PAPABILES

Simulation-based evaluation of the impact of telematics in the Lausanne area: a pilot study

Phase 2: third lane and ramp metering

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PAPABILES – Phase 2

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Abstract

This study follows the first phase of the PAPABILES project of which the purpose was to judge the efficiency of variable speed limits on the section of the A1 motorway ranging between the junction of Morges West and the Ecublens interchange. The results had shown that this traffic management tool is of interest but did not really allow solving the problem of chronic congestion observed in the Morges East junction zone.

This second phase of the PAPABILES project proposes to evaluate and to compare two types of response to this problem. The first consists in prolonging the acceleration lane of the Morges East junction up to the Ecublens interchange, thus allowing the traffic to flow out on 3 lanes between these two points. The second, typical application of the ITS field, is the implantation of a ramp metering on the Morges-east junction ramp

These evaluations were carried out by using the microscopic simulator AIMSUN, a tool developed at the Polytechnic University of Catalunya, in Spain.

The results show that the construction of a third lane between the Morges East junction and the Ecublens interchange would allow decreasing travel times on the studied section of almost 27 % and this in the case of very high traffic flows. This increase of the network performance is the result of the addition of two positive impacts generated by the presence of the third lane, the suppression of the bottleneck at the exit of the Morges East junction and the increase in fluidity and average speed.

The results also show that ramp metering does not allow avoiding the presence of congestion at the Morges East junction. Nevertheless, it makes possible the decrease of the propagation upstream of the junction and especially the duration in time.

Ramp metering also makes possible to reduce in a significant way the delays generated by the presence of an accident located downstream of the junction. This decrease is particularly important for medium demand flows (which do not involve congestion due to a lack of capacity at the Morges East junction) where reductions of 40 % were recorded.

This study made it possible to concretely evaluate the improvements that can be achieved by two solutions of completely different characteristics concerning importance, cost and implication. It also allowed comparing two types of strategies answering a problem of capacity lack: the increase of the supply or a better demand management.

Keywords

ITS – Telematics – Simulation – Ramp Metering – Swiss Transport Research Conference – STRC 2001 – Monte Verità

1. Introduction

The general traffic situation on the Lausanne by-pass motorway asks for new solutions. Close to saturation, the traffic on the motorway is seriously disturbed during peak hours. The main goal of the PAPABILES project is to evaluate the impacts of different measures that can be engaged to improve traffic fluidity. The project is divided in several phases:

Phase 1: This preliminary study (as presented at the STRC 2001) has showed the relevance of the methodological approach and the possibilities of the simulation tools used, based on an analysis of the whole process from the modelling to the evaluation of possible outcomes. The study has been restricted in space (one section of the motorway) and time (peak hours).

Phase 2: The first phase pointed out that the installation of variable speed signs wasn't sufficient to improve the saturation problem between the Morges West junction and the Ecublens interchange, especially at the Morges East junction. Still restricted in space and time, this stage is used to compare two different solutions:

- Construction of a 3rd lane between the Morges East junction and the Ecublens interchange
- Installation of a ramp metering at the Morges East junction

Subsequent phases: A full model with a wider scope in both space and time will be developed to be used as a systematic evaluation tool for regulation strategies. A more systematic calibration will be performed in order to also benefit from quantitative results from the simulator.

