

# **Evaluation of HERO Coordinated Ramp Metering Installation at the M1/M3 Freeway in Queensland, Australia**

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**ABSTRACT**

The recently developed traffic-responsive feedback control strategy HERO (HEuristic Ramp metering cOordination), that coordinates local ramp-metering actions in freeway networks, was implemented at the M1/M3 Freeway in Queensland, Australia. HERO employs an extended version of the feedback regulator ALINEA at the local level. HERO outperforms uncoordinated local ramp metering and approaches the efficiency of sophisticated optimal control schemes. HERO has been implemented by TMR (Transport and Main Roads), the road authority for the state of Queensland, Australia, at six on-ramps of the M1/M3 Freeway. The obtained results show significant improvements in traffic throughput and travel times compared with the previously used fixed-rate ramp-metering system. A rapid economic benefit analysis concluded on a benefit-cost ratio (BCR) of 13.8:1 at a 7% discount rate, and hence a very strong economic merit for the implementation of HERO. The economic payback period for capital expenditure on this pilot is approximately 4 months.

**Keywords:** HERO; ALINEA; Coordinated ramp metering; M1/M3 Freeway in Queensland.

## INTRODUCTION

Ramp metering aims at improving traffic conditions by appropriately regulating inflow from on-ramps to the freeway mainstream. Traffic-responsive ramp-metering strategies, as opposed to fixed-time strategies, are based on real-time measurements from sensors installed in the freeway network and can be classified as local or coordinated. Local ramp-metering strategies make use of measurements from the vicinity of a single ramp to control each on-ramp independently of all other metered ramps in the network, the feedback-based ALINEA strategy (1, 2) being a prominent example. Coordinated ramp-metering strategies make use of measurements from an entire freeway network to control all metered ramps within the network. Coordinated strategies may be more equitable and efficient than local ramp-metering strategies, particularly in the frequent case of restricted ramp storage spaces. Coordinated ramp-metering approaches include multivariable control strategies, optimal control strategies, as well as various heuristic or rule-based approaches; see (3, 4, 5) for discussion and comparison of distinct features.

Coordinated ramp metering (CRM) is deemed to have a significant potential for improving freeway traffic conditions; hence, there is a strong interest in developing, testing and evaluating new algorithms in realistic conditions. However, only a tiny part of the proposed CRM algorithms have actually found their way to practical implementation; and even less of the corresponding field evaluation results have been actually published. As a matter of fact, given the high complexity of the underlying freeway traffic process, the mere methodological description of a CRM strategy is not sufficient and should be accompanied by its practical performance results in different conditions, to enable its adequate judgment. Although simulation-based evaluation studies may also be helpful in this respect, the importance of field assessment, as reported in (6, 7, 8, 9) must be emphasized.

In view of various identified disadvantages of existing approaches in terms of practicality, robustness or efficiency, a new heuristic feedback control strategy that is responsive to traffic and coordinates local ramp-metering actions in freeway networks was developed recently. The strategy was named HEuristic Ramp-metering cOordination (HERO) and it was extensively tested by simulation (10, 11) as well as in field implementations (12, 13). It should be noted that several significant improvements and additions were incorporated into the strategy on the grounds of the rich operational experiences gained. The developed coordination scheme is simple and utterly reactive (i.e., based on readily available real-time measurements), without the need for real-time model calculations or external demand prediction. HERO employs an extended version of the feedback regulator ALINEA at a local level. The strategy targets the critical occupancy for flow maximization, which is deemed more robust than targeting a pre-specified capacity value. HERO was implemented during a pilot project at six consecutive inbound on-ramps on the Monash Freeway in Melbourne, Australia, and was evaluated against the previously used ramp-metering system. The strategy was found to lead to a significant increase of traffic flows and a sensible reduction of travel times during the peak periods (12). That successful pilot implementation and evaluation of HERO led to its rollout during 2009–10 at 63 sites across the entire 75-km route of the M1 Freeway in Melbourne, as well as at other Victoria freeways.

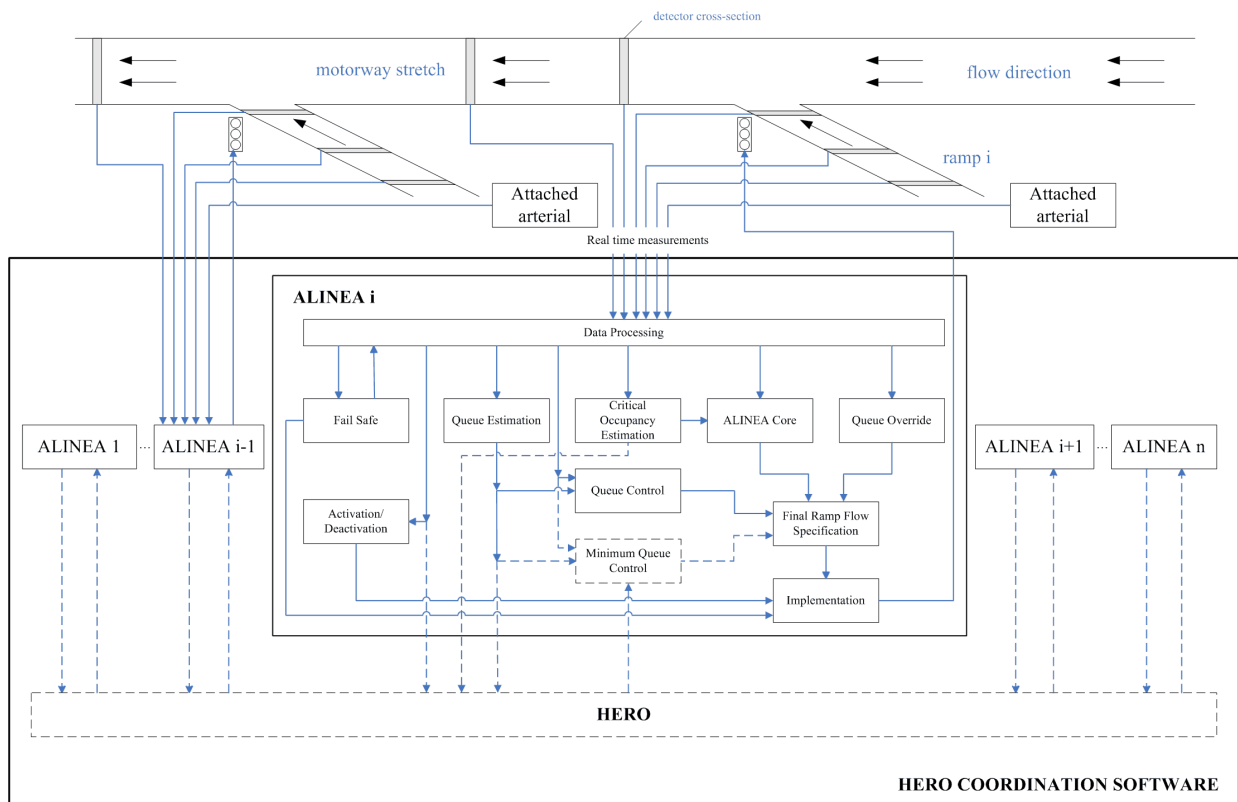
In September 2011, HERO was deployed by the TMR (Transport and Main Roads) Authority of Queensland, Australia, as part of its Managed Motorways Program, along a section of the Pacific Motorway and South East Freeway between Springwood and Woolloongabba. HERO replaced the fixed-rate ramp signaling system that had operated for a number of years

