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Queue protection parameters' fine-tuning for variable speed limits

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Abstract

Any incident on motorways potentially can be followed by secondary crashes. Rear-end crashes also could happen as a result of queue formation downstream of high speed platoons. To decrease the occurrence of secondary crashes and rear-end crashes, Variable Speed Limits (VSL) can be applied to protect queue formed downstream. This paper focuses on fine tuning the Queue Protection algorithm of VSL. Three performance indicators: activation time, deactivation time and number of false alarms are selected to optimise the Queue Protection algorithm. A calibrated microscopic traffic simulation model of Pacific Motorway in Brisbane is used for the optimisation. Performance of VSL during an incident and heavy congestion and the benefit of VSL will be presented in the paper.

1. Introduction

Variable Speed Limits (VSL) is a type of Intelligent Transportation Systems (Uno et al.) that according to the road, traffic, and weather conditions, determines the proper speed for drivers in a dynamic manner. VSL are among the most effective systems in freeway control management. The aim of using VSL is to improve safety or to raise capacity on motorways. Apart from the VSL advantages into improving capacity of the road networks, there are multiple benefits of using VSL for traffic safety. "*VSL could be implemented in appropriate areas to reduce the potential for driver error, excessive speeds, and speed differential between cars and to enhance safety*"(Lennie et al., 2009).

VSL application, particularly for incident management has increasingly gained importance for improving safety on motorways. The appropriate definition of an incident within VSL design context could be any event that causes queue and congestion. The VSL algorithm responsible for reducing speed at the time of queue occurrence (as a result of incident or congestion) is called the Queue Protection (QP) algorithm. Queue Protection also detects the occurrence of incidents and guarantees a well-timed reaction to protect the end of queues created downstream from encountering high speed traffic. The QP algorithm causes a reduction in the occurrence of secondary crashes in crash situations and prevents rear-end crashes in traffic congestions simply by decreasing the speed limits. The QP algorithm needs to be fed by information provided from the Queue Detection (QD) algorithm. Not only the QP algorithm is triggered by the QD algorithm but also during the queue formation till the queue discharges QD is in interaction with the QP algorithm and provides updated information which is very critical to predicting queue tail location continuously.

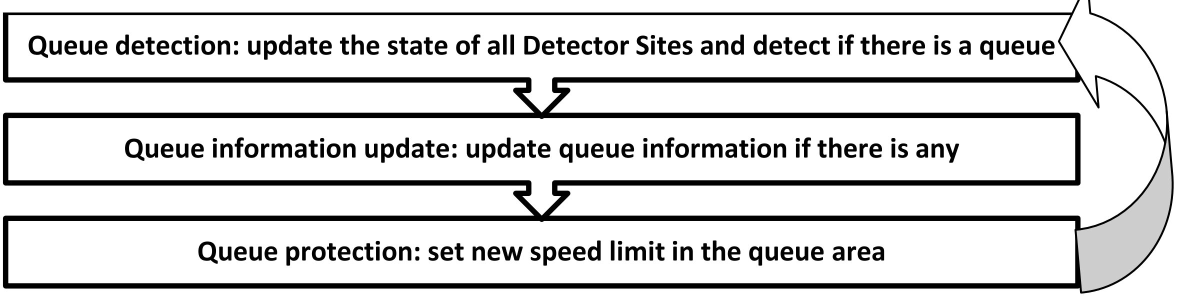
According to Ikeda and Matano (1999), for Queue Detection the most important tasks are congestions judgement process and determination of the queues' tail position. To determine the congestion occurrence or clearance on motorways, the QD algorithm observes local traffic performance measures of embedded loop detectors. For instance, speed, occupancy and volume at every minute are the kinds of information that loop detectors provide on

Motorways. Specific values of the mentioned measures that can be used to determine the queue occurrence or clearance are "*the thresholds*" for activation or deactivation of QP algorithm. Apart from these threshold values, to confidently verify that a queue has formed or discharged, and to determine the queue propagation speed, 1- the number of successive detectors that should report the existence or discharge of a queue (*consecutive sites*) and also 2- the time intervals that each of these detectors should report exceeding the predetermined thresholds (*consecutive interval*) are essential.

The questions that can be raised are, how to assure that the QP algorithm triggers in a minimum time period after queue occurrences and as a result, protects the end of queues and also how does this be deactivated after the queues' discharge? Answering these questions help to optimise QP algorithm performance. In the literature there is not comprehensible optimized combination of these thresholds and parameters.

The Queensland Department of Main Roads (DTMR) is also currently developing a QP algorithm. Finding a method of tuning the QP algorithm parameters and thresholds is of interest to DTMR. This paper focuses on tuning the QP algorithm parameters and thresholds. Three performance indicators namely activation time, deactivation time and number of false alarms as the objective values are targeted to be minimised. For this purpose six variables are tuned, namely speed and occupancy thresholds for both activation and deactivation time and also number of consecutive sites and consecutive time intervals exceeding the predetermined thresholds. Figure 1 illustrates the QP algorithm main stages. The discussed above thresholds are needed in the first two stages of the algorithm.

Figure 1: QP algorithm stages for determining new speed limits in every calculation interval



In the second part of this paper, the procedure for finding the best threshold combinations for the QD algorithm is discussed. A calibrated microscopic traffic simulation model of the Pacific Motorway in the Brisbane area is used as a test bed. In the third Section, the performance of the tuned QP algorithm during an incident and a non-incident situation at heavy congestion is tested and benefits are discussed. Conclusions are presented in the fourth section.