2. Network modelling

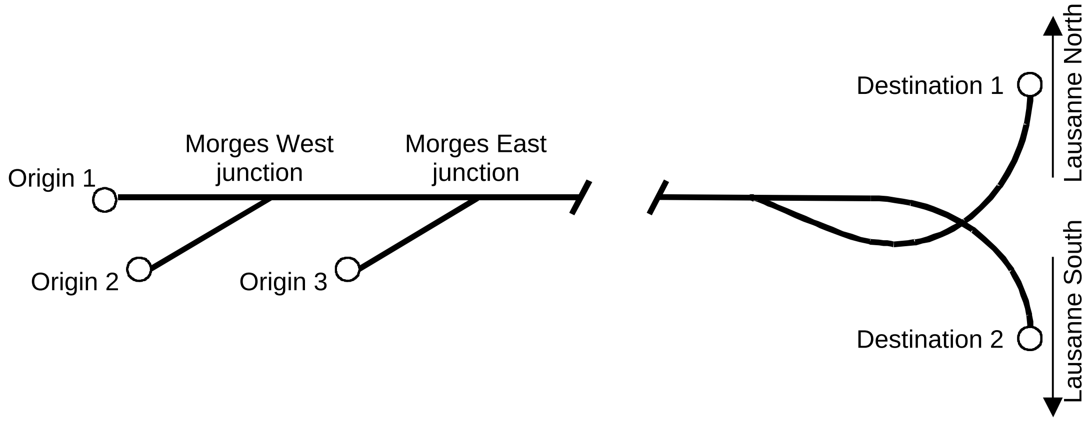
2.1 Simulation tool

For the first phase of the PAPABILES project the MITSIM simulator (developed at the MIT) had been used for modelling the network. Practical reasons have incited the project team to change the simulator for the second phase. AIMSUN, a product of the Technical University of Catalonia in Barcelona, has been chosen for the continuation of the project.

2.2 Network

The network was coded with a graphic editor. Official maps were used as visible support for the coding. Figure 1 is a sketch of the studied network.

Figure 1 Schematic view of the network showing its points of entry (origins) and exit (destinations)



2.3 Origin-destination matrix

In order to generate traffic, the simulation tool requires, for each different vehicle type, either the input of an origin-destination (OD) matrix or a fixed number of entering vehicles at each origin and turning proportions at each junction. The first method, an OD matrix, was used for this project. It is the same single time-dependant OD matrix as in the first phase of PAPABILES, calibrated using the data collected on Tuesday, 2nd November 1999, from 7h00 to 8h00 in 5-minute intervals. For each interval, the distribution of the entries of vehicles onto the network is assumed to follow a normal distribution.

Two vehicle types are taken into account, light vehicles and heavy vehicles, using different parameters, especially for acceleration and deceleration.

3. Calibration of the model

3.1 Method

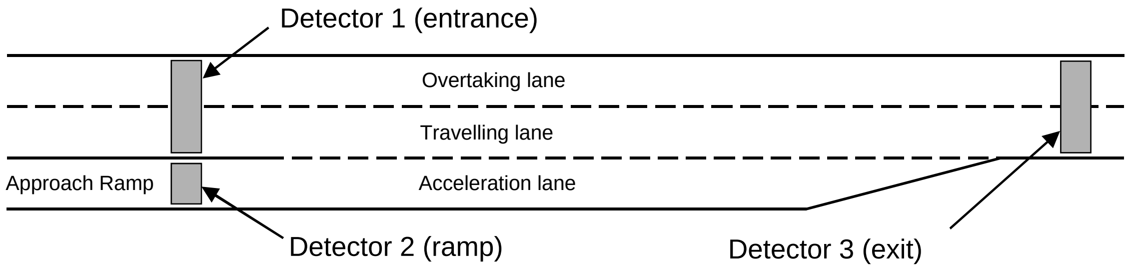
The different parameters of the model have to be adapted until the model provides similar results as observed in reality. This process is done using two reference bases:

- The first one is the visual appreciation on the screen. The user can evaluate if the vehicles behave in a realistic manner and first modifications of the parameters can be made. This is especially important for the junctions, where several traffic flows merge.
- The second one is a comparison between traffic data (flow, speed) measured in reality at certain places and the data calculated by the simulator at the same points. The cameras for counting traffic were placed at both the Morges East and Morges West junctions.

3.2 Results

The default parameters showed good results for the visual approach. The only important problem observed was the fact that some heavy vehicles drove along the acceleration lane without finding a gap between vehicles to enter the freeway. As the simulator does not permit the vehicles to drive on the hard shoulder they stop at the end of the acceleration lane and wait for the next acceptable gap. This behaviour creates important deceleration by the following vehicles and therefore a serious disturbance for traffic on the motorway. Modifying the speed parameters on the on-ramp and on the right lane of the motorway as well as raising the aggressiveness of the drivers allowed solving a good part of this problem.

Figure 2 Position of the measuring points (detectors) used in the simulation



Speed and lane occupation can be measured at any point of the network. Six virtual detectors were placed for this study, three per junction, as illustrated in Figure 2.