previously. HERO was piloted to demonstrate the benefits of dynamic, coordinated ramp signaling as a key tool within the managed motorways suite of intelligent transport system (ITS) technologies. The pilot application introduced only minor changes to ramp signaling cycle times, but with greater flexibility to respond to real-time traffic conditions and better manage vehicle flows. This paper reports on the evaluation results of this recent HERO installation, produced by TMR (14), by examining travel speeds, traffic flows and travel time reliability before and after implementation. Using these results, an economic appraisal was undertaken which revealed an ex-post benefit cost ratio of 13:1 over 10 years. In view of the limited number of CRM field evaluation studies, the reported results, indicating the specific benefits of the HERO algorithm, is a valuable complement to methodological developments.

The rest of this paper is organized as follows. The modular structure of the generic HERO coordination strategy and software is outlined first. This is followed by a description of the field application site and conditions. The efficiency evaluation comparative results are presented next, followed by an analysis of the expected economic benefits. The paper ends with a summary of the main conclusions.

## HERO COORDINATION STRATEGY AND SOFTWARE

A generic software implements the HERO coordination scheme for any freeway network via suitable input configuration. The modular structure of this software is presented in Figure 1. As the figure indicates, one ALINEA block is assigned to each metered on-ramp; this constitutes the



**FIGURE 1 Modular structure of the HERO coordination software.**

(functionally) local part of the overall strategy that comprises several modules (outlined below) with corresponding specific tasks. The local ALINEA blocks are coordinated by the HERO scheme, as indicated in Figure 1. The overall control software may be implemented in a central control room (as in this application) with dual communication to the ramp signaling sites to receive the real-time measurements and to submit the control decisions, respectively. Alternatively, the ALINEA blocks may be installed locally at each ramp, while the HERO module is installed centrally.

Figure 1 also indicates the measurement requirements for HERO operation, which comprise three measurement locations at each metered on-ramp (at both on-ramp boundaries as well as around the middle of the on-ramp) and one mainstream measurement, preferably downstream of the on-ramp nose (as required by ALINEA). In case of a mainstream bottleneck downstream of the on-ramp merge area with a capacity lower than the merge area capacity, an additional mainstream measurement from the downstream bottleneck location may be required. The particular modules are outlined in what follows.

Real-time data from the mainstream and the on-ramps are appropriately averaged and smoothed by the data processing module, while the fail safe module decides on possible graceful-degradation actions in case of measurement failures. The activation–deactivation module switches the signal control on or off according to respective pre-set traffic conditions at the mainline.

The ALINEA core module calculates the desired ramp exit flow at each ramp for local maximization of the mainstream flow, according to the ALINEA strategy (1, 2), using real-time occupancy measurements from the merge area. In case measurements from the merge area are not available, upstream measurements are used by a variation of ALINEA called UP-ALINEA (15). In case of a bottleneck situated downstream of the merge area and featuring a capacity lower than the merge area capacity, ALINEA must be fed with measurements collected at the downstream bottleneck (16). The system can also handle multiple downstream bottlenecks, if it is uncertain which bottleneck is the most critical at any time (17). Finally, in case the targeted critical occupancy (for flow maximization) is not known, it can be automatically estimated (and updated) by activating the critical-occupancy estimation module, which involves a Kalman filter–based estimator (18).

The application of any ramp-metering strategy may lead to the creation of ramp queues. If a queue covers the whole on-ramp space and queue spillover is imminent, appropriate queue management actions are necessary to avoid interference with the adjacent street network. An efficient queue management strategy calls for an estimated queue length on the on-ramp. The ramp queue length estimates can be calculated by using flow measurements from the entrance and the exit of the ramp and occupancy measurements from the middle of the ramp. The queue estimation procedure is based on a Kalman filter approach [see (19) for details] and is included in the queue estimation module. Creation of long ramp queues that would interfere with adjacent street traffic is avoided with the application of an ordinary queue override or a queue control (15) policy, whose decisions may supersede those of ALINEA if the respective calculated queue override ramp exit flow or queue control ramp exit flow are higher. Both queue management policies are implemented in the queue override module and the queue control module, respectively. There is also an option to additionally limit the maximum waiting time for vehicles in the ramp queue.

When ALINEA is applied to each on-ramp independently without any coordination actions, it may be superseded by queue management actions, in which case freeway congestion is

created that propagates upstream and activates local ramp metering at the next upstream on-ramp as well and so forth. The HERO module in Figure 1 coordinates local ramp-metering actions so as to delay the activation of queue management actions by exploiting the available storage space at upstream ramps. Coordination materializes via occasional appropriate setting of minimum ramp-queue lengths that should be created and maintained, so as to hold traffic back at specific upstream ramps via superseding of local ALINEA actions there. To this end, a suitable queue controller is used, and a minimum queue control exit flow is calculated for each ramp by the minimum queue control module. The interested reader is referred to (10, 11, 12), although several significant improvements and additions were incorporated into the strategy and software on the grounds of the rich operational experiences gained in the meantime.