1.1. Terminology

Tuning parameters:

Consecutive Sites (CS): The number of successive detectors that should report the existence or discharge of a queue.

Consecutive Interval (CI): The number of time intervals that each detector should report exceeding the predetermined thresholds.

Activation and Deactivation thresholds: A specific traffic performance metrics' value. (speed and occupancy) reported from traffic detectors, which can determine start or finishing of a queue states.

Performance indicators (Objective variables):

Activation time: The time that it takes from a queue formation till VSL are triggered.

Deactivation time: The time that it takes from queue clearance till VSL deactivation.

False Alarms: Activation of the VSL for a non queue situation in a very short time.

2. QP algorithm parameter fine-tuning procedure

As briefly discussed in the introduction, QD algorithm monitors the traffic metrics at upstream and downstream of queue occurrence location to anticipate the location of queues. "*It determines the speed at which an approaching vehicle will encounter a queue*"(DTMR, 2010b). By predicting the location of the queues according to the approaching traffic flow, the VSL drops the speed limits to look after the stoped or slow moving queues (DTMR, 2010b).

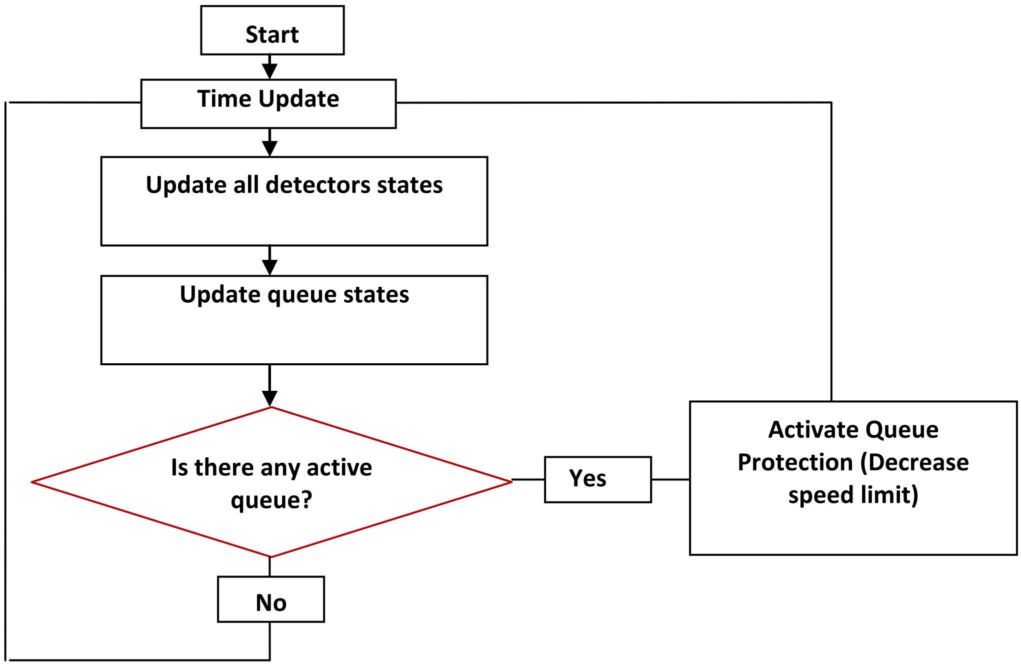
Detectors can usually provide volume, speed and occupancy data. From these three metrics, volume cannot directly be used to detect the congestion or queue occurrence, because from a volume-speed fundamental diagrams, the same volume can happen in both congested and non-congested situation, since the diagram has two wings. However speed and occupancy can explain the occurrence of queue. Hence these two metrics are used as the main metrics.

In order to optimise the parameters and thresholds that are involved in the QP algorithm, which can significantly affect the performance of the VSL system, few performance measures are chosen. The performance measures also determine the stopping point for testing parameters. The activation time and deactivation time are the performance measures that should be minimised. The number of false alarms should also be minimised. In Figure 2 the step of "*is there any active queue*" needs critical thresholds and parameters. The thresholds that the QP algorithm needs, to activate or deactivate the VSL are:

- *Activation Thresholds:* 1-Speed, 2-Occupancy, 3-Number of consecutive intervals and 4-Number of consecutive sites
- *Deactivation Thresholds:* 5-Speed Head of Queue 6-Occupancy head of queue 7-Speed tail of queue 8-Occupancy tail of queue 9-Number of consecutive intervals for queue head and 10-Number of consecutive sites for queue tail

The first four activation thresholds optimised in this paper. For the Deactivation, the Speed and Occupancy queue head will be tested. It has been decided not to deactivate queue tail before queue head for safety reasons, hence tail of queue speed and occupancy threshold are fixed in a high value to never the tail deactivates before the queue head. On the other hand, since in real experiment there was not much difference between deactivation number of consecutive intervals and sites for queue head they are also fixed to values equal to 1 and 2 respectively and will not be tuned.

Figure 2: Schematic Queue Protection algorithm



To sum up, the first six thresholds and parameters that can highly affect the performance of the QP algorithm are determined to be vital. During different stages, there are a few questions which are addressed: Is the QP algorithm reacts fast enough to protect end of queues with current infrastructure? How many false alarms caused by these thresholds? After incident clearance would the deactivation process also be in a proper timing? The most appropriate way of tuning thresholds and parameters adjustment should be introduced as well.