On the motorway, cameras were placed at positions 1 (entrance) and 2 (ramp) in order to count the traffic flow on the motorway and the on-ramp. Figure 3 shows that the real flow is within the simulated values (10 replications) at all time except at 7h35 and 7h45, where the simulation was not able to match the real values. This is not mainly a calibration problem, but rather due to the fact that one single sample has been used for calibrating.

Figure 3 Average flow and standard deviation at the entrance of the Morges East junction (detector 1)

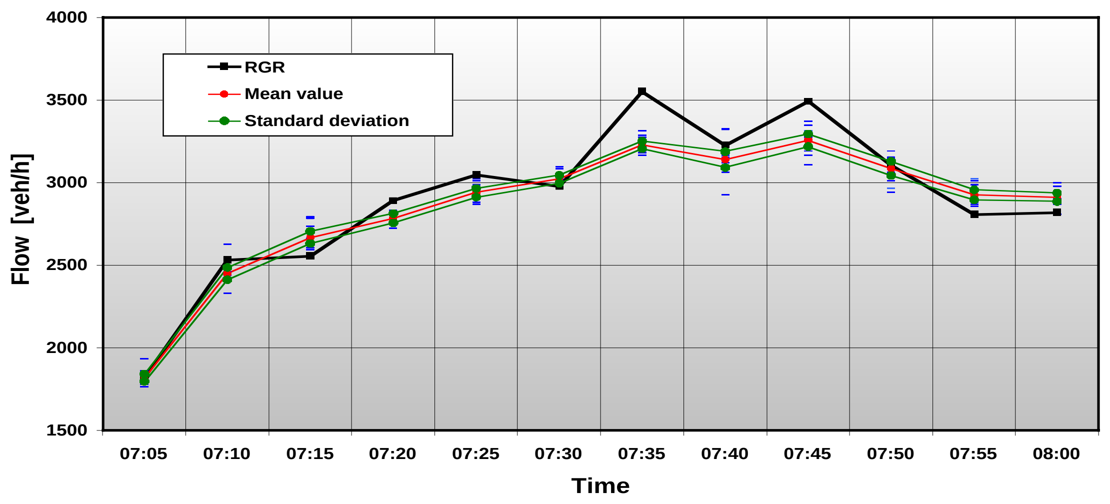
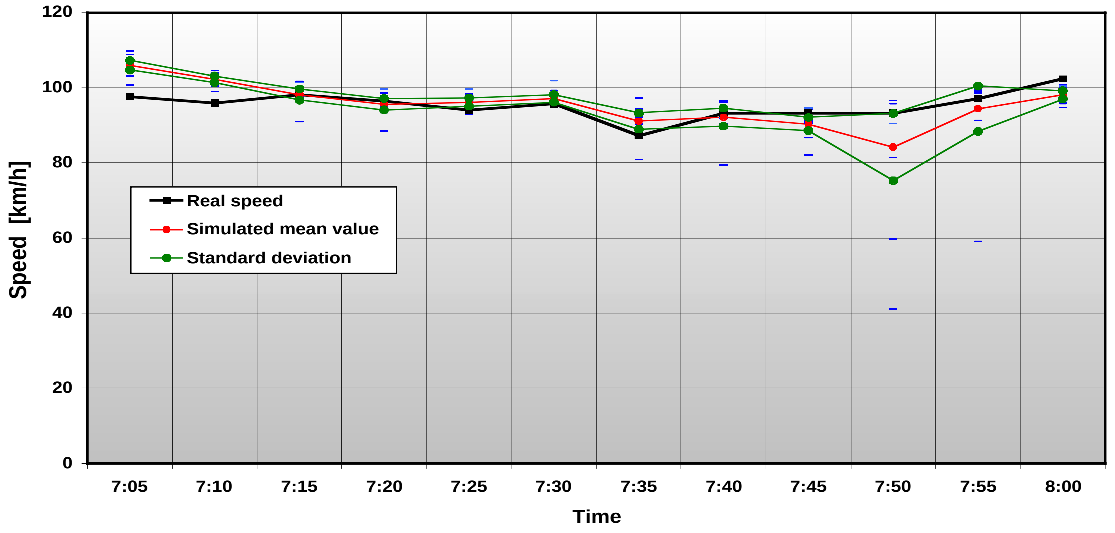


Figure 4 Average speed and standard deviation at the entrance of the Morges East junction (detector 1)



The comparison of the real and the simulated speed shows good results (Figure 4). The simulated values match the real ones to a good extent, except for the first two points, which is due to the “warming up” of the model. Another interesting parameter is the ratio of the flows on the left and the right lane. At high flow values (> 3600 veh/h) this ratio is near to 2 for the real measures as well as for the simulated values.

