A Network Wide Evaluation of the SCATS Ramp Metering System Using Microsimulation

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Abstract

During the last century, there has been considerable economic growth and development of cities around the world. The growth has led to an expansion of car-ownership and ultimately increased congestion of the road network. Traffic engineers and transport planners have attempted to mitigate the consequences of congestion of motorways and freeways using a number of techniques. One of which has been Ramp Metering, that regulates the flow of traffic entering the motorway in order to improve mainline flow and minimise congestion. Many ramp metering algorithms have been developed based on a variety of strategies. The more advanced algorithms allow coordination between a series of subsequent on-ramps to improve the performance of the network holistically. One of the leading ramp metering solutions is the SCATS Ramp Metering System (SRMS).

This study evaluates the effectiveness of the SRMS using state-of-the-art microsimulation modelling. SRMS is implemented in AIMSUN using the SCATSIM interface applied to a freeway stretch of over 25km with seventeen on-ramps,. Arterial roads parallel to the freeway are included in the study to account for the route diversion effects due to on-ramp delays. The calibration of the coordinated ramp meters was conducted in conjunction with RMS and a number of different demand conditions were modelled to understand the sensitivity of ramp metering. The study considers a series of key performance metrics discussed within the literature and highlights the strengths and limitations of the microsimulation modelling paradigm.

1. Introduction

The increased usage of personal vehicles, combined with the spatial and economic constraints on constructing new motorways, has been attributed to road congestion (Yuan 2008). Increasing levels of congestion has resulted in an increase of total travel times, economic losses, reduction of traffic safety and deterioration of the environment. This has put pressure on transportation authorities around the world to develop novel solutions to efficiently manage congestion.

Various approaches have been used to mitigate the impacts of congestion, such as investment into further capital infrastructure to increase the capacity of the motorway networks to cater for the higher levels of traffic volumes. However, this approach is economically and spatially constrained. An alternative approach focuses on the optimal use of the available infrastructure using various traffic management techniques. In the case of the freeway and motorway management, optimal use of infrastructure can be achieved by ensuring the utilisation of their full capacity (Yuan 2008).

Ramp Metering (RM) is one such traffic management technique that aims at optimising the use of the currently available infrastructure. Since the early 1960s, RM has been used to effectively alleviate the congestion on motorways. It was first implemented in the United States of America (in Chicago, Detroit and Los Angeles) and has also been widely used in

Europe. In the last 20 to 25 years it has become prevalent within Australasia, in particular within Melbourne and Auckland.

RM employs traffic signals to control the traffic flow entering the motorway. As a result, congestion on the mainline is controlled, travel times are reduced, network traffic is redistributed, and road safety within the mainline corridor and merge areas of the motorway is improved (Aydos 2014, O'Brien 2014). The main concerns of implementing RM are related to the development of ramp queues and their impact on the surrounding arterial network (Burley and Gaffney 2013, 2014), as well as the equitable deployment of a RM solution for support of public officials and the general public (WDoT and DoT 1988, Duthie and Waller 2008, TfNSW 2013, Duthie, Cervenka et al. 2015).

This study is an extract from a technical report in collaboration with the Roads and Maritimes Services (RMS) (Amini, Wijayaratna et al. 2015). The goal of the study is to evaluate the *SCATS Ramp Metering System* (SRMS) using a large microsimulation network. Previous studies that simulated ramp meters have typically utilised METANET (mesoscopic) (Papamichail and Papageorgiou 2008, Xiao-Yun, Qiu et al. 2011) or AIMSUN (microsimulation) (Jiang, Lee et al. 2013, Li and Ranjitkar 2013, Amini, Grzybowska et al. 2015). Each platform has advantages and disadvantages in regards to implementation and evaluation of the ramp metering solution. In this study a microsimulation model has been adopted for considering aspects of RM such as arterial diversions, on-ramp queueing and arterial integration.

The contributions of this paper are as follows, (1) the implementation of SRMS using the SCATSIM interface for AIMSUN, (2) the evaluation of SRMS at a system level and (3) inclusion of novel performance metrics which should be considered during evaluation of RM systems (e.g. arterial diversions). The paper is organised as follows. Section 2 describes the Base model and the hypothetical demand conditions developed to evaluate SRMS. Section 3 presents the SRMS algorithm and the calibration of SRMS. Section 4 discusses the evaluation measures. The results and discussions are summarised in Section 5, followed by concluding remarks in Section 6.

2. Base Model Development

2.1 Network and Demand Conditions

The focus of the analysis was on broad general comparisons spanning ranges of possible data rather than a single specific case study. As a result, hypothetical demand data was employed and it should be stressed that the results are not tied to a specific physical motorway. However, to ensure that the underlying infrastructure represented a realistic setting, the geometry from a section of the M2 motorway in northern Sydney was employed. This selection was essentially random and is not intended to convey any specific insight for this facility.

The coordination effects of a ramp metering algorithm and the diversion effects due to on-ramp delays can be evaluated by considering a long section of a freeway network and its parallel arterial roads, respectively. The model includes 25km-long stretch of motorway with seventeen on-ramps and fifteen off-ramps (Figure 1).

Figure 1: Microsimulation network geometry and on-ramp referencing
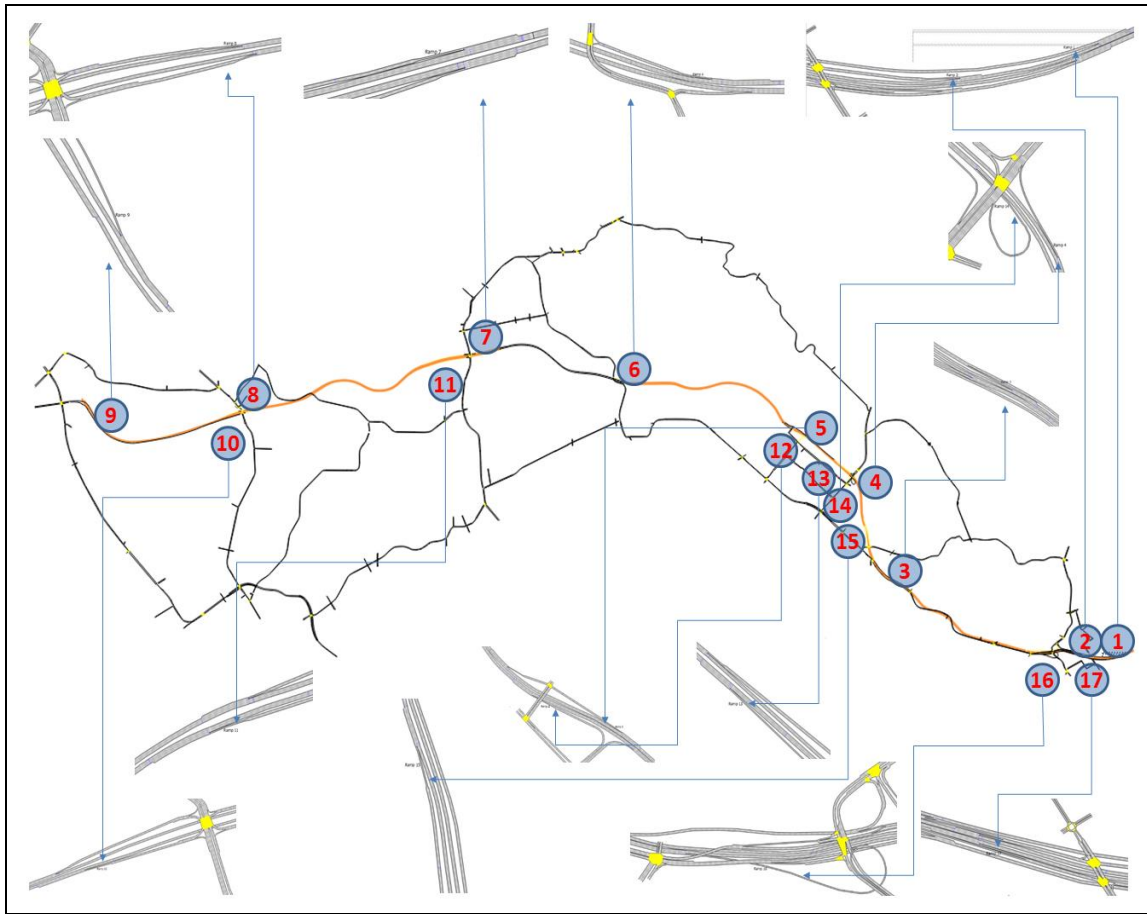
In order to evaluate the RM solution under different traffic states, six hypothetical demand conditions were developed (Table 1). A highly congested network was deemed necessary to effectively reveal the benefits of the implementation of a RM solution. The hypothetical demands were derived from the theoretical capacities of the road infrastructure (Erceg 2009).