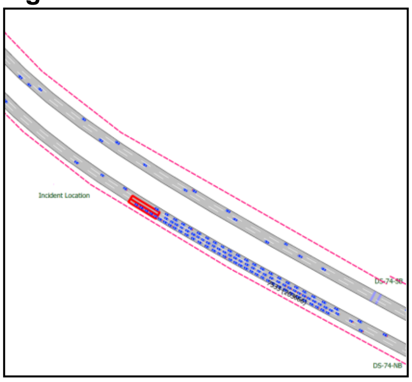
In this research the simulated model of Pacific Motorway in Aimsun 6.1 (TSS-Transport Simulation Systems, 1997) is used as the test bed. This simulation model is precisely calibrated against aggregate and individual real data at the Smart Transport Research Centre at QUT (2010). The QP algorithm is written as an API for the Aimsun model. Overall all the tests and simulations, creating incidents have been conducted in the Aimsun model.

There are two kinds of queues: queue as a result of an incident or queue as a result of traffic jams. So, two situations are consistently considered. In this paper first the incident situation, which is artificially created in the network is considered first. Morning peak and protecting queues in the traffic bottlenecks, without any incident are considered second.

2.1. Creating an artificial incident

An incident is artificially created in a section of north bound of the Pacific Motorway in the Aimsun simulation model. The incident is created in the middle of the section and the incident location is in 400 meters distance with the first upstream detector. The section is far enough from any off and on-ramp and as a result the ramps traffic does not affect the incident detection. Figure 3 illustrates the section and the incident position in the network. The incident is created both in morning peak and afternoon off peak to have both high and low flow rate scenarios. In this incident two lanes out of three lanes are blocked. The duration of the incident is 20 minutes.

Figure 3: Incident location in the network



2.2. Thresholds calibration

2.2.1. Parameters combination sets

The approach to adjust each of thresholds or parameters in this paper is systematic. While the first two elements vary the rest are fixed. Then once the best first combination for the first objective variable is chosen, for the next step those are fixed and the other varies until the best combination is found. This approach has been followed during this Section until the last parameter sets. The parameter combinations in Table 1 are the overall parameter sets in this document that have been tested in different parts of the paper.

Table 1: The parameter combinations

Objective Parameters	Scenario	Combination ID	Activation				Deactivation	
			Speed (km/h)	Occupancy (%)	CI	CS	Speed-H (km/h)	Occupancy-H (%)
Consecutive sites and intervals	Incident	1	40	25	2	3	50	15
		2	"	"	2	3	"	"
		3	"	"	2	2	"	"
		4	"	"	1	2	"	"
		5	"	"	2	1	"	"
		6	"	"	1	1	"	"
	Morning peak	7	"	"	1	1	"	"
		8	"	"	2	1	"	"
		9	"	"	1	2	"	"
Activation thresholds	Incident	10	55	25	1	2	"	"
		11	45	30	"	"	"	"
		12	40	35	"	"	"	"
		13	55	25	2	1	"	"
		14	45	30	"	"	"	"
		15	40	35	"	"	"	"
	Morning peak	16	55	25	"	"	"	"
		17	45	30	"	"	"	"
		18	40	35	"	"	"	"
Deactivation thresholds	Incident	19	45	30	"	"	65	17
		20	"	"	"	"	60	20
		21	"	"	"	"	55	25

H: queue head, " : same as above

2.2.2. Activation thresholds calibration

Consecutive Sites and Consecutive Intervals at incident scenario:

To find out the best number of Consecutive Sites and Consecutive Intervals for a queue detection algorithm, firstly the incident scenario is tested. According to the preliminary observations of activation speed and occupancy thresholds are fixed respectively to 40 km/h and 25%. Deactivation speed and occupancy thresholds also are fixed to 50 km/h and 15%. After fixing the thresholds, six combinations of consecutive sites and intervals have been tested (combination 1 to 6 at Table 1).

The incident scenario is created, in peak and off-peak condition. For each of these two scenarios three replications are run. The best two combinations out of the 6 combinations results of these tests are presented in the Table 2. As it can be seen in low volume, the activation time is higher than in high volume scenario. This is rational because the queue formation speed in these two scenarios is different.