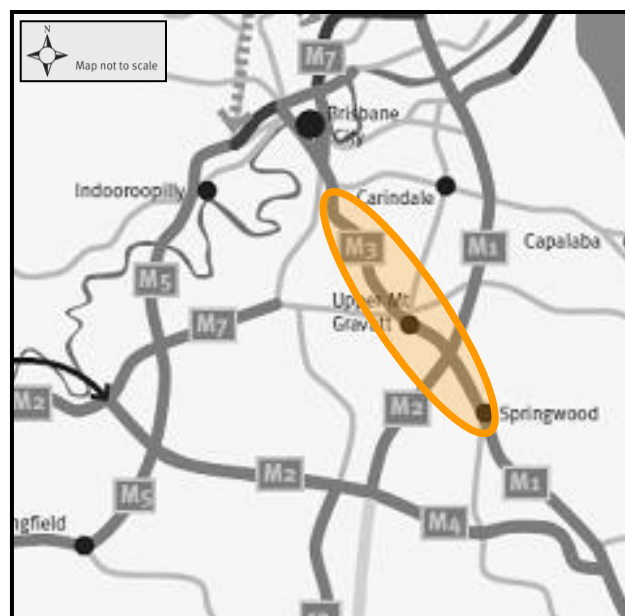
The final ramp flow specification module is responsible for the choice of the ramp exit flow to be applied at the next control period, while the implementation module calculates the cycle time of the ramp-metering traffic signals that corresponds to the final flow according to the ramp-metering policy used (e.g., one car per green).

Beyond the Victoria and Queensland implementations of HERO, the latter being evaluated in this paper, the strategy is currently under implementation at a U.S.A. freeway; while farther implementations in Europe and Australia are in a planning phase.

## IMPLEMENTATION OVERVIEW

The purpose of the reported Queensland project was to pilot the implementation of the HERO coordinated ramp signaling system along the Pacific Motorway (M1) and South East Freeway (M3) between Springwood and Woolloongabba (see Figure 2). This project was delivered as part of the Managed Motorways Program to demonstrate the benefits of a more dynamic and responsive ramp metering system.

This section of motorway carries around 120,000 vehicles per day and serves primarily as



**FIGURE 2 Implementation location.**

a commuter route between Brisbane and southern activity centers such as Logan and the Gold Coast. It had previously operated as a fixed-rate, time-of-day ramp signaling system for 20 years prior to the implementation of HERO. The fixed-time system has limited capability in properly managing access and flows along the length of the route due to its lack of responsiveness to the current traffic conditions, which may lead to unnecessarily strong or insufficient control actions. Under the pilot project, ramp signal and vehicle detection equipment was upgraded to allow for implementation of the HERO dynamic ramp signaling algorithms along the route, made operational through the motorway management module within the STREAMS ITS platform. This follows the successful implementation of the HERO algorithms on ramp signaling sites along motorways in Victoria also using the STREAMS platform (12).

It is important to note that the upper and lower bounds imposed to the real-time ramp metering operations were very tight; hence changes to the ramp signaling cycle times under the pilot were small, with average cycle times increasing from 4.8 seconds under the fixed regime to 5.4 seconds under the HERO algorithms (with an imposed maximum of 6 seconds).

The overall objective of the project was to test and demonstrate the effectiveness of the HERO coordinated ramp signaling system against the previous fixed-rate system by measuring improvements in travel speeds, traffic flows and travel time reliability that could be achieved through small changes to ramp signaling cycle times.

The project scope included the design, upgrade, calibration and operation of six existing on-ramp signaling sites along the M1 and M3 freeways between Springwood and Woolloongabba. The upgrade included, beyond the software, the installation of sensors on the mainline and in the ramps (which were not needed for fixed-rate operation), along with the corresponding communication lines. The upgraded sites included:

- Northbound (inbound)
  - Sports Drive on-ramp
  - Logan Road on-ramp
  - Mains Road on-ramp
  - Birdwood Road on-ramp
  - Duke Street on-ramp.
- Southbound (outbound)
  - Marquis Street on-ramp.

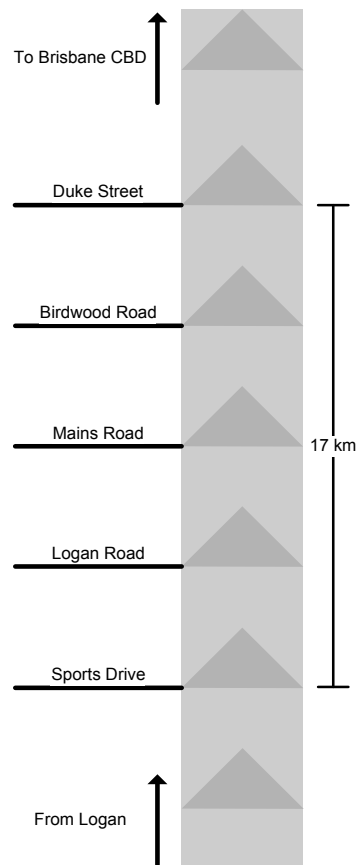
For the purposes of this report, performance improvements for the northbound (inbound) section only have been evaluated (see Figure 3). This is because of the limited control and influence that one southbound site at Marquis Street has on the operational performance of the southbound carriageways of the motorway.

Upgrades to the ramp signaling and associated ITS equipment were delivered between May and July 2011 with system deployment and configuration undertaken between July and September 2011. The HERO algorithms became operational on Tuesday 20 September 2011.