Table 1: Hypothetical demand conditions

Demand Profile	Demand Multiplier			Demand Profile (15minute periods)
	0.5 (Low) 25k PCU	1.0 (Typical) 50k PCU	1.5 (Extreme) 75k PCU	
Uniform Profile	0.5 Flat	1.0 Flat	1.5 Flat	7.5%,10%,12.5%,15%, 17.5%,15%,12.5%,10%
Concentrated Profile	0.5 Peaky	1.0 Peaky	1.5 Peaky	5%,7.5%,10%,20%, 27.5%,15%,10%,5%

2.4 Arterial Signals

The major signalised intersections within the arterial network were coded as fixed signals, and the remaining signalised intersections were coded as priority controlled intersections. A signalised intersection was considered major if it was an intersection between the arterial network and a motorway ramp, an intersection between two arterial roads, or a large intersection particularly if slip lanes were present.

A total of 64 signalised intersections were coded using fixed time control plans. The phase sequence and timing plans were extracted from RMS SCATS database and initially coded for the AM peak period. The signals were then manually fine-tuned to '*1.5 Peaky*' demand condition.

2.5 Route Choice Model

The Logit stochastic route choice model was applied to simulate the diversions due to delays on the on-ramps. Thus, given the demand between an origin-destination (OD), the proportion of vehicles P_k assigned to path k (from a set of the plausible paths l) is calculated using the path costs v_l as shown in equation (1):

$$P_k = \frac{1}{1 + \sum_{l \neq k} e^{(v_l - v_k)\theta}} \tag{1}$$

The scale factor of θ=4.01 was calculated from the average OD travel times obtained from the '*1.0 Flat*' demand condition. This demand condition was considered to represent the moderate traffic state.

3. SCATS Ramp Metering System

The *SCATS Ramp Metering System* (SRMS) was developed by the road authority in New South Wales, Roads and Maritime Services (RMS) (2014). SRMS has been successfully implemented on 84 on-ramps along the Southern, Northern, North-Western motorways and in the Central motorway junction (at a total length of 140km) in Auckland (Aydos 2014, O'Brien 2014). In order to better understand the implementation of SRMS the authors conducted an interview with RMS and the Auckland Transport Operations Centre (ATOC). The calibration process described in Section 3.2 is informed by the findings of these interviews.

3.1 Algorithm Description

SRMS is a heuristic based algorithm that is capable of coordinating ramp meters to optimise network wide performance. SRMS is comprised of two strategies. These strategies are: "*overlapped occupancy control*" and "*feedforward disturbance compensation*" as described below.

3.1.1 Overlapped occupancy control

The overlapped occupancy control is a feedback strategy similar to the ALINEA algorithm, refer to (Papageorgiou, Hadj-Salem et al. 1997, Papamichail and Papageorgiou 2008) for details. The main difference is that the error in occupancy (i.e. $\varepsilon = O_{critical} - O_{measured}$) is formulated in a non-linear form that allows the system to respond more rapidly to a congested condition.

$$q(k) = q(k-1) + c \times f(\varepsilon(k)) \tag{2}$$

Where, $q(k)$ is the metering rate at time interval *k, c* is a configurable parameter, $f(\varepsilon(k))$ is the non-linear function of $\varepsilon(k) = O_{critical} - O_{measured}(k)$, as shown in Figure 2. $f(\varepsilon(k))$ is also referred to as $\Delta\alpha$ in the *SRMS Principles and Operational Strategies* (2014).

Figure 2: The non-linear function used in the overlapped occupancy control of SRMS algorithm
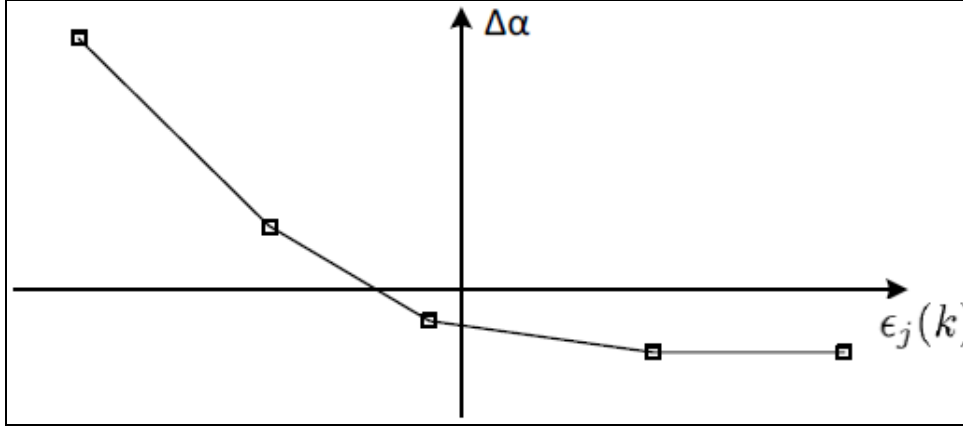
A number of on-ramps can be assigned to one detector station on the mainline, to achieve maximum control over a bottleneck. The detector station with the maximum occupancy error dictates the metering rate applied to the assigned on-ramps.