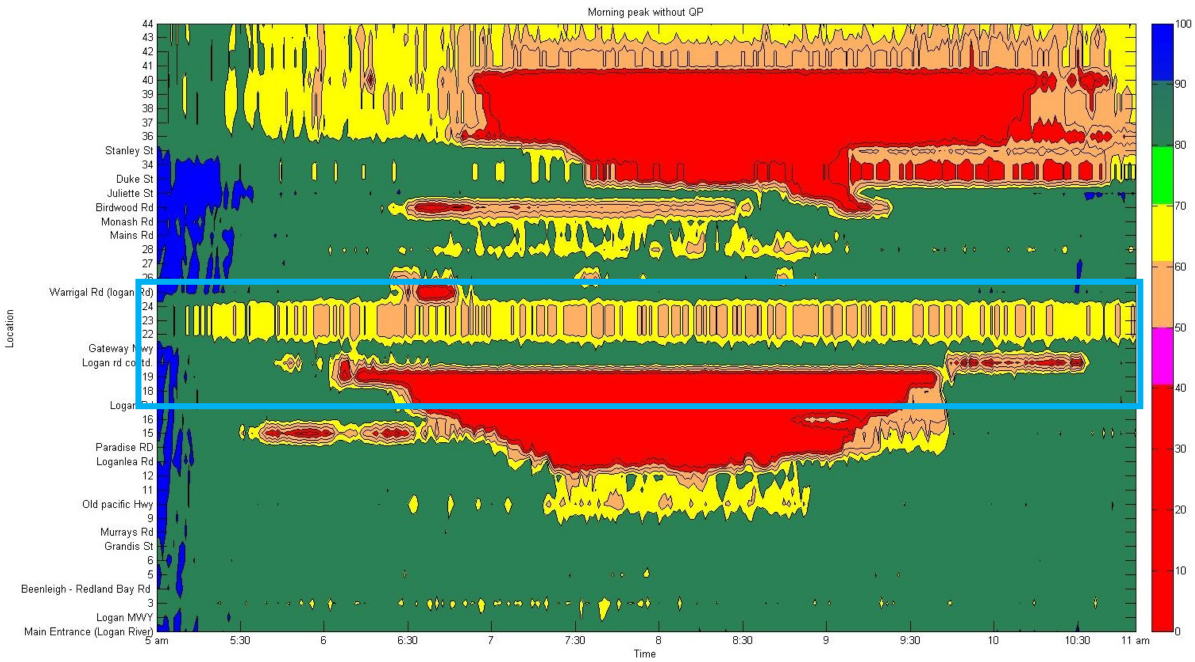
Table 2: Results of tests to tune consecutive sites and intervals in QP algorithm at incident scenario

Flow scenario	activation or deactivation status	high flow		mid-low flow	
Combinations		Replication ID	activation and deactivation time (minutes)	Replication ID	activation and deactivation time (minutes)
Comb_5 (CI=1; CS=1)	a	25	3.15	60	5.25
	d		12.6		12.6
	a	22	3.15	61	5.25
	d		16.8		14.7
	a	23	3.15	62	5.25
	d		12.6		12.6
Comb_6 (CI=2; CS=1)	a	25	4.2	60	6.3
	d		13.65		15.75
	a	22	4.2	61	6.3
	d		16.8		10.5
	a	23	4.2	62	6.3
	d		10.5		15.75

- a: activation, d: deactivation, CI: Consecutive intervals, CS: Consecutive sites

Morning peak scenario without incident: In this part particularly the VSL performance for queues in heavy traffic volumes without having incident is tested. The links at Figure 4 during the morning peak experience both traffic congestion and free flow situations. So the QP algorithm performance within this area in morning peak between 5 to 9 am is tested. Three combinations have been tested here (combinations 7-9 in Table 1). In this scenario specifically, the number of false alarms is important. In queue formation in morning peaks the traffic measures slowly worsen and the risk of having false alarms become more important. Within incident scenario the traffic measures dramatically drops.

Figure 4: Observed speed contours at northbound of Pacific motorway and the chosen links to check the QP performance within non-incident situation, in the morning peak time



- X axes: Time of day
- Y axes: link ID and name if the Motorway

Table 3: Results of the QP performance within non-incident situation in morning peak, showing number false alarms, and activation and deactivation times, per minutes

Combinations	LUMS ID	LUMS 25	LUMS 24	LUMS 23	LUMS 22	LUMS 21	LUMS 20	LUMS 19	LUMS 18	LUMS 17	LUMS 16	LUMS 15	LUMS 14	LUMS 13	LUMS 12	LUMS 11	Sum	Delay compare with base case (Min/Lums)
Comb _7 CI=1 CS=1	false alarm	3	3	-	-	-	-	-	-	1	1	-	-	-	-	-		
	Rep	212								68	72	72	58	58	112	115	55	Base
	Rep									69	73	84	44	44	57	115	48	
	Rep									68	72	80	37	37	46	51	39	
Comb _8 CI=2 CS=1	false alarm	2	2	1	1	1	1	1	1	1	-	-	-	-	-	-	-	
	Rep	82	82							77	77	91	59	59	116	120	59	-6.29
	Rep									69	72	84	52	52	61	116	50	-2.86
	Rep									71	73	85	38	38	46	53	40	-1.86
Comb _9 CI=1 CS=2	false alarm	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	Rep									68	68	74	98	98	116	120	64	-12.4
	Rep									66	66	72	100	100	117	121	64	-22.3
	Rep									72	72	84	47	47	47	127	49	-15

- Each number in this table shows activation time per minutes since the simulation start time 5:00 am.
- LUMS: VSL and Lane Use Management System
- Rep: Simulation Replication