## **EFFICIENCY EVALUATION**

### **Congestion Plots**

Figures 4a and 4b present vehicle occupancy heat plots for a typical day before and after HERO implementation, respectively. These plots display the occupancy variation along the route over time. The color red indicates occupancy of greater than 30% which is representative of heavily



**FIGURE 3 Scope of M1/M3 HERO evaluation.**

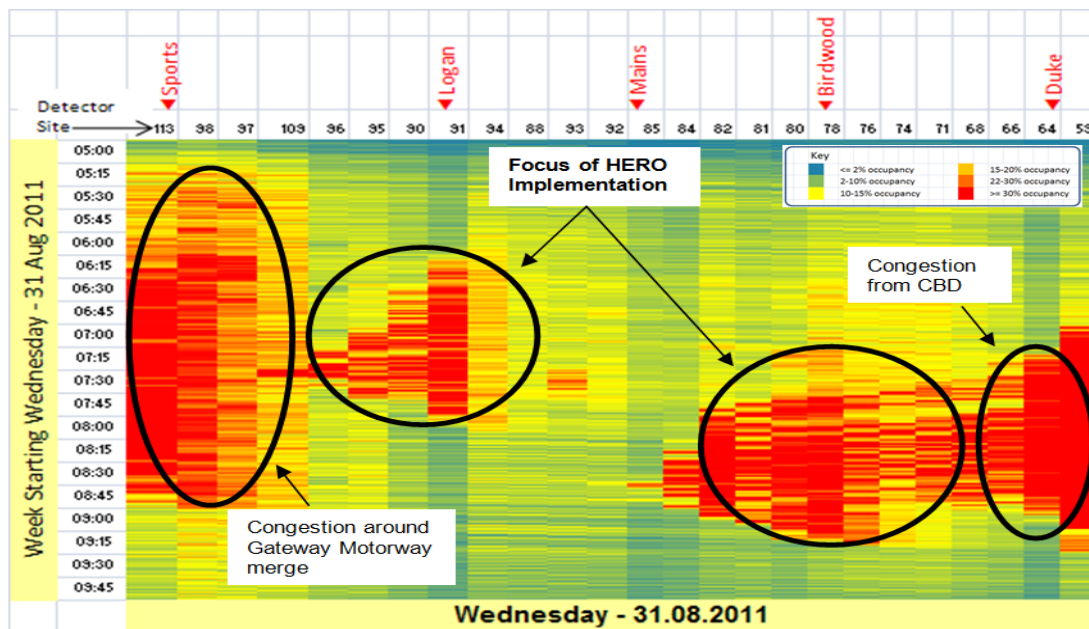
congested conditions. For the shown area and time period, the average vehicle flow during the “after” period is 4% higher compared to the “before” period.

Figure 4a shows that four ‘bottlenecks’ are evident along the route; namely at Sports Drive, Logan Road, Birdwood Drive and the Brisbane CBD. During the AM peak, these bottlenecks (resulting from excess demands at motorway on-ramps) create shockwave conditions that propagate upstream causing congestion that extends through time and space to reduce motorway efficiency and productivity for the duration of the peak period.

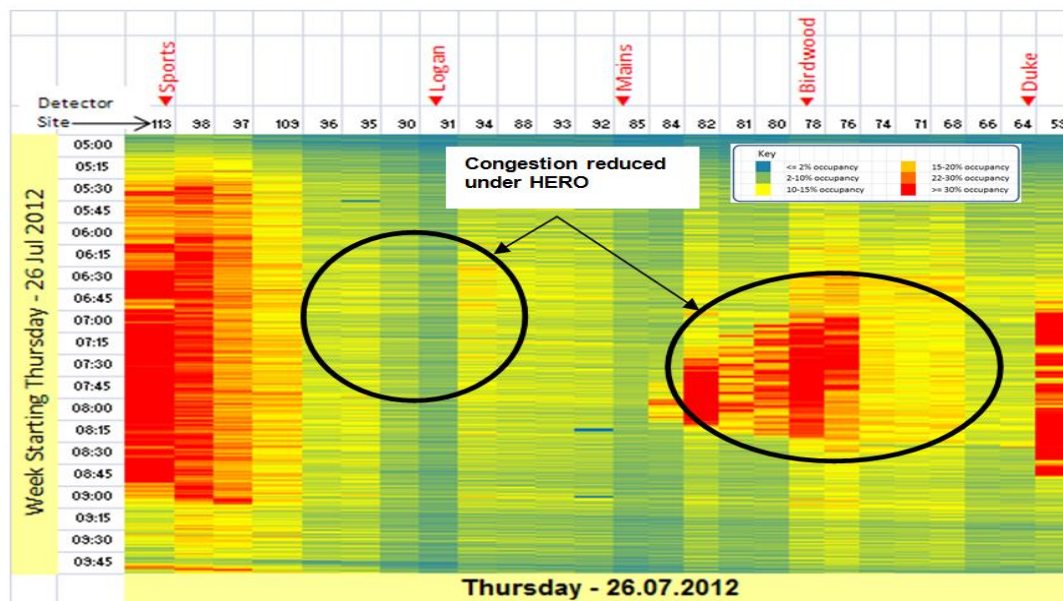
The focus of the HERO implementation was on reducing the severity of congestion and flow breakdown between Logan Road to Duke Street. As ramp signaling controls motorway access to better match flows with downstream capacity, the pilot had little impact on motorway operating conditions upstream of Sports Drive. There is also a weave zone and lane drop at the Gateway Motorway off-ramp just past the Sports Drive on-ramp that the system has little control over.

It is important to note also that the Brisbane CBD downstream from Duke Street is a natural end condition with the level of congestion propagating back along the motorway dependant on the rate at which the CBD and surrounding road network can absorb the arriving traffic demand. Again, the limited scope of the pilot meant there was little influence on congestion downstream from Duke Street.





(a)



(b)

FIGURE 4 (a) 'Before' and (b) 'After' occupancy heat plots.