3.1.2 Feedforward disturbance compensation

The feedforward disturbance compensation strategy attempts to compensate for the oscillations in ramp-metering rate due to delays in response time. It utilises the *Demand-Capacity* strategy within a defined zone as follows:

$$N = B - A - U + X \qquad (3)$$

Where, N is the capacity within the zone, B is the bottleneck capacity (typically at the end of the zone), A is the measured flow upstream of the bottleneck, U is the flow of all unmetered on-ramps within the zone, X is the flow of all off ramps within the zone. The available capacity N is divided between the metered on-ramps based on the relative proportion of the expected on-ramp demands within the zone. The expected on-ramp demands are based on historical data. These two strategies are combined as follows:

$$q(k) = q(k-1) + \frac{N \times Q_i}{\sum Q_i} \times f(\varepsilon(k)) \qquad (4)$$

Where, Q_i is the expected demand on the metered on-ramp i and ΣQ_i is the sum of the expected demand for all metered on-ramps within a zone. The core working of the SRMS algorithm is described above. However, SRMS has many other features including:

- estimating and reallocating residual spare capacity,

- ramp queue management (using red time decrement or red time limiting),

- ramp queue balancing (both inter and intra-zonal using the spare capacity N within the feedforward disturbance compensation strategy),

- incidence detection and response,

- integrated ramp metering with arterial system,

- critical occupancy estimation.

3.2 Implementation and Calibration

SRMS was implemented in AIMSUN using the SCATSIM interface, which allows SCATS and SRMS to be simulated. The interface enables the real-time exchange of detector and signal data with a simulator such as AIMSUN. Detectors and meters were placed in the Base model

in accordance with the SRMS configuration manual (shown in Figure 3). Each on-ramp (and associated detectors) was coded with a unique controller, allowing communication of detector information between AIMSUN and SRMS. The zone configuration was initially based on a maximum spacing of 3 km between the on-ramps, as recommended in the SRMS configuration documents (2014).

Figure 3: SRMS detector layout
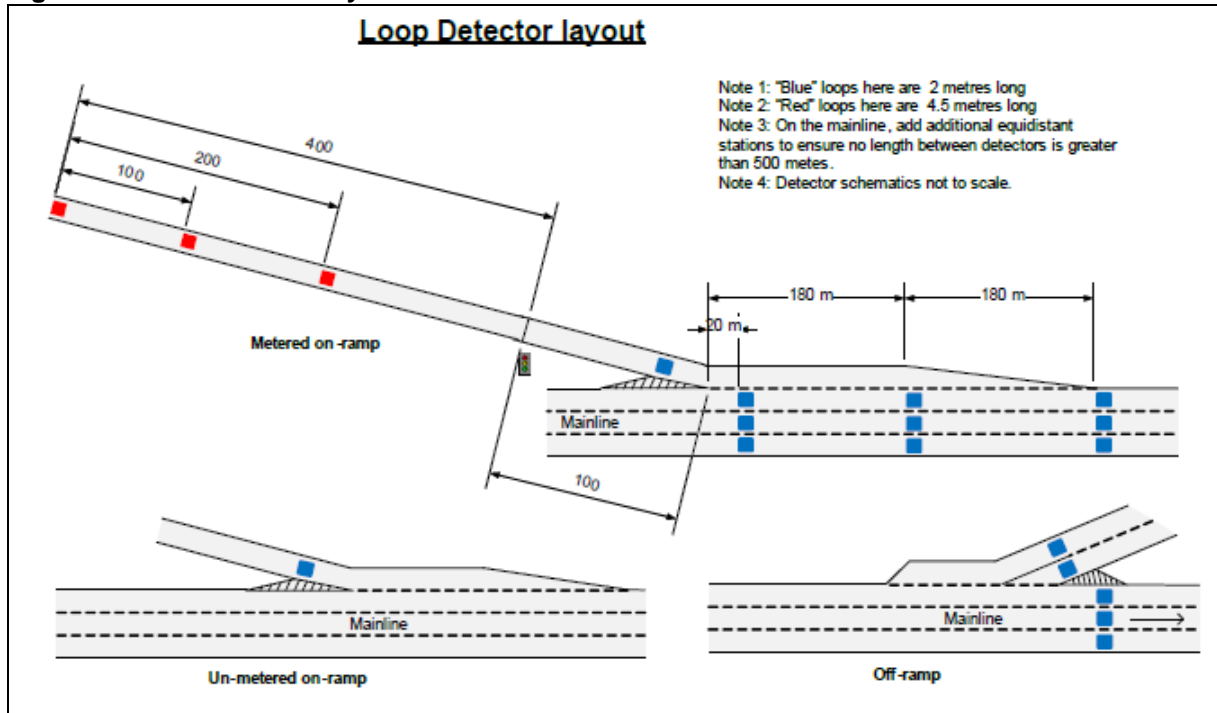
The calibration of SRMS in AIMSUN was predominantly conducted with the "*1.5 Peaky*" demand condition, as it was considered the worst case scenario. The main focus of the calibration process included:

- Placement of detector stations to best represent bottlenecks within the network.
- A maximum red time of 16 seconds to reflect the maximum cycle time used in practice within the implementation of SRMS in Auckland.
- Queue dumping was allowed. This option allows the ramp meter to switch-off while a queue is present on the ramp, when the switch-off criteria is met.
- The critical occupancy module in SRMS required data from a few preliminary simulation runs of the model. During each simulation run, the module refines the critical occupancy estimation. After a number of runs, this calibration was considered complete and was not further refined.
- The zoning configuration was refined to allow greater influence from the high demand on-ramps on the downstream bottlenecks. The final zone configuration is shown in Figure 4.
- The initial on-ramp demands and bottleneck capacities were estimated from the '*1.5 Peaky'* demand condition.
- The bottleneck capacities for each zone, as well as the expected on-ramp demand were further refined by observing the changes in the two strategies utilised by SRMS as defined in Section 3.1. In general, a flag for a refinement in the calibration was raised if one of the strategies dominated the metering rate for most of the simulation period.

Figure 4: SRMS Zone Configuration (On-ramps in one zone are encircled by the dotted lines)
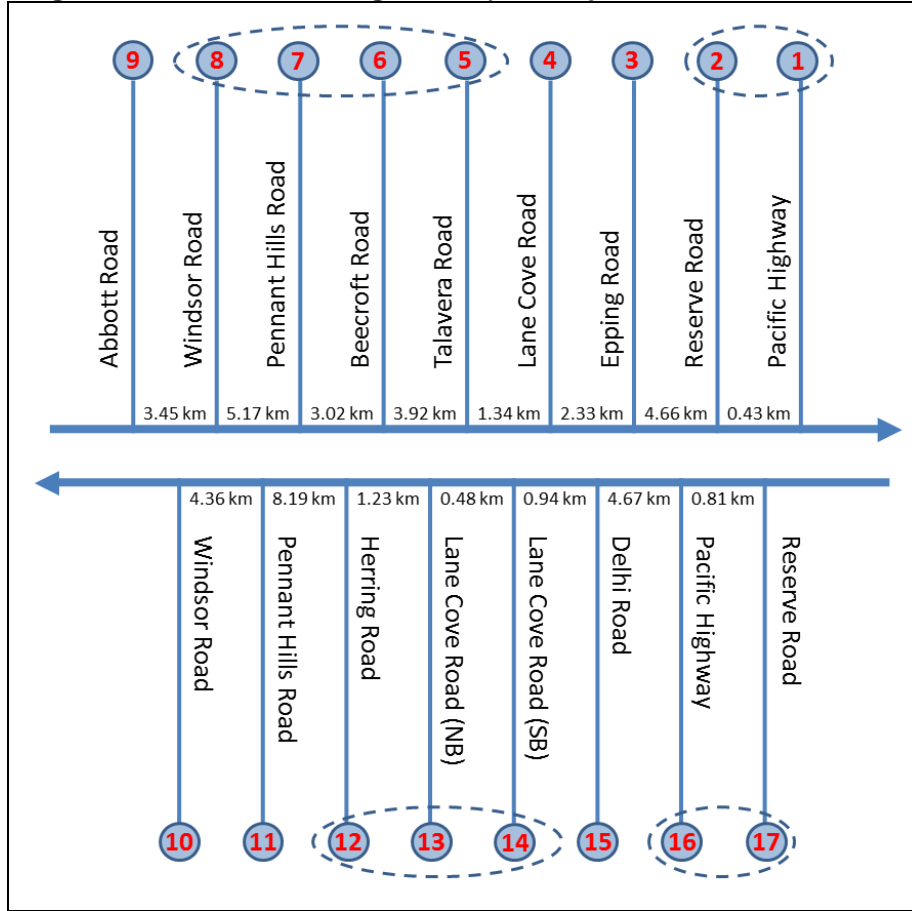
4. Evaluation Measures