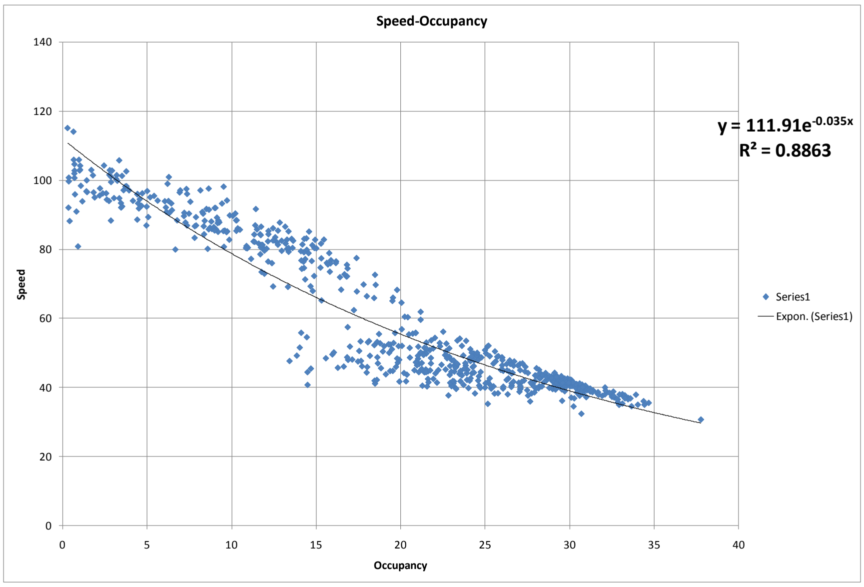
In Table 3 if VSL is activated for two or less than two intervals, they are counted as a false alarm for the QP algorithm. In Combination 9, with the number of consecutive sites 2, no false alarms happens, however the activation time on average has more than 12 minutes delay. So it does not perform well. Combination 8 compare with Combination 7 has fewer false alarms and compare with combination 9 has a shorter activation time.

According to the calibrations based on incident scenario and morning peak scenario, Table 2 and Table 3, the Consecutive Sites is suggested to be 1 for quick detection and the Consecutive Interval is suggested to be 2 for reducing the false alarms. This is because current detector site distance is about 650 meters. If we decide to use 2 consecutive sites to verify a queue, the delay is high and it is better to increase the consecutive interval to verify a queue occurrence.

Queue Detection *thresholds:* after finding the preferred combination of consecutive sites and interval numbers the next task is to find the appropriate traffic measure thresholds. There is a method which is a successful method used in Canada, called MCMaster method. This method detects sudden changes in traffic measures (e.g. speed and occupancy) to detect incidents. However this method specifically should be calibrated for each site (Martin and Perrin, 2001).

To implement a similar process, it is necessary to find out when congestion occurs in different sites of the motorway. For eight selected sections of the network, the speed-occupancy diagrams for both observed and simulated data are extracted and the critical values are used as the queue detection thresholds. This process is in progress to decide in what speed and what occupancy of the Pacific Motorway sections, congestions can happens. An Example of these sections' speed-occupancy diagrams comes in Figure 5.

Figure 5: Speed-occupancy diagram for one of the chosen links as an example, average of all lanes



From all the speed-occupancy diagrams the exponential trend lines at Equation 1 and Equation 2 are concluded (for simulated and observed data). The formulas would be used to predict speed for and occupancy thresholds where congestion occurs. The coefficients of the following models are acquired from an average taken of all the data. It should be noted that this needs to be separately calibrated for each specific section of the road. However to get a specific values to input into the simulation model and API to generally get an average of all the speed-occupancy equations, these models are needed.

Equation 1: Simulated data: **Speed = 116.35e**$^{-0.031*\text{Occupancy}}$

Equation 2: Observed data: **Speed = 117.73e**$^{-0.024*\text{Occupancy}}$

Real data gives a slightly higher speed for the same occupancy values. If we enter occupancy of 25% in the observed model, the speed is predicted as about 65 km/h though simulated data gives 53 km/h. The reason for that could be the way the real data was collected. The occupancy or speed may not be that reliable in the available observed data to be used for prediction. The formula from the simulation model data which is a calibrated model based on individual data for global parameters and local parameters based on aggregate data from multiple data source is used in the following Sections. According to Equation 1 a range of thresholds to be tested comes in Table 4.

Table 4: Six threshold combinations to be tested in activation and deactivation

Type	Attribute	Activation			Deactivation		
Input	**Occupancy (%)**	25	30	35	17	20	25
Output	**Speed (km/h)**	55	45	40	65	60	55

Incident scenario for activation thresholds:

Threshold combinations which are chosen in Table 4 are tested for both, incident and morning peak scenario. Table 5 indicates result of different activation thresholds.

Table 5: Activation thresholds tests in incident scenario, (activation and deactivation are per minutes)

Combinations	activation or deactivation	high flow		mid-low flow	
		Replication ID	activation and deactivation time (minutes)	Replication ID	activation and deactivation time (minutes)
Comb_13 Speed=55 (km/h) Occupancy=25 %	a	25	2.55	60	4.65
	d		-		14.05
	a	22	2.55	61	4.65
	d		-		15.1
	a	23	1.5	62	4.65
	d		-		14.05
Comb_14 Speed =45 (km/h) Occupancy =30	a	25	2.55	60	5.7
	d		-		14.05
	a	22	2.55	61	4.65
	d		-		13
	a	23	2.55	62	4.65
	d		-		14.05
Comb_15 Speed =40 (km/h) Occupancy =35	a	25	2.55	60	5.7
	d		-		14.05
	a	22	2.55	61	4.65
	d		-		13
	a	23	2.55	62	4.65
	d		-		14.05

Table 5 illustrates that by changing the thresholds, little difference can be observed in the VSL activation time. The reason for this is, because after the incident the occupancy and speed immediately drops. Therefore the threshold changes are not going to change the activation time.

Without Incident scenario at morning peak, activation thresholds:
Testing the three thresholds that are chosen for activation in morning peak traffic without incident is presented in Table 6.