4. 3rd lane between Morges East and the Ecublens interchange

Among possible solutions to improve traffic fluidity at the Morges East junction the construction of a 3rd lane between this junction and the Ecublens interchange promises an increase in capacity of the section. This part of the report investigates the gain in efficiency and safety this construction offers.

4.1 Network modification

The network had to be adapted for this part of the study. The acceleration lane of initially 200 meters was extended to the Ecublens interchange in order to form a 3rd lane. The exit detector of the junction (position 3) was enlarged to be able to count the traffic on all of the three lanes.

4.2 Scenarios

To be able to judge the performance of the 3rd lane, the results of the simulation were compared to those made with the current configuration of two lanes. Different scenarios were applied, starting with the standard OD matrix described in chapter 2.3. The traffic was raised by 5 % steps up to 40 %. Only the number of vehicles was changed, the structure (spatial and temporal distribution) remained the same. These scenarios will be named OD (standard matrix), OD05 (standard matrix + 5 %), OD10, …, OD40.

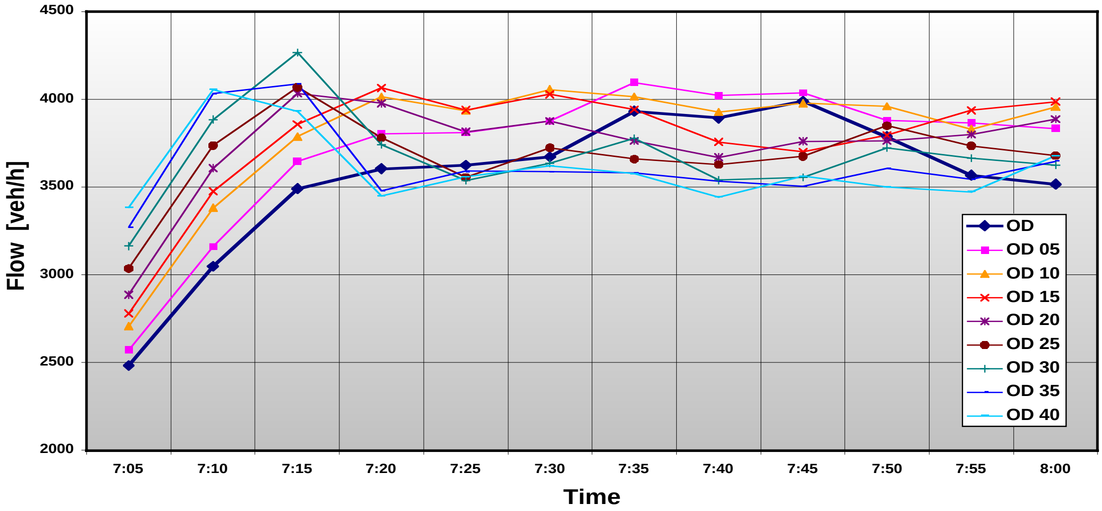
One parameter for the performance comparison of the two networks is the probability that congestion appears at either of the two junctions. This probability consists of the number of simulation runs on which congestion is noticed, out of a total number of ten. In this case this means a drop of the average speed under 80 km/h during two consecutive measures.

Table 1 Number of congestions (of ten replications) at the Morges East and Morges West junctions

	Morges East		Morges West	
	2 lanes	3 lanes	2 lanes	3 lanes
OD	0	0	0	0
OD05	5	0	0	0
OD10	7	0	1	1
OD15	10	0	7	1
OD20	10	0	10	2
OD25	10	0	10	6
OD30	10	0	10	9
OD35	10	0	10	10
OD40	10	0	10	10

These results (Table 1) confirm that, with the current two-lane network, congestion at the Morges East junction seems unavoidable having traffic 15 % higher than with the original matrix. Figure 5 confirms that for matrices above OD15 the flow raises up to a capacity limit of about 4100 veh/h before stabilizing around 3600 veh/h, which is the maximum flow capacity in the case of congestion.

