ARRB Group (2014) Research on benefits and Warrants for LUMS and VSL on Managed Motorways
- Austroads (2009) Freeway design parameters for fully managed operations, AP-R341/09, Austroads, Sydney, NSW.
- Austroads (2014) Development of Guide Content on Managed Motorways
- Austroads (2016) Guide to Smart Motorways
- BITRE (2017) Costs and benefits of emerging road transport technologies, Research Report 146, Bureau of Infrastructure and Regional Development.
- FHWA (2015) Smart Roadside Initiative Macro Benefit Analysis, project report
- FHWA (2017) Intelligent Transportation Systems benefits, Costs and Lessons Learned
- Highways Agency (2010) Highways Agency Managed Motorways Portfolio Foresighting Project, Global Approaches to Managed Motorways and Research Activities
- Jacobs (2015) Implications of advanced and emerging technologies for Victoria's transport future
- Parsons Brinckerhoff 2011, 'Final report: national managed motorways prioritisation project', Parsons Brinckerhoff Australia, Brisbane, Qld.
- Queensland TMR (2014) Managed Motorway, Engineering Policy
- RMS (2017) key benefits of smart motorway, http://www.rms.nsw.gov.au/projects/sydney-west/m4/benefits.html
- VicRoads (2013) Managed freeways handbook for lane use management, variable speed limits and traveller information, VicRoads, Kew, Vic.
- VicRoads (2017) Implications of advanced and emerging technologies for Victoria's transport future
- US DOT (2013) Longitudinal study of ITS implementation: decision factors and effects
- Authors' economic appraisals and business case developments for smart motorways, managed motorways in Australia