Table 6: Sensitivity test for activation thresholds in morning peak without incident scenario

Combination of activation	**Replication**		**LUMS 25**	**LUMS 24**	**LUMS 23**	**LUMS 22**	**LUMS 21**	**LUMS 20**	**LUMS19**	**LUMS18**	**LUMS17**	**LUMS16**	**LUMS15**	**LUMS14**	**LUMS13**	**LUMS12**	**LUMS11**	**LUMS10**
Comb_18 Speed =40(km/h) Occupancy =35%	25	False Alarms	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Activation	0	10	10	10	10	10	10	10	68	71	82	10	10	11	12	14
	22	False Alarms	0	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
		Activation	0	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	23	False Alarms	0	17	17	17	17	17	17	17	65	70	77	97	10	11	12	13
		Activation	0	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
Comb_16 Speed =55(km/h) Occupancy =25%	25	False Alarms	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Activation	0	0	0	0	0	0	0	0	65	68	74	99	10	12	12	13
	22	False Alarms	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Activation	0	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	23	False Alarms	0	68	68	68	68	68	23	83	76	83	64	61	61	12	12	14
		Activation	0	69	69	69	69	69	69	13	13	13	13	13	13	13	13	13
Comb_17 Speed =45(km/h) Occupancy =30%	25	False Alarms	0	1	2	2	2	2	2	2	2	2	2	3	5	6	6	6
		Activation	0	0	0	0	0	0	0	18	72	76	58	46	46	60	12	12
	22	False Alarms	0	0	0	0	0	0	0	22	22	22	22	47	47	47	47	47
		Activation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	23	False Alarms	0	22	22	22	22	22	70	70	74	77	45	39	39	44	44	13
		Activation	0	0	0	0	0	0	95	15	15	15	15	15	15	15	15	15

Table 6 shows that in the high values of speed and low occupancy values of thresholds which indicate more sensitive thresholds, activation times are minimal and numbers of false alarms are high (Comb_16). On the other hand, a less sensitive threshold which has larger values for occupancy and smaller values for speed to detect any queue, the number of false alarms is few but there is a long delay in activation (Comb_18). Consequently it is necessary to choose less sensitive thresholds to have fewer false alarms. However detection time needs to be short as well. So the average of these thresholds is chosen (Comb_17).To date the results for the final thresholds of activation are: Consecutive interval: 2, Consecutive sites: 1, Speed threshold: 45 km/h, Occupancy Threshold: 30%

2.2.3. Deactivation thresholds calibration

The proposed thresholds combinations for deactivation test are as Table 4. The QP algorithm for the chosen thresholds is tested. The results are displayed as Table 7. Table 7 indicates that combination 21 has a shorter deactivation time, about 12 minutes after the incident clearance. It should be noted that the incident location is in the middle of a motorway section, about 400 meter above the upstream detector. The deactivation thresholds are not tested for morning peak, since it is not deactivated for very long due to the heavy traffic.

Table 7: Deactivation time for three different deactivation thresholds for incident scenario

Combinations of deactivation thresholds	Replication ID	peak (minutes)	Replication	non peak (minutes)
Comb_19 Speed = 65 (km/h) Occupancy =17%	25	never cleared	60	15.1
	22	never cleared	61	16.15
	23	never cleared	62	16.15
Comb_20 Speed = 60 (km/h) Occupancy =20%	25	never cleared	60	14.05
	22	never cleared	61	14.05
	23	never cleared	62	14.05
Comb_21 Speed = 55(km/h) Occupancy =25%	25	never cleared	60	11.95
	22	never cleared	61	11.95
	23	never cleared	62	11.95

2.2.4. The QP parameters final results

The final parameter sets of the QP algorithm as found from the optimization process for the Pacific Motorway are presented in Table 8. In the next section the performance of the QP algorithm is examined. This 6 parameters and thresholds at Table 8 found to be the most appropriate parameters sets for QP algorithm of VSL. Apart from these parameters the following points are also recommended.

- The head of queue should only be deactivated due to safety considerations. Further the tail and body should never be deactivated before the head.
- Adding a deactivation settling time to reduce fluctuation after deactivation.

Table 8:The final results of the Queue Protection algorithm as found from the optimization process for the Pacific Motorway

Item	Value
Consecutive Sites	1
Consecutive Intervals	2
Activation thresholds	speed=45 (km/h);
Deactivation Thresholds	speed=55 (km/h);

3. The performance of QP

3.1. Incident scenario

The effectiveness of the parameters is examined in an incident scenario. The speed contours are extracted from the simulated network, both with and without running the QP algorithm. Examining contours at Figure 6 and Figure 7 shows the QP algorithm performance. As it is expected, by optimising the QP algorithm and setting the final recommended thresholds and parameters the activation and deactivation time is minimised. Although the first detector was about 400 meters upstream of the incident location, in less than five minutes after the incident, the VSLs are activated and as can be seen the average speed, immediately two sites before the incident, is damped. Accordingly the upcoming traffic flow approaches the end of queue with a lower speed and speed differences at the end of queue are significantly declined. It should be remembered that the scenario is designed in a low volume hour of traffic and as a result the queue speed propagation is low. So activation time is decreased in any higher volume scenario.

Figure 6 and Figure 7 also indicate that after 10 minutes of the incident clearance and less than 3 minutes of the whole queue discharge, the VSLs are deactivated, these records also placed in acceptable and minimised ranges. Apart from safety improvements, the caused bottleneck of the incident seems to become lighter, which shows that traffic can pass the incident location much more smoothly.