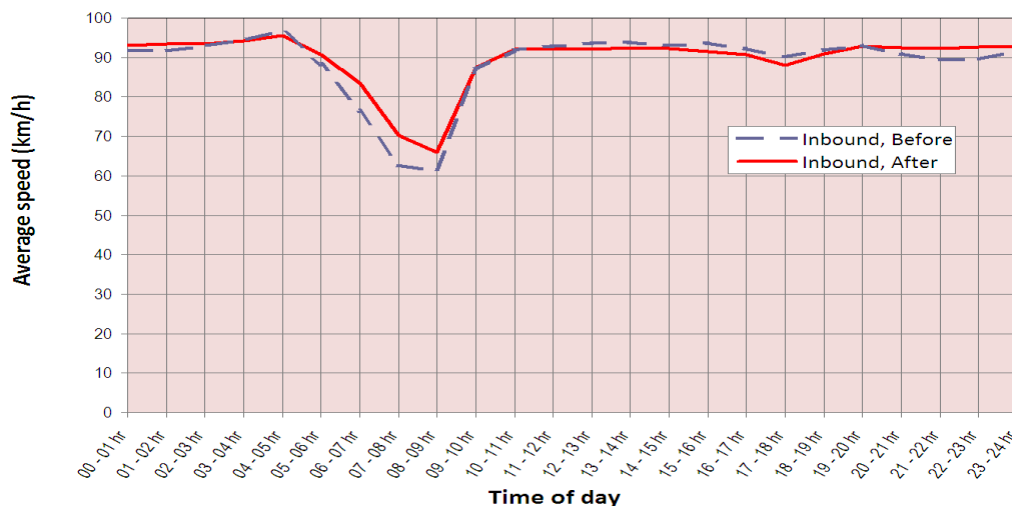
Figure 4b shows that the duration and extent of congestion around Logan Road and between Birdwood Drive and Duke Street has reduced with the HERO system. This is in-line with the system's area of influence, as previously discussed, and shows that it is necessary to

upgrade ramp signals upstream of Sports Drive to reduce the bottleneck that is still evident in the vicinity of the on-ramp.

A before and after comparison of key managed motorway performance metrics has also been undertaken to determine the improvements and benefits of the HERO implementation compared to the previous fixed rate system. The STREAMS Business Intelligence system was used to analyze motorway performance data for weekdays between 14 May 2011 and 31 August 2011 to represent the 'before' situation and compared this with data from 14 May 2012 and 31 August 2012 to represent the 'after' situation<sup>1</sup>. The after situation represents normal operations where it is likely that initial benefits of the HERO implementation have settled to a level that can be sustained over time. The analysis has been undertaken for the northbound AM peak (6 am -10 am), only between Sports Drive and Duke Street, a distance of approximately 17 kilometers.

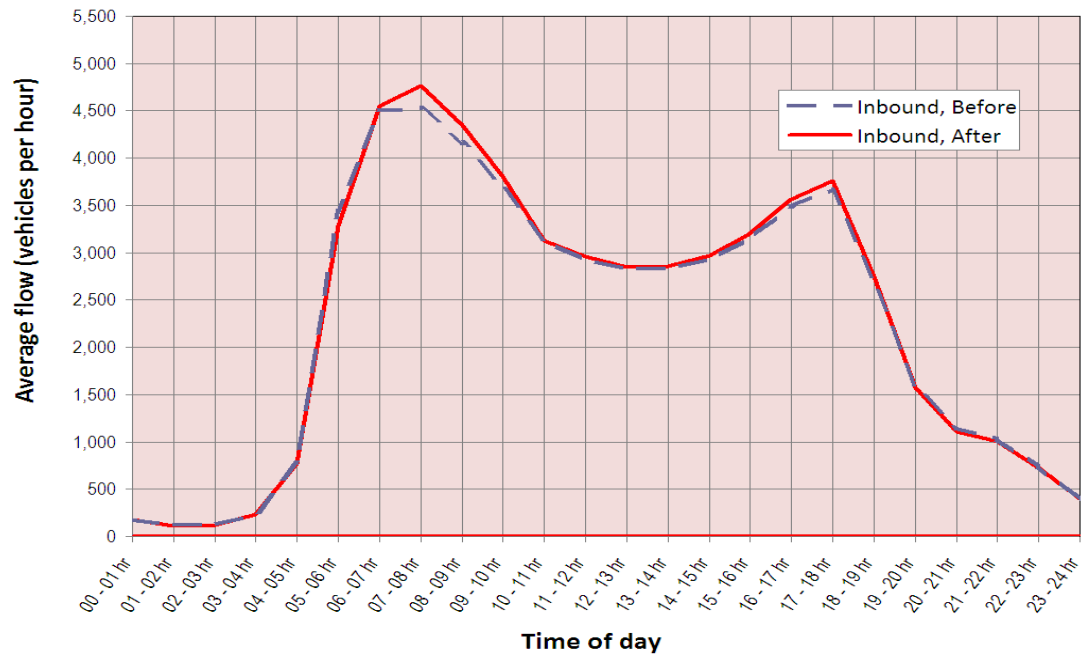
### Speed Plots

Figure 5 presents the hourly travel speed profile before and after HERO implementation. The displayed travel speed is the traffic volume weighted harmonic mean speed (total distance travelled/total time travelled). The graph shows the improvement in travel speed during the AM peak for inbound traffic, with a higher speed being maintained for the duration of the AM peak period. On average, AM peak travel speed has increased from 70 km/h to 75 km/h under the HERO system, equating to a 7% increase in travel speeds.



**FIGURE 5 Average travel speed (km/h).**

<sup>1</sup> To increase confidence that the measured improvements can be attributed to the HERO implementation and not to other factors, some periods outside the times when HERO normally works were also compared. These were during weekdays outside the AM peak periods, weekends and public holidays. For these periods the differences in average speed were found to be insignificant, which supports the findings that improvements can be attributed to HERO implementation.