Figure 5 Average flow (of ten replications) for each OD matrix after the Morges East junction



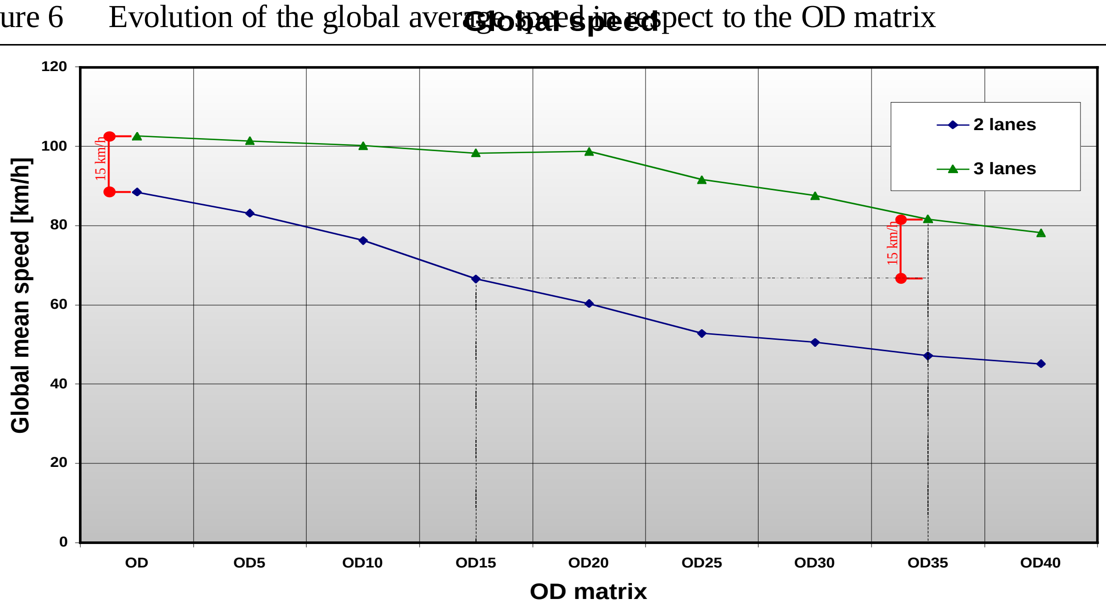
For the three-lane network no congestion is observed for any of the used matrices. This can be explained as follows: The flow of vehicles entering the Morges East junction on the motorway is depending on the exit flow of the Morges West junction. The capacity of the latter is the one of a two-lane motorway. This causes the appearance of congestion at the Morges West junction rather than at the Morges East junction like for the original network. Yet, congestion appears at higher OD matrices than for the two-lane configuration. This can be explained by the fact that in the original network the congestion of the Morges East junction reaches the Morges West junction and disturbs traffic there.

A first estimation of the gain in performance can be calculated by comparing the two different demand levels causing congestion in all of the ten replication runs. For the original two-lane network this is reached with OD15 and in the three-lane network it's OD35 causing systematic congestion:

$$\left(\frac{1.35}{1.15}-1\right)*100=17\ \%$$

This criteria is not able to completely show the efficiency of the construction of a 3rd lane, as it only takes congestion into account. Therefore it is interesting to compare the two networks in terms of average speed as shows Figure 6. A difference of 15 km/h can be observed for the original matrix between the two-lane and the three-lane configuration. The construction of a 3rd lane not only delays the appearance of congestion, but also improves fluidity and reduces therefore the travel time on this section of the motorway.

Figure 6 Evolution of the global average speed in respect to the OD matrix



Taking the congestion causing matrices (OD 15 for two lanes and OD 35 for three lanes), a difference of 15 km/h can once more be found, which is the initial speed difference on the section between the Morges East junction and the Ecublens interchange.