Figure 6: Incident scenario without QP algorithm

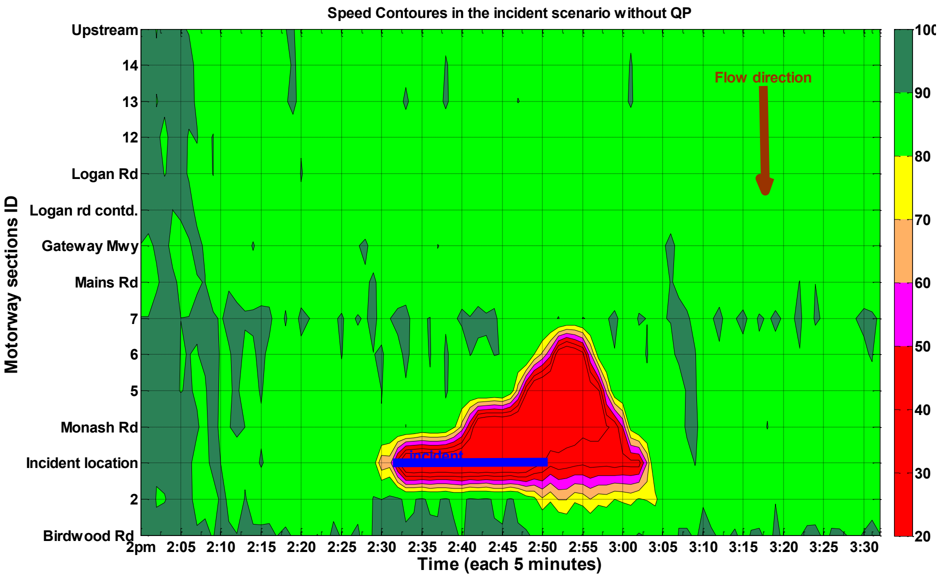
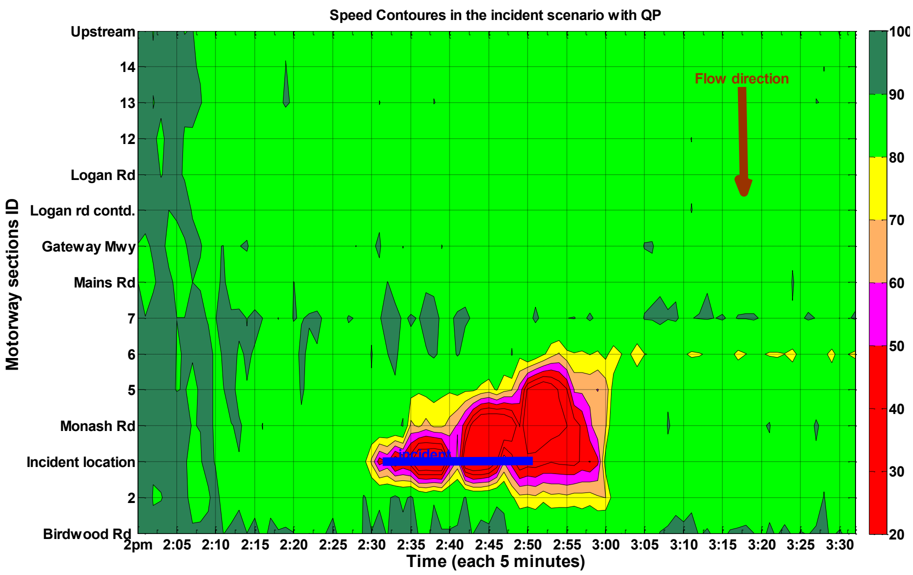


Figure 7: Incident scenario with QP algorithm



3.2. Morning peak performance scenario

Figure 8 and Figure 9 shows that after running the QP algorithm the speed area from 60 to 70 KM/H becomes thicker. This proves that the QP works for non incident situation as well as incident scenario and can protect end of queues in morning peak traffic jams. Again traffic jams are declined by running QP.