**FIGURE 6 Average volume (veh/h).**

## Volume Plots

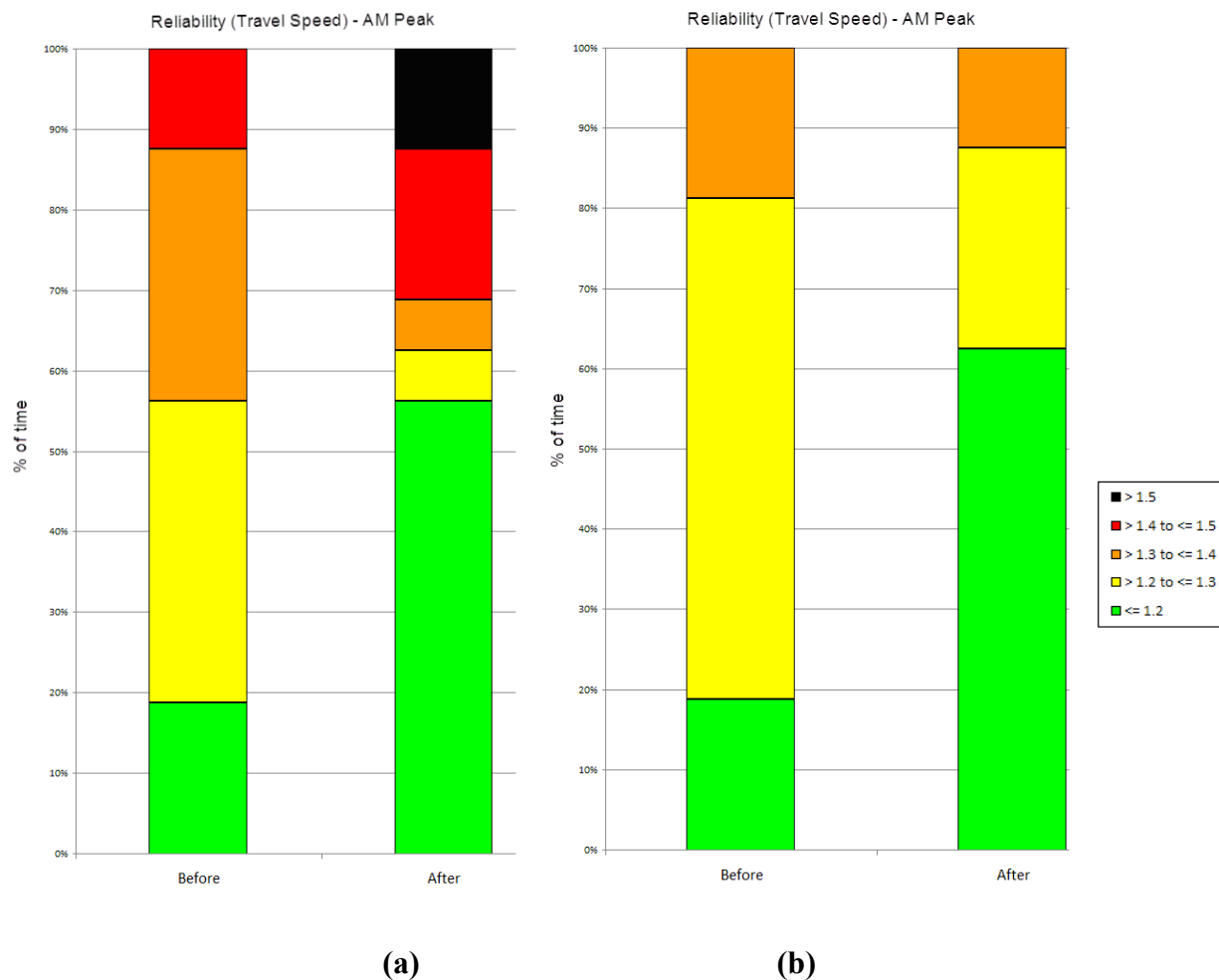
Figure 6 presents the hourly volume profile before and after HERO implementation. This shows a slight improvement in vehicle throughput during the AM peak for inbound traffic, with higher flows sustained for the duration of the AM peak period. Average AM peak flows have increased by 150 vehicles per hour (600 vehicles from 6 am to 10 am) under the HERO system, equating to a 4% increase in throughput. The throughput increase is possibly due to additional traffic attracted to the freeway as a result of the improved traffic conditions after HERO implementation.

## Austroads National Performance Indicators (NPIs)

**Reliability (Travel Speed):** The reliability indicator measures the day-to-day variability of travel speeds by calculating the coefficients of variation. It is displayed as proportions of time at different levels of variability before and after the HERO implementation.

Figure 7a presents the before and after reliability NPI graphs. The graph on the left shows that prior to HERO the route was achieving poor levels of reliability with only 19% of travel receiving reliable travel times (reliability factor of 1.2 or less<sup>2</sup>). Following HERO implementation, 'good' reliability increased to 56% indicating an improvement of 37%. More than half of inbound AM peak trips now receive reliable travel along this route.

<sup>2</sup> A reliability factor of 1.2 implies that a buffer of 20% has to be added to the average travel time to ensure on-time arrival for most trips (95%). The calculation is based on the comparison of the 15 minute average route travel time in each day with the average travel time of that 15 minute period for the entire reporting period and is therefore a function of the day-to-day variability of travel time.