4.1 Overall Network Performance Criteria

The performance metrics reported for the entire network include: *Total System Travel Time* (TSTT), *Vehicle Kilometres Travelled* (VKT), speed, and exit flow. The network wide performance criteria are arguably the most important metrics to consider as the road network is assessed holistically. The metrics reported directly from AIMSUN should be interpreted with caution when comparing scenarios, as these measures typically exclude the vehicles that did not exit the network by the end of the simulation period. The methodology for calculating the default AIMSUN outputs is described in the AIMSUN user manual (TSS 2014). A modified metric for TSTT is utilised so that all the vehicles are considered regardless of their exit time:

$$TSTT_{Calc} = TSTT_{AIMSUN} + TT_{Last2:30} \times veh_{in} + T_{sim} \times veh_{AvgVirtualQ} \tag{5}$$

Where, $TSTT_{AIMSUN}$ is the travel time of all vehicles that exited the network by the end of the simulation period. $TT_{Last2:30}$ is the average travel time of all vehicles exiting the network in the last 2.5 minutes of the simulation period, Veh_{in} are the total number of vehicles inside the network at the end of the simulation period. $Veh_{AvgVirtualQ}$ is the average number of vehicles unable to enter the network during the simulation period (i.e.: average virtual queue length), and T_{sim} is the length of the simulation period (i.e. 2 hours). The term $(T_{sim} \times veh_{AvgVirtualQ})$ assumes that vehicles which are in the virtual queue are stationary. This measure considers all vehicles in the demand matrix and is comparable across scenarios.

4.2 On-ramp Performance Criteria

RMs cause additional delays at the on-ramps which may lead to spill-backs onto the arterial network. Accordingly, the following metrics were further used to evaluate the on-ramps' performance.

- *Percentage of Time at Maximum Queue* (%). The proportion of time that the occupancy of the detector at the entrance of the on-ramp was greater than 80%.
- *Maximum Observed Queue* (vehicles). The queues on the on-ramps were manually observed and recorded throughout the simulation.
- *Maximum Number of Affected Intersections* (number of intersections). The number of intersections affected by the "Maximum Observed Queue".

The measurement of queue lengths and propagation can be a complex task, particularly when the queues spill-back in multiple directions within the upstream arterial roads. By considering the above measures concurrently, it is possible to assess the impact of on-ramp queueing. The length of time the on-ramp queue extends to the entrance of the on-ramp provides an indication of the frequency of the queue spill-back. While the maximum observed queue (and the maximum number of affected intersections) represents the magnitude of the issues caused by the queue. A limitation of this methodology is that in some scenarios the maximum queue observed is primarily caused by the arterial network, in which case the on-ramp queue is a minor contributor to the maximum queue.
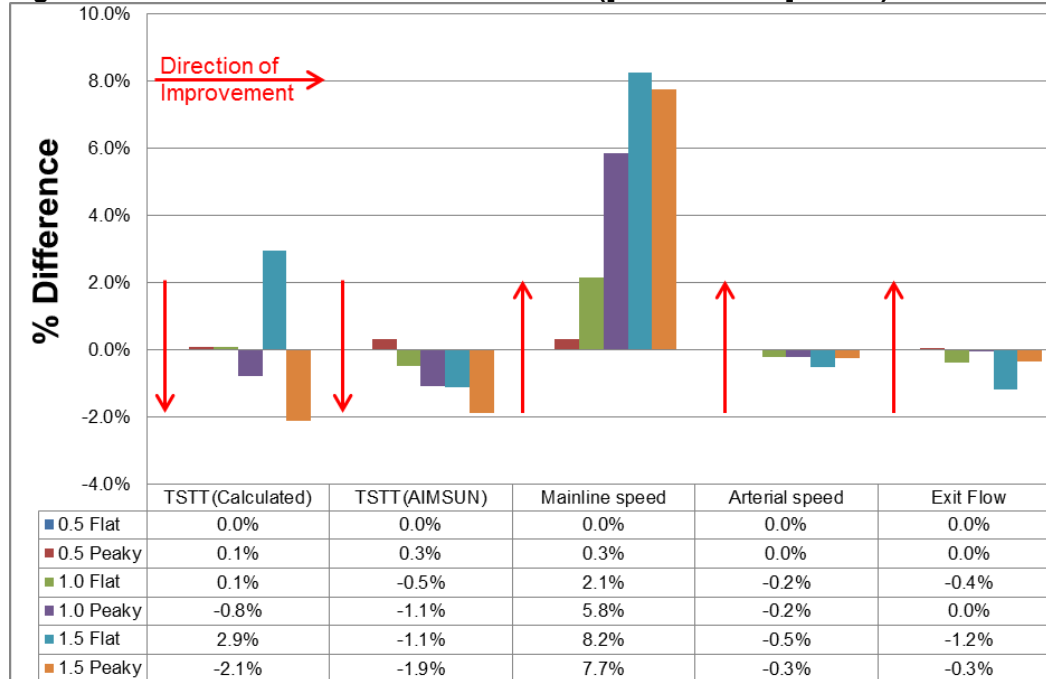
5. Results and Discussion

5.1 Overall Network Performance Criteria

The differences between the network-wide metrics for the Base and SRMS scenarios are shown in Figure 5. The $TSTT_{AIMSUN}$ is provided as a point of reference and to highlight the need for the extrapolation of the $TSTT_{Calc}$. This is because only the vehicles that exit the network (by the end of the simulation) are included in the $TSTT_{AIMSUN}$. The fluctuations in the Exit Flow (shown in Figure 5) indicate that the $TSTT_{AIMSUN}$ statistics cannot be compared across scenarios.