Figure 8: Speed contour plots for morning peak scenario without QP

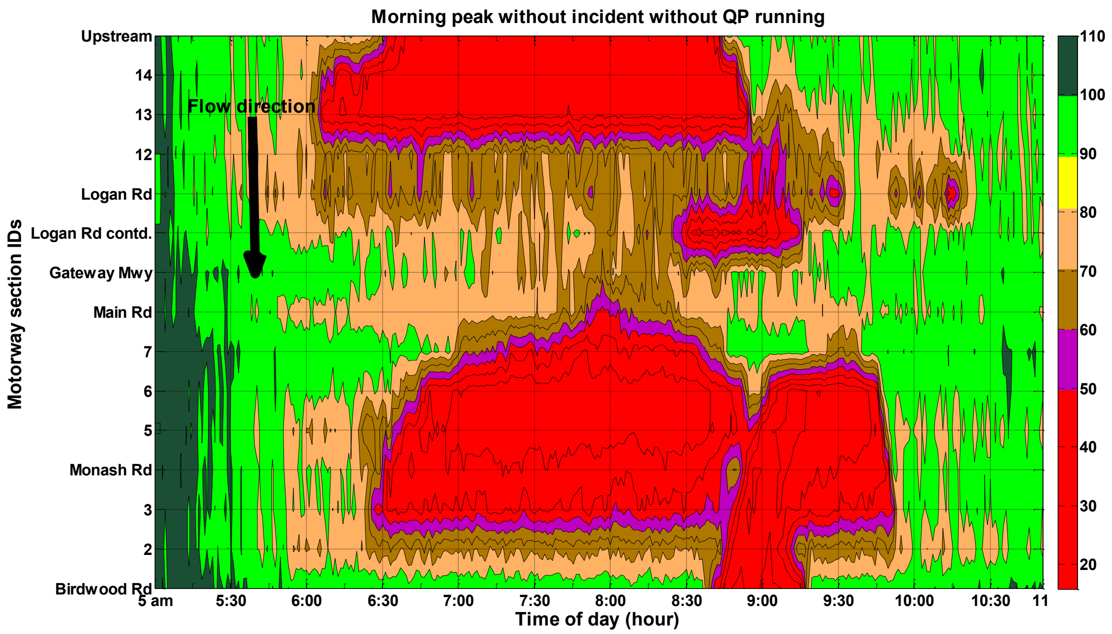
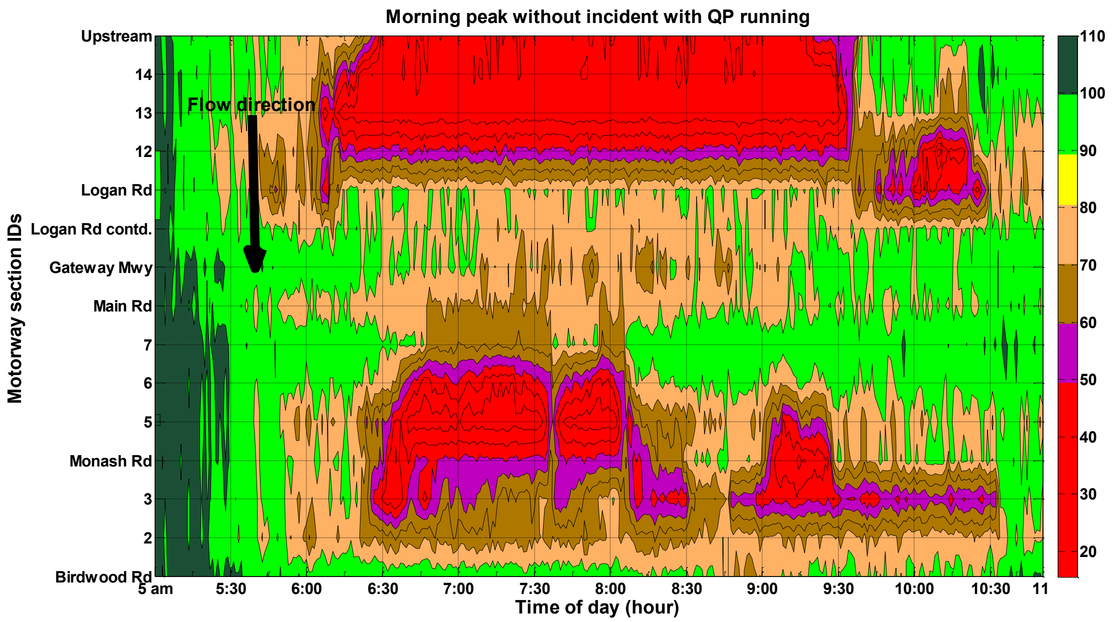


Figure 9: Speed contour plots for morning peak scenario with QP



- It should be considered in this contour figure the traffic upstream will start from bottom of y axis, to downstream at the upper side of y axis.

4. Conclusions

This paper has introduced a concrete procedure for tuning QP algorithm's parameters for VSL. Although the practical part of this paper has been carried out on the Pacific motorway in the Brisbane area, a similar procedure could be undertaken in any other traffic network management systems. It has been shown that a timely response from VSL in the incident situation to protect the queues created downstream is highly dependent on activation and deactivation thresholds depending on the field infrastructure. A sensitivity analysis in this paper showed how the number of false alarms can deviate by changing the thresholds. The performance of QP in a non-incident situation in heavy jams was examined as well. The speed contours in morning peaks showed that the QP algorithm cannot cause extra bottlenecks. It is expected that the buffer low speed zone of the upstream section of congested area highly helps the safety element and decreases rear-end crashes.

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References

DTMR(2010a) Appendix D: Qeue protection algorithm. *Variable Speed Limits and Lane Control Signs.* Brisbane, Department of Transport and Main Roads.

DTMR (2010b) Appendix D: Queue protection algorithm. *Variable Speed Limits and Lane Control Signs.* Brisbane, Department of Transport and Main Roads.

Ikeda, H. & Matano, M. (1999) Introduction of congestion tail display system into Metropolitan Expressway. *Intelligent Transportation Systems, 1999. Proceedings. 1999 IEEE/IEEJ/JSAI International Conference on.*

Lennie, S., Han, C., Luk, J., Pyta, V. & Cairney, P. (2009) Best Practice for Variable Speed Limits: Literature Review. Sydney, Austroads.

Martin, P. T. & Perrin, J. (2001) Incident Detection Algorithm Evaluation. IN TRANSPORTATION, P. F. U. D. O. (Ed. Utah, University of Utah.

QUT, S. T. R. C. O. (2010) Evaluation of Queensland Department of Transport And Main Roads Managed Motorway. Brisbane.

Tss-Transport Simulation Systems (1997) Aimsun. IN BARCELÓ, J. (Ed. *Aimsun.* 6.1 ed. Barcelona.

Uno, N., Iida, Y., Itsubo, S. & Yasuhara, S. (2005) A microscopic analysis of traffic conflict caused by lane-changing vehicle at weaving section. *13th Mini-EURO Conference Handling Uncetainity in the Analysis of traffic and Transportation Systems.*