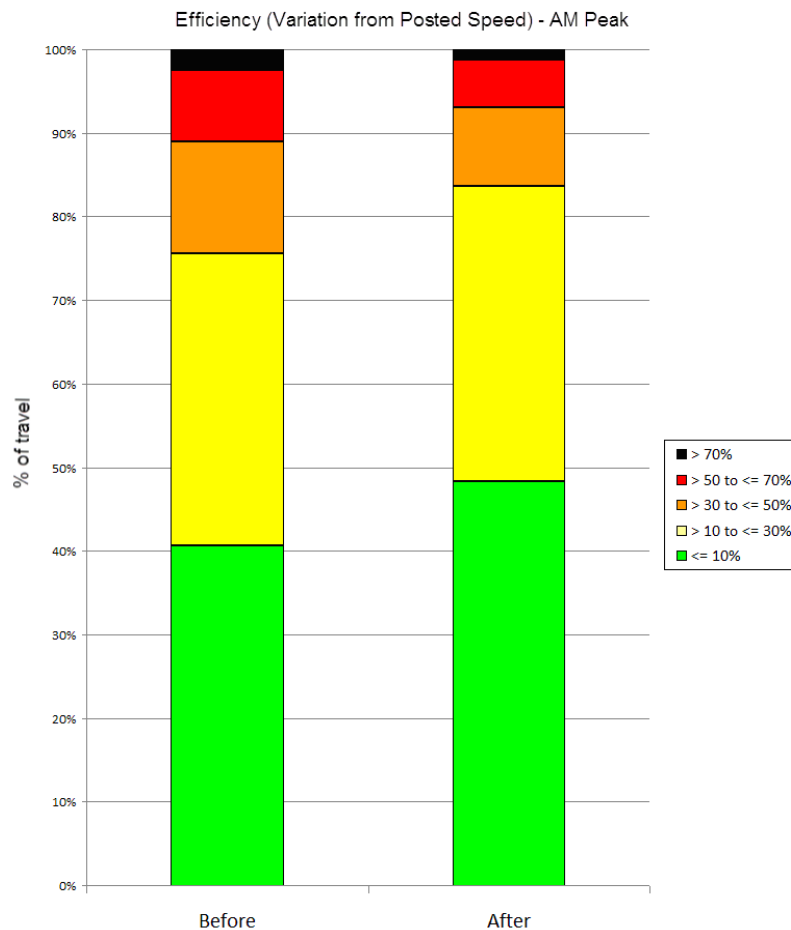


**FIGURE 7 Reliability NPI graphs (a) including and (b) excluding traffic incidents.**

It is noted that the portion of time with poor reliability (factors of >1.4 to <=1.5 and >1.5) indicated by the red and black portions of the bar graphs appear in Figure 8 to be worse after the HERO implementation. This reflects the significantly lower average travel speeds recorded for days where traffic incidents impacted on the operation of the motorway. By excluding such days from the analysis for the before and after periods (3 worst days were removed for both periods), the resulting NPI bar graphs are as presented in Figure 7b. By removing these outliers<sup>3</sup> from the analysis, the reliability indicators point to even greater improvements after HERO implementation, as the standard deviation in average travel speeds is reduced.

**Travel Efficiency (Variation from Posted Speed):** The efficiency indicator measures the proportion of the time and route at various levels of deviations from the posted speed limits.

<sup>3</sup> Outlier days where traffic incidents impacted reliability include 20 June 2011 (broken down vehicle), 12 July 2011 (broken down vehicle), 13 July 2011 (abandoned vehicle), 22 May 2012 (multi vehicle crash), 30 May 2012 (crash) and 13 July 2012 (multi vehicle crash).



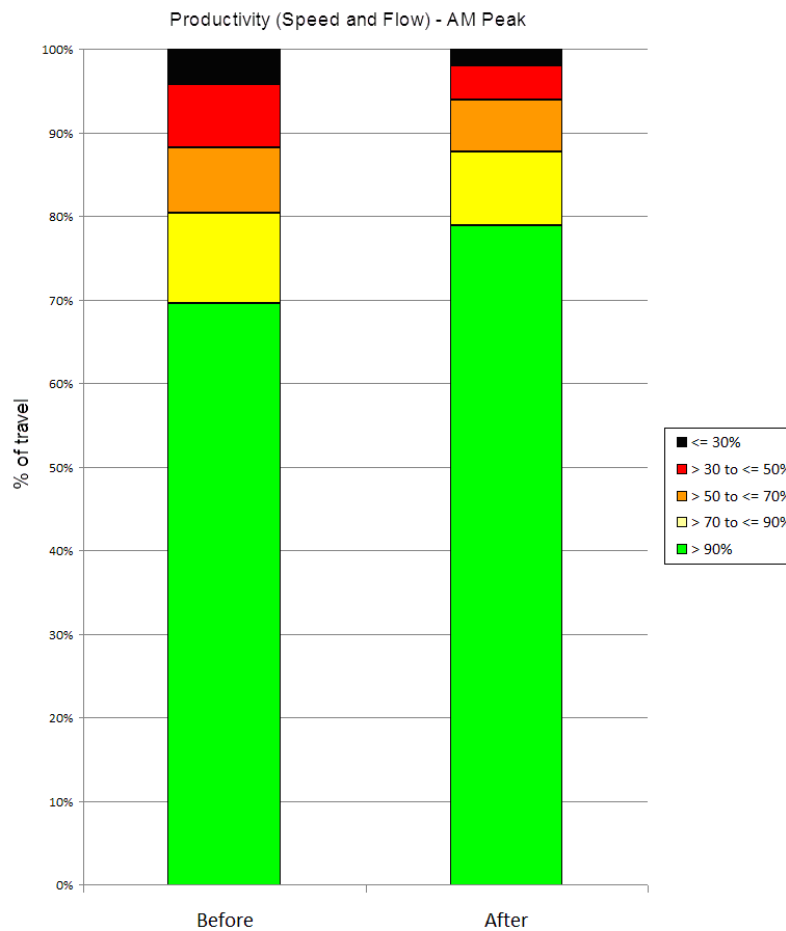
**FIGURE 8 Efficiency NPI Graphs.**

Figure 8 presents the before and after efficiency NPI graphs. The bar graph on the left shows that 76% of travel during the AM peak received good levels of efficiency with average speeds within 30% of the speed limit. Following HERO implementation this improved to 84% of travel receiving a good level of efficiency, indicating an 8% improvement.

**Travel Productivity (Speed and Flow):** This indicator is based on the product of speed and traffic flow per lane, benchmarked against reference values of speed and flow per lane. A high productivity is achieved if both speed and flow are maintained near maximum values (i.e. near free-flow speed and capacity flow). It is displayed as the proportions of travel at various levels of productivity in a measurement period<sup>4</sup>.

Figure 9 presents the before and after productivity NPI graphs. The bar graph on the left shows that 80% of the route was performing at good levels of productivity prior to the HERO

<sup>4</sup> For motorways, productivity is 100% if the travel speed is above a threshold value of 80% of the posted speed, irrespective of the flow. If not it is calculated as:  $\text{Speed} \times \text{flow per lane} / (80\% \text{ of posted speed} \times 2000 \text{ vehicles per hour per lane})$ .



**FIGURE 9 Productivity NPI Graphs.**

implementation. Following HERO implementation, good levels of productivity were increased to around 88% of travel during the AM peak, indicating an 8% improvement.