Figure 5 indicates that the $TSTT_{calc}$ was reduced in the SRMS scenario compared to the Base scenario, for the '*1.5 Peaky*' and '*1.0 Peaky*' demand conditions. The other demand conditions showed an increase in the $TSTT_{calc}$ metric, indicating the importance of calibration particularly for RM. The calibration of both the arterial signals and the RM was conducted using '*1.5 Peaky*', which indicates the importance of the calibration when evaluating RMs.

The mainline speeds have increased due to RM across all six demand conditions. The arterial speeds have reduced slightly because of the diversion of traffic from the mainline to the arterials. The '*0.5 Flat*' demand condition did not trigger the necessary conditions for SRMS to turn-on and thus performed exactly the same in both Base and SRMS scenarios.

Figure 5: Difference in network wide statistics ([SRMS – Base] / Base)

	TSTT (Calculated)	TSTT (AIMSUN)	Mainline speed	Arterial speed	Exit Flow
■ 0.5 Flat	0.0%	0.0%	0.0%	0.0%	0.0%
■ 0.5 Peaky	0.1%	0.3%	0.3%	0.0%	0.0%
■ 1.0 Flat	0.1%	-0.5%	2.1%	-0.2%	-0.4%
■ 1.0 Peaky	-0.8%	-1.1%	5.8%	-0.2%	0.0%
■ 1.5 Flat	2.9%	-1.1%	8.2%	-0.5%	-1.2%
■ 1.5 Peaky	-2.1%	-1.9%	7.7%	-0.3%	-0.3%

5.2 Mainline Performance

Figure 6 shows the *Austroads Productivity Graph* which considers both speed and flow, indicating the performance of the mainline under different scenarios. The detailed explanation of this graph is presented in Troutbeck et al. (2007). The productivity graph presents that the productivity of the mainline improves after the implementation of SRMS scenario across each of the demand conditions.
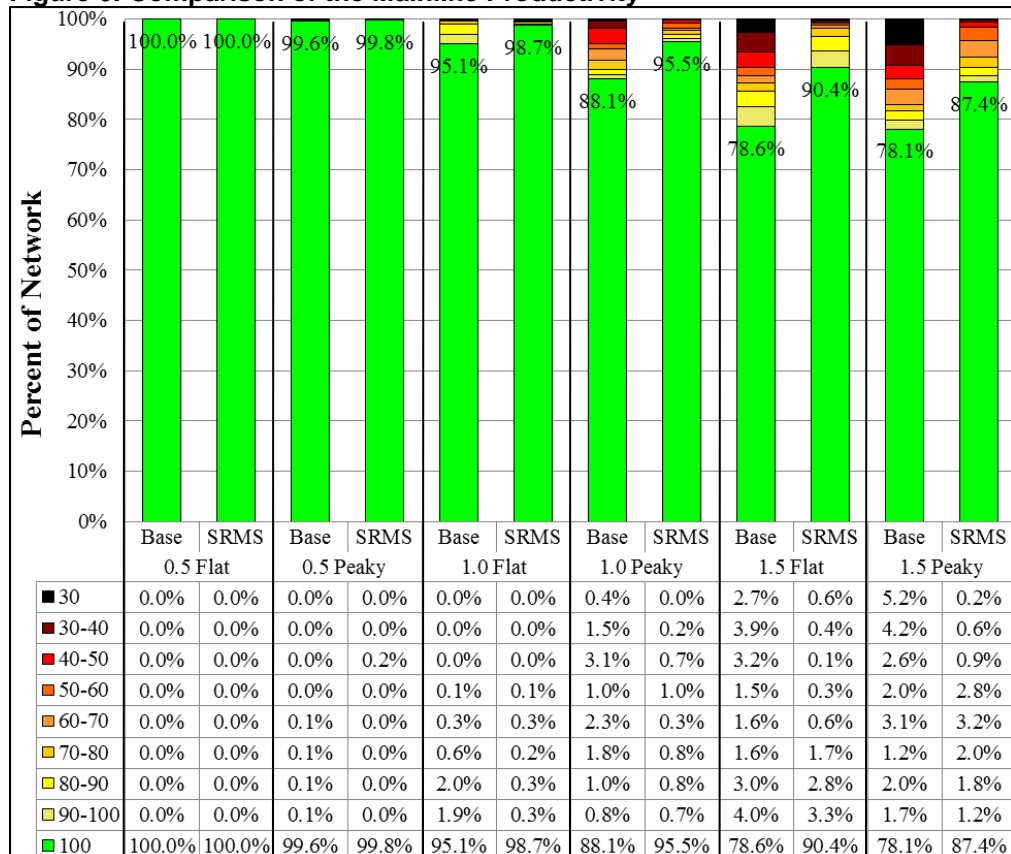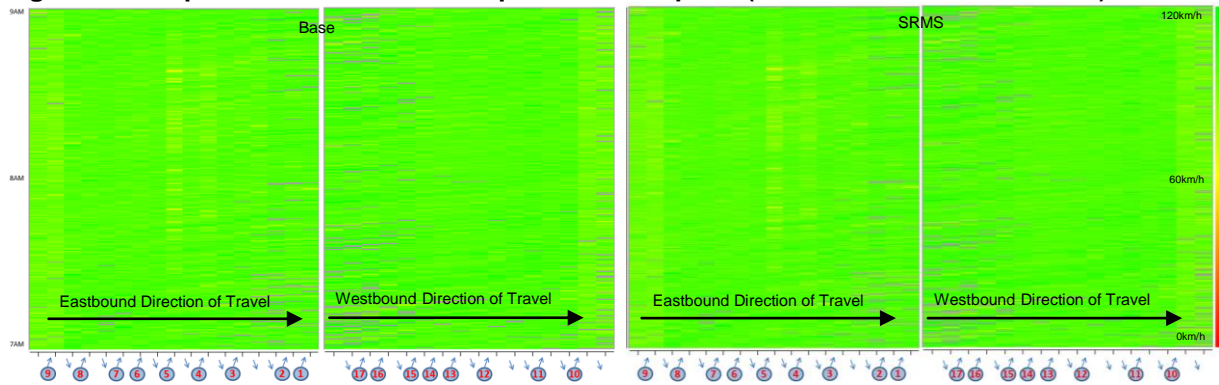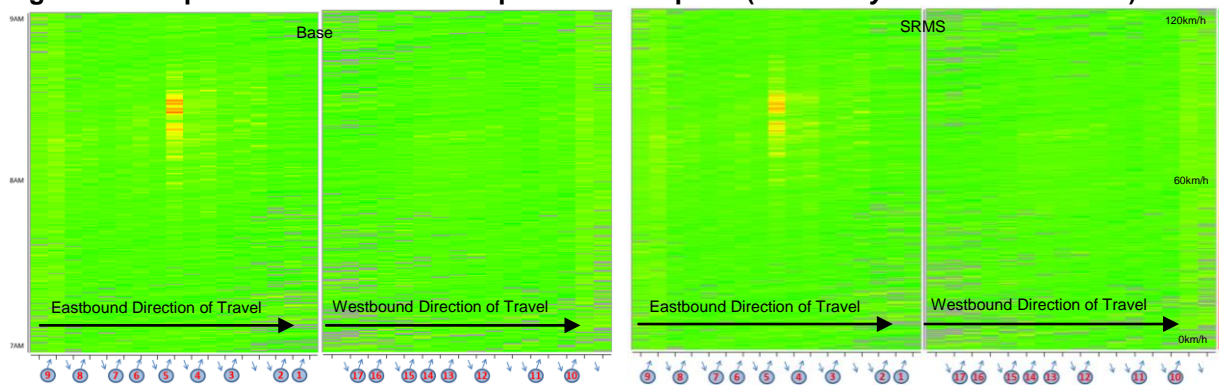
Figure 6: Comparison of the Mainline Productivity