Only taking into consideration the global average speed we find a similar value at OD10 for two lanes (76 km/h) and OD40 for three lanes (78 km/h). The gain in speed performance is therefore:

$$\left(\frac{1.40}{1.10}-1\right)*100=27\,\%$$

As said before, the increase in traffic fluidity allows a reduction of travel time. At OD40, for example, the average gain in travel time per car exceeds 4 minutes, as shown in Table 2. In terms of total gain the effect is amplified by the higher number of vehicles (40 % compared to the standard case).

Table 2 Gain in travel time on the entire section per car and in total in respect to the origin of the vehicle

	Gain per vehicle [sec]				Total gain [hours]			
	Genève	Morges West	Morges East	Global	Genève	Morges West	Morges East	Global
OD	41	37	32	38	23	9	6	38
OD05	60	50	39	53	35	12	8	56
OD10	92	82	41	80	57	20	9	88
OD15	152	138	43	127	98	38	10	146
OD20	212	188	41	172	143	53	10	207
OD25	268	250	40	219	189	74	10	274
OD30	275	276	40	229	202	85	10	298
OD35	297	325	38	252	226	104	10	340
OD40	318	344	37	269	251	114	10	376

4.3 Conclusions

The construction of a 3rd lane between the Morges East junction and the Ecublens interchange allows improving efficiency of the section by two positive impacts:

- Fluidity is improved, especially for high traffic, which results in a higher average speed and therefore a lower travel time
- A higher demand level is reached before congestion appears

Depending on the used criteria, the gain in efficiency is found between 17 % and 27 %. As for the gain in travel time, it reaches a total of 38 hours for the standard matrix and 376 hours for a demand 40 % higher than the standard case.

5. Ramp metering at the Morges East junction

This second scenario keeps the network as it is today, but it suggests controlling the flow on the on-ramp at the Morges East junction by the means of a ramp metering. The goal of this measure is to improve fluidity of the motorway traffic at the junction in order to delay the appearance of congestion and to reduce its importance.

5.1 Algorithms and parameters

The ramp metering is applied using a traffic light on the on-ramp. The length of the green time per cycle determines the flow of cars to pass. The flow is generally calculated with an algorithm using real-time traffic measures from the motorway as input. Usually, the on-ramp flow is limited in order not to exceed the capacity limit of the junction, thus avoiding the appearance of congestion.

Different ramp metering strategies exist and the most known are based on:

- Comparison between demand and capacity
- Local prediction algorithms
- Possible insertion distance between vehicles

This study does not intend to make a comparing analysis in order to find the most efficient ramp metering strategy. It was decided to use the most commonly applied, especially in European cities, the so-called ALINEA algorithm (Asservissement LINéaire d'Entrée Autoroutière), recently tested on the Paris ring road. The algorithm, based on local prediction, is written as follows:

$$r(k) = r(k-1) + K_R\left[\hat{o} - o_{out}(k)\right]$$

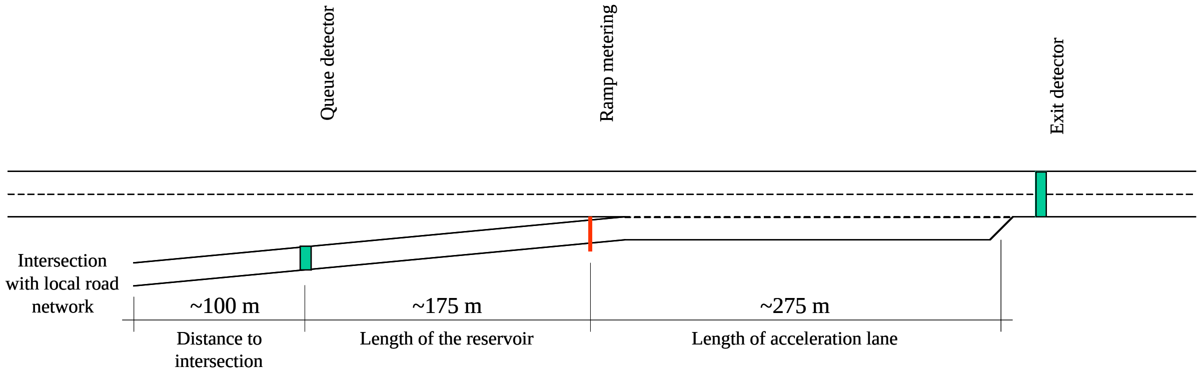
where:

r	on-ramp flow [veh/h]
k	measurement step [sec]
o	occupation factor at the junction exit [%]
ô	occupation factor of saturation [%]
K_R	regulating parameter

This algorithm tends to keep the occupation factor at the junction exit under a certain limit. Exceeding this value would cause the appearance of congestion. The control is applied by choosing an adapted cycle of green time, thus decreasing the on-ramp flow. In order to determine the new flow the algorithm uses the one measured during the preceding time step. This guarantees certain continuity in the changing of the green time cycle and avoids violent variation.