### Ramp delays

Observational analysis indicates that there has been no additional delay or increases in queuing at motorway on-ramps under the HERO algorithms. This is because HERO has the functionality to monitor the on-ramp queue lengths along the corridor and dynamically change metering rates to balance demands. For example, when the queue length reaches 60% of the maximum storage capacity at a particular on-ramp (the “master”), HERO will engage upstream on-ramp signals (“slaves”) to help maintain control of the bottleneck conditions, thus releasing the pressure from the master on-ramp. Once the queue length at the master on-ramp reduces, HERO will disengage the upstream ramp signals and revert back to local control. HERO has been configured in this installation to allow the ramp signals to operate cycle times between 4.8 seconds to 6 seconds when required for congestion control. This configuration allows the system to be tightly

controlled and thereby assists in managing delays and queuing experienced by the road users at the on-ramps.

## ECONOMIC BENEFITS

This section presents the results of an ex-post cost benefit analysis undertaken on the M1/M3 HERO Ramp Signaling Implementation pilot. The base case is the 'do minimum' strategy where the fixed-rate ramp signaling system is used, and there are no other changes to the route other than would normally occur without the HERO implementation. The project case includes the upgrade of the ramp signals and associated ITS equipment, software, training, operations and maintenance to enable the operation of the HERO suite of algorithms. The cost benefit analysis follows the standard procedures laid out in (20).

The following assumptions have been used to undertake the appraisal:

- Evaluation period is 11 years: Construction in 2011 (year 0) followed by 10 years of operation. Benefits start in 2012 (year 1 of the evaluation).
- All costs and benefits are calculated at June 2011 prices (using ABS 6401.0 June 2012).
- Total capital cost of the project is \$ 1.065 m and covers research and development, initial software licenses, upgrades to on-ramp detector loops and signal lanterns, new CCTV systems, deployment and configuration, system training and network monitoring.
- Project case annualized operations and maintenance costs are \$142,000 and cover the additional ongoing software licenses and administration, operations, power and maintenance.
- Austroads Report AGPE04-12 is used for travel time and vehicle operating cost calculations. Light vehicles are assumed to comprise 75% private travel and 25% business travel. Heavy vehicles are assumed to comprise 100% heavy (3 axle) rigid trucks. A sensitivity test was undertaken for a different composition of light vehicles.
- Travel time and vehicle operating cost (incl. vehicle emission) benefits to the road user are calculated. Accident benefits and reliability benefits have not been quantified.
- Average travel speeds are 70 km/h in the base case and 75 km/h in the project case.
- Fixed demand (no change in throughput between the base and project case). A sensitivity test was undertaken for higher throughput.
- On-ramp travel times are held constant between the base and project cases. A sensitivity test was undertaken for longer ramp delays in the project case.
- Traffic composition is held constant at 97% light vehicles and 3% heavy vehicles.
- No growth in traffic is applied.
- Uplift (annualisation) factor is 230.
- Section length is 17 km.
- Discount rates of 4% and 7% are applied.

Ex-post cost-benefit analysis results are presented in Table 1.

With a benefit-cost ratio (BCR) of 13.8:1 at a 7% discount rate, the implementation of HERO has demonstrated very strong economic merit. The economic payback period for capital expenditure on this pilot is approximately 4 months.

**TABLE 1 Decision Criteria**

<b>Discount Rate</b>	<b>4%</b>	<b>7%</b>
<b>Discounted Costs</b>	\$2,217,250	\$2,062,852
Capital Costs	\$840,503	\$840,503
Operations and Maintenance Costs	\$1,376,747	\$1,222,349
<b>Discounted Benefits</b>	\$32,936,353	\$28,521,037
Vehicle Operating Cost Savings	\$16,912,390	\$14,645,183
Travel Time Cost Savings	\$16,023,963	\$13,875,855
<b>Decision Criteria</b>		
<b>Net Present Value (NPV)</b>	\$30,719,103	\$26,458,186
<b>Benefit Cost Ratio (BCR)</b>	14.9	13.8

Sensitivity tests were also conducted around areas of some uncertainty in the project case, including longer on-ramp delays, increased throughputs and the composition of light vehicle classification. The results of these tests are presented in Table 2.

Overall, the pilot still proves to be a very robust project even under scenarios of uncertainty for key variables.

**TABLE 2 Sensitivity Tests**

<b>Variable</b>	<b>Change</b>	<b>NPV (7% discount rate)</b>	<b>BCR (7% discount rate)</b>
On-ramp delays	10 second increase in travel time per vehicle accessing motorway via an on-ramp	\$25,611,361.1	13.4
Throughput	150 vehicles per hour additional throughput	\$27,472,635.4	14.3
Composition of light vehicle traffic	Assume 95% private and 5% commercial traffic	\$23,096,749.4	12.2

## CONCLUSIONS

The implementation of the HERO ramp signaling system under this pilot is a good example of how smart infrastructure systems can improve the performance of existing motorway assets. Given the relatively minor changes made to the ramp signal cycle times, the measured performance benefits are impressive. This points to further opportunities to improve motorway performance through the expanded rollout of coordinated ramp signaling along the motorway corridor and experimentation with different minimum/maximum cycle times to balance motorway and arterial network performance.



The paper also highlights the strong economic justification for employing ITS to improve service levels for motorway users which can be delivered at much less cost than traditional capacity enhancements through new additional capacity.

In summary, the following improvements to the operation of the route have been achieved to date:

- Average AM peak inbound travel speeds have increased by 7% from 70 km/h to 75 km/h.
- Average AM peak inbound traffic flows have increased by 4% with an additional 150 vehicles per hour throughput.
- Average AM peak inbound travel productivity has improved by 8%.
- The proportion of AM peak inbound trips with good reliability has improved by 37%.

It is important to note that these performance improvements were in addition to the generally good traffic performance that was already being achieved under the fixed-rate ramp metering system previously in operation. Therefore, the potential gains for urban motorways currently without ramp metering capability could be even greater.

In conclusion, the reported evaluation confirms that dynamic, coordinated ramp signaling can provide user benefits compared to fixed-rate systems. It also supports the high economic return that ITS can derive in its ability to achieve higher levels of efficiency on Queensland's motorways.

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