	Base	SRMS	Base	SRMS	Base	SRMS	Base	SRMS	Base	SRMS	Base	SRMS
	0.5 Flat		0.5 Peaky		1.0 Flat		1.0 Peaky		1.5 Flat		1.5 Peaky	
■ 30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	2.7%	0.6%	5.2%	0.2%
■ 30-40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.5%	0.2%	3.9%	0.4%	4.2%	0.6%
■ 40-50	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	3.1%	0.7%	3.2%	0.1%	2.6%	0.9%
■ 50-60	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	1.0%	1.0%	1.5%	0.3%	2.0%	2.8%
■ 60-70	0.0%	0.0%	0.1%	0.0%	0.3%	0.3%	2.3%	0.3%	1.6%	0.6%	3.1%	3.2%
■ 70-80	0.0%	0.0%	0.1%	0.0%	0.6%	0.2%	1.8%	0.8%	1.6%	1.7%	1.2%	2.0%
■ 80-90	0.0%	0.0%	0.1%	0.0%	2.0%	0.3%	1.0%	0.8%	3.0%	2.8%	2.0%	1.8%
■ 90-100	0.0%	0.0%	0.1%	0.0%	1.9%	0.3%	0.8%	0.7%	4.0%	3.3%	1.7%	1.2%
■ 100	100.0%	100.0%	99.6%	99.8%	95.1%	98.7%	88.1%	95.5%	78.6%	90.4%	78.1%	87.4%

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Figure 7 to Figure 12 shows the Speed Contour Plots for the Base and SRMS scenarios across the six demand conditions. The speed measurements are obtained from mainline detector stations placed between each ramp. The figures indicate that the SRMS scenario has significantly higher speeds for a longer period of time. In particular, the effects of the reduction in the number and length of the bottlenecks in the SRMS scenario are clearly visible. It is noted that in some sections of the mainline speed improvements of up to 38% was observed for the '*1.5 Peaky*' demand condition highlighting the benefits of the RM solution when considering the mainline performance.
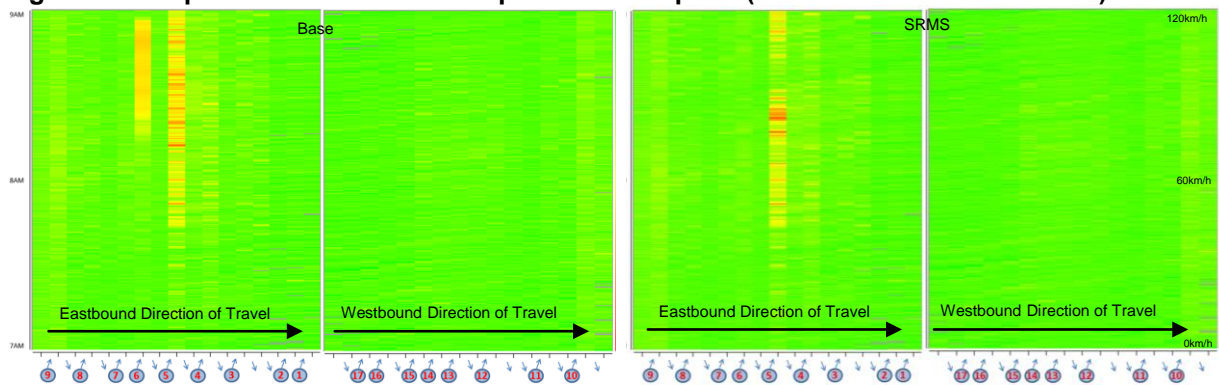
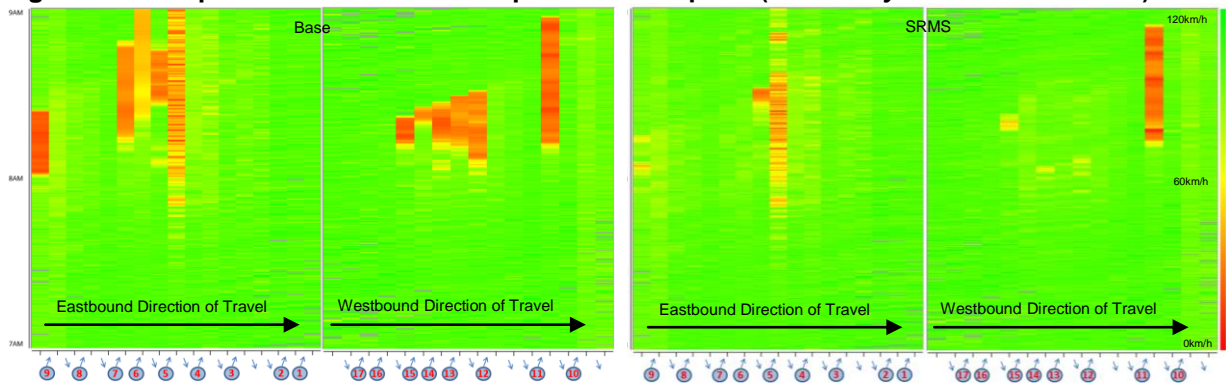**Figure 7: Comparison of the mainline speed contour plots ('*0.5 Flat*' demand condition)**

Figure 8: Comparison of the mainline speed contour plots ('*0.5 Peaky*' demand condition)
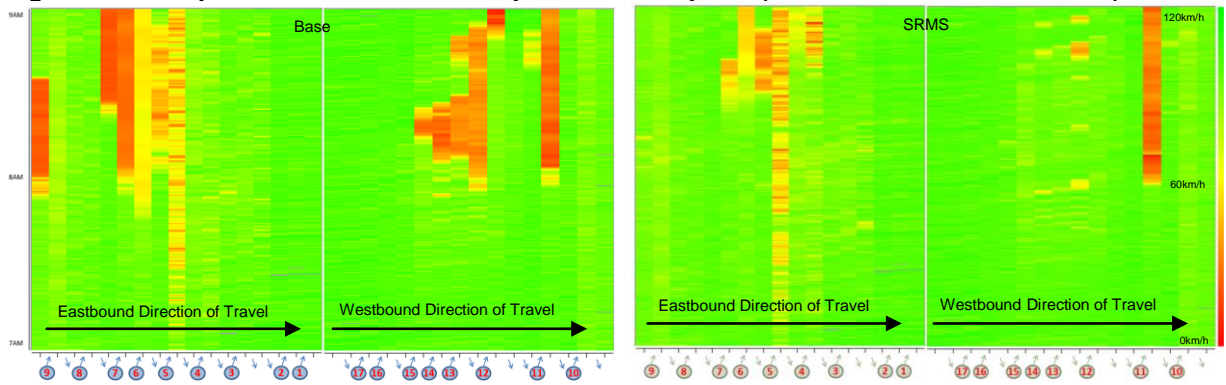