The following figure shows the implantation of the ramp metering system:

Figure 7 Schematic view of the ramp metering installation



- Access for 2 vehicles per green time
- Measurement step (algorithm time step): 30 seconds
- Occupation factor: 55 %

The last two parameters were determined by a sensitivity analysis; the values offering the best performance were taken.

The ALINEA algorithm does not use a minimum value for the on-ramp flow, thus offering to completely block the vehicles during at least one measurement step. An analysis made for this study showed an improvement of the ramp metering using a minimum flow of 300 veh/h, avoiding the saturation of the on-ramp. The maximum flow is fixed at 2000 veh/h, which is the capacity of the on-ramp.

In order to avoid that the queue of waiting vehicles reaches into the local road network a queue detector was placed. As soon as it detects a stopped vehicle the algorithm is stopped and the traffic turns green during the next 30 seconds. Afterwards, the metering is re-installed as long as the queue detector remains free. The queue detector is placed far enough from the intersection in order to have a certain buffer zone, as the vehicle on the detector will not be able to leave immediately.

5.2 Results

5.2.1 Normal conditions

As in the case of the 3rd lane a comparison between the evolution of the traffic on the current network and the one on the changed network is made. The different OD matrices are applied, starting with the standard one. For each case an average of ten replication runs was calculated.

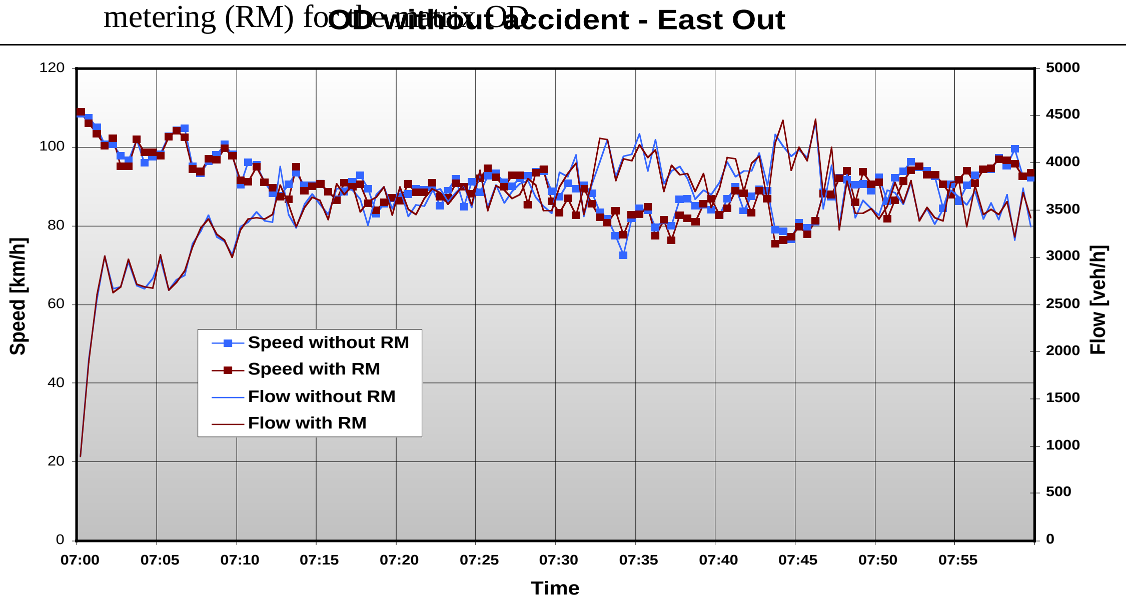
Table 3 Gain in travel time with or without ramp metering (RM)