Figure 9: Comparison of the mainline speed contour plots ('*1.0 Flat*' demand condition)

Figure 10: Comparison of the mainline speed contour plots ('*1.0 Peaky*' demand condition)

Figure 11: Comparison of the mainline speed contour plots ('*1.5 Flat*' demand condition)

Figure 12: Comparison of the mainline speed contour plots ('*1.5 Peaky*' demand condition)
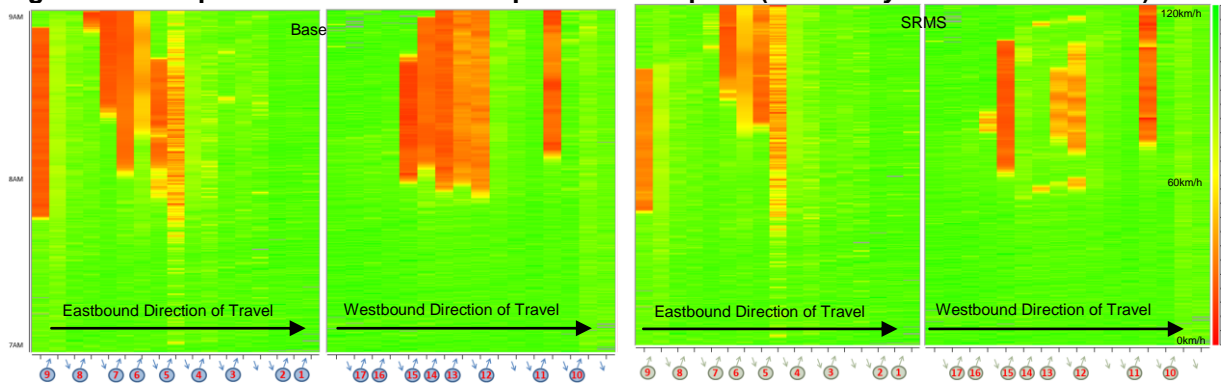

Figure 13 highlights the mainline flow follows the demand profile until mainline capacity is reached. As the demand multiplier is increased the capacity of the mainline is reached and the mainline flow plateaus. A similar pattern was observed from the mainline detectors, where the flow plateaued even at higher occupancies. Unlike what is present in the field observations (i.e. flow reducing after critical occupancy is reached) the flows from the microsimulation reduced only slightly during congested conditions (Cassidy and Bertini 1999, Chung, Rudjanakanoknad et al. 2007). In the microsimulation results, large flow rates are achieved even at significantly lower speeds, thus some of the main benefits of RM are not realised. This is currently one of the limitations of the state-of-the-art microsimulation models and was also reported by Zhang, et al. (2001).

Figure 13: Average mainline flows in vehicles/hour (eastbound, SRMS Scenario)
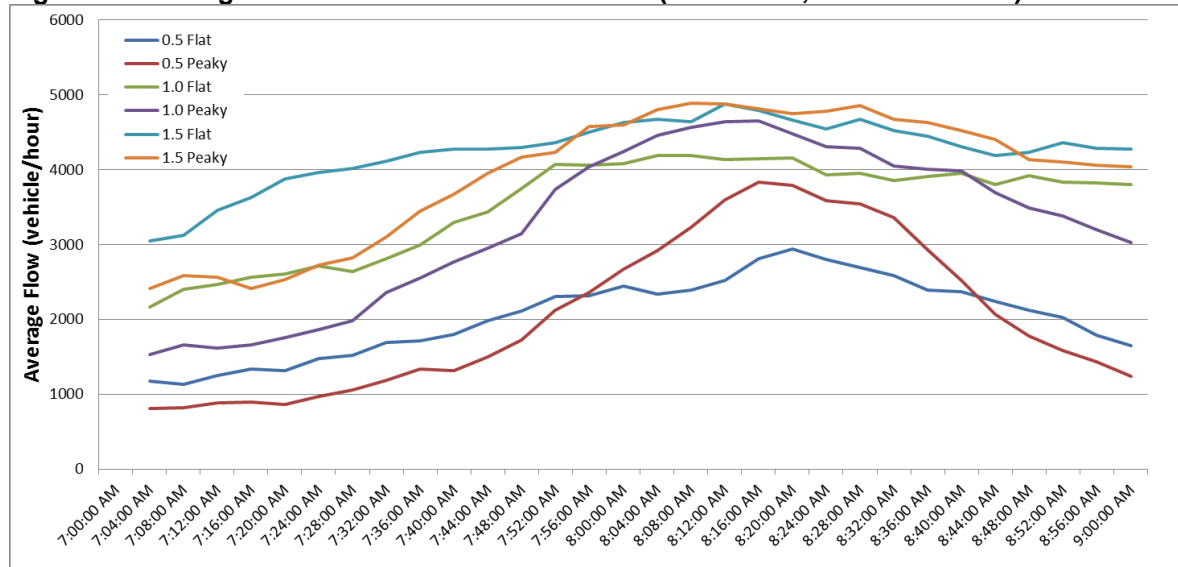
5.3 On-ramp Performance

Ramp meters cause an increase of queue length at the on-ramps that may spill-back onto the adjacent arterial network. Queue spill-backs can have significant negative effects on the network performance. The two most representative traffic conditions have been presented to highlight the effects of queuing as a result of the implementation of the SRMS algorithm.

Table 2 shows the two on-ramps that were observed to contain queues which spilled-back onto the arterial network for the '*1.0 Flat'* demand condition. The queue spill-back from the on-ramps may join other queues formed within the arterial network. The maximum queue and the number of intersections affected is a combination of the effect of the on-ramp queue and the queues within the arterial network. For example, comparison of the percentage of time at maximum queue for on-ramp 8 shows that the SRMS scenario has 1.0% less time at maximum queue. However, the maximum observed queue length was higher for the SRMS scenario. The queue at on-ramp 8 was observed to reach the entrance of the on-ramp for a relatively short amount of time. The maximum queue was a combined effect of the queues from the on-ramp and the arterial network. Thus, the on-ramps with small percentage of time at max queue but large maximum queue length are likely to be due to combined effect of spill-back from the ramp meter and the existing congestion within the arterial network.

On-ramp 9 presents a more intuitive result, where both the 'percentage of time at maximum queue' and the 'maximum observed queue' are both relatively large. The SRMS scenario has a large increase in percentage of time at maximum queue (i.e. 16.0%) and a relatively modest increase in maximum observed queue (i.e.102 vehicles). Thus, the reported maximum queue length is likely to be due to on-ramp 9 and less so from the arterial network.

Table 2: On-ramp performance ('*1.0 Flat*' demand condition)

On-ramp ID*	Queue Capacity (vehicles)		Queue Performance Measures					
			Percentage of time at Max Queue		Maximum Observed Queue (vehs)		Maximum Affected Intersections	
	BN[1]	SL[1]	Base	SRMS	Base	SRMS	Base	SRMS
8	128	118	8.7%	6.7%	408	648	3	4
9	186	258	9.1%	25.1%	190	292	0	2

1) Capacity of the on-ramp is measured from: BL = Bottleneck on the on-ramp, SL = Stop Line.

The queue performance measures for the '*1.5 Peaky*' demand condition is presented in Table 3. Eight on-ramps were observed to exceed the available queue storage capacity. On-ramps 11, 13 and 14 have significant queues due to the ramp meters (more than doubling the percentage of time at maximum queue and the number of arterial intersection affected). This is an indication that the design of the ramps does not adequately meet the requirements of RM for the '*1.5 Peaky*' demand condition.

Table 3: On-ramp performance ('*1.5 Peaky*' demand condition)

On-ramp ID*	Queue Capacity (vehicles)		Queue Performance Measures					
			Percentage of time at Max Queue		Maximum Observed Queue (vehs)		Maximum Affected Intersections	
	BN^2	SL^2	Base	SRMS	Base	SRMS	Base	SRMS
6	69	79	9.8%	16.7%	132	516	0	3
8	128	118	11.1%	7.6%	2624	3038	6	10
9	186	258	54.2%	55.1%	1740	1870	3	4
11	359	369	7.3%	19.1%	790	2230	1	4
12	117	127	7.3%	2.9%	194	254	1	1
13	100	64	0.0%	38.7%	62	440	0	2
14	-	52	13.6%	43.8%	50	522	0	4
15	105	115	14.0%	40.2%	184	204	1	2

2) on-ramp capacity is measured from: BL = Bottleneck on the on-ramp, SL = Stop Line

The proposed methodology could be used to identify the on-ramps that should be considered for queue mitigation strategies when implementing the RM system.

5.4 Arterial Diversion (re-routing)

The additional delays experienced by road users when on-ramps are metered, can result in a diversion (re-routing) of the traffic from the motorway to the arterial network.

The redistribution of traffic throughout the network due to the implementation of the SRMS was assessed by comparing the VKT along the arterial sections of the hypothetical network. The network flows are different in each model and as a result the absolute VKT cannot be directly compared, because each model has a different total number of vehicles included within the VKT statistics. The proportion of VKT traveling on the arterial roads as compared to the mainline is less sensitive to the total throughput and is used to compare the traffic diversion between scenarios.

The proportion of the total network VKT that was on the arterial roads is shown in Figure 14. Approximately 40% of the total VKT is on the arterial networks with a demand multiplier of 0.5. As the demand increases, the proportion of VKT on the arterial network increases in both Base and SRMS scenarios. This is likely to be due to congestion on the mainline and the on-ramp delays.
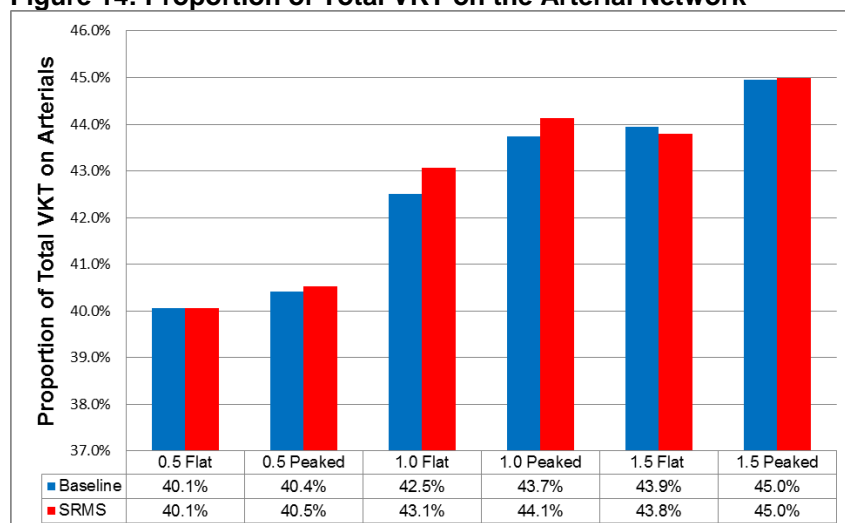
There is a small increase in the proportion of VKT on the arterial network for the SRMS scenario, across the demand conditions. The only exception is the '*1.5 Flat*' demand condition where SRMS has a slight reduction (i.e. 0.1%) in the proportion of vehicles travelling on the arterial network.

The change in proportion of arterial VKT due to SRMS is more significant for the '*1.0 Flat*' and '*1.0 Peaky*' demand conditions. The diversion onto arterial network maybe a desirable outcome depending on the policy adopted. It is also noted, that the diversion effect onto the arterials may be due to the limited capacity drop on the mainline as modelled in the microsimulation environment (discussed in Section 5.2). If the reduction in flow due to the congestion in the Base scenario was simulated more accurately, the Base scenario would be

expected to show a higher proportion of vehicles on the arterial network as a result of the reduction in capacity of the mainline.

Figure 14: Proportion of Total VKT on the Arterial Network

	0.5 Flat	0.5 Peaked	1.0 Flat	1.0 Peaked	1.5 Flat	1.5 Peaked
Baseline	40.1%	40.4%	42.5%	43.7%	43.9%	45.0%
SRMS	40.1%	40.5%	43.1%	44.1%	43.8%	45.0%

6. Conclusions

A network wide evaluation of the SRMS RM system was conducted using the microsimulation platform (AIMSUN). The evaluation is conducted on a road network based on 25 km stretch of the M2 motorway and its parallel arterials. Six hypothetical demand conditions were tested to check the performance of the RM system under varying traffic states. The SRMS algorithm was implemented using the SCATSIM interface for AIMSUN. The authors with the help of RMS, calibrated SRMS to the '*1.5 Peaky*' demand condition.

SRMS was found to provide a maximum mainline speed benefit over various motorway sections of approximately 38% (for the specific network and demand profiles examined), however the arterial speeds were found to be affected negatively in certain cases (thereby establishing the need to examine broader metrics than the mainline motorway). For instance, the network-wide impact on total system travel time was found to range from -2.1% to 2.9%, further highlighting that the implementation of RM could result in network improvements or deterioration depending on the specific case being examined. Calibration of the arterial signals, the coordination of the arterial signals and the RM system can also affect the performance of the algorithm. In other words, even in some cases where the mainline improved, the overall system could suffer (e.g., if RM was not optimally deployed with a consideration of the network impact). This highlights the need to consider metrics beyond only mainline conditions and stresses overall deployment, planning and configuration.

Though motorway data is available in some cases, the lack of arterial network data and, more critically, the simultaneous infrastructure improvements during the implementation of RM limit the opportunity to conduct network level analysis or conduct a controlled before and after analysis based on available data sets. This highlights the need for simulation tools that can be used to evaluate such scenarios.

The capabilities of microsimulation models remain an active field of research and development. For instance, even state-of-the-art simulation approaches may not fully account for the full benefits of RM. However, such models are the only tool capable of conducting controlled experiments over numerous hypothetical cases with clearly calculable metrics at both the mainline and network level. Thus current limitations of microsimulation models such as the mainline capacity drop in congested environment remains an open research question and should be considered in future research.

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