	Standard OD			OD 10			OD 20		
	Current	With RM	**Gain**	Current	With RM	**Gain**	Current	With RM	**Gain**
Global travel time [sec]	279.2	279.2	**0.1**	333.1	317.3	**15.8**	414.4	380.3	**34.1**
Travel time from origin 3 (Morges East) [sec]	223.4	225.4	**-2.0**	236.8	254.4	**-17.6**	237.3	283.9	**-46.5**

Table 3 shows the different travel times and the gain made applying the ramp metering strategy. The first line indicates the global travel time, which is an average of the travel time of all vehicles having left the network between 7h00 and 8h00, ignoring their origin. The average travel time of the vehicles entering at Morges East (origin 3), those directly affected by the ramp metering, is found in the second line.

For the standard OD matrix no notable change is observed. This is no surprise as for this demand the occupation factor on the exit detector rarely exceeds the limit of 55 % and the allowed on-ramp flow is hardly ever below 2000 veh/h. As a consequence, the ramp metering has almost no effect, as shows Figure 8.

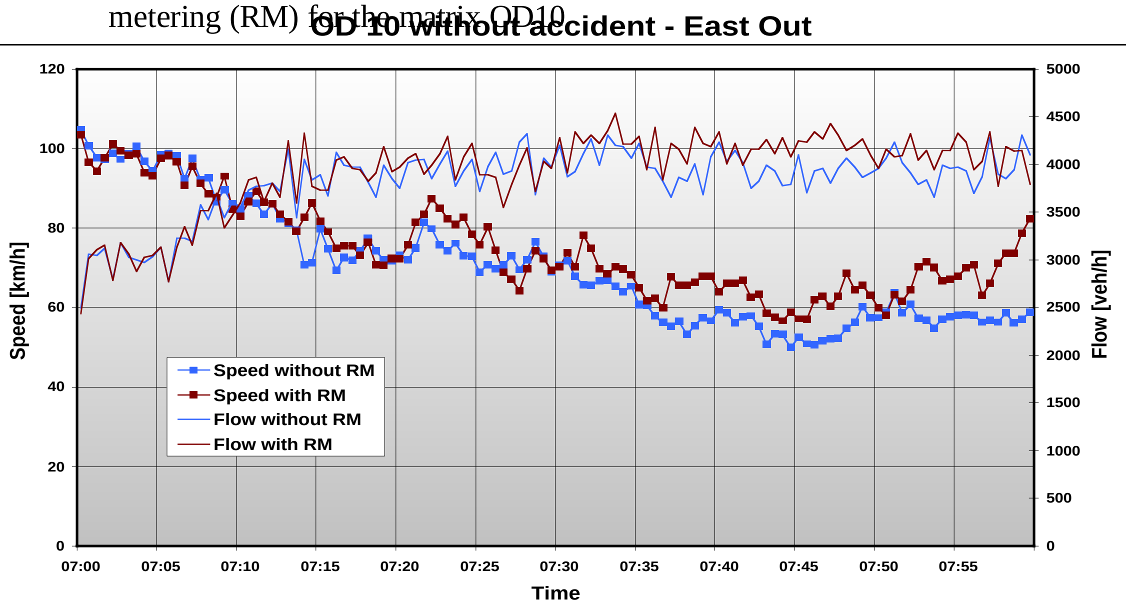
Figure 8 Average speed and flow after the Morges East junction, with or without ramp metering (RM) for the matrix OD



For the OD10 matrix the results show an average gain of about 15 seconds and a 17 seconds loss for those entering at the Morges East junction (Figure 9). These results are representative for a ramp metering strategy, trying to reduce overall travel travel time by retaining those passing the controlled on-ramp. As said before the global average (15 seconds in this case) includes the loss of time of those entering at the Morges East junction.

In order to show what the 15 seconds signify, we need to establish the difference in travel time between the matrix OD (which can be considered as the limit before congestion appears) and the matrix OD10 for the current network: 333 – 279 = 54 seconds. This value represents the global time loss due to congestion. Hence, applying the ramp metering has reduced travel time loss by 30 % (15*100/54).

Figure 9 Average speed and flow after the Morges East junction, with or without ramp metering (RM) for the matrix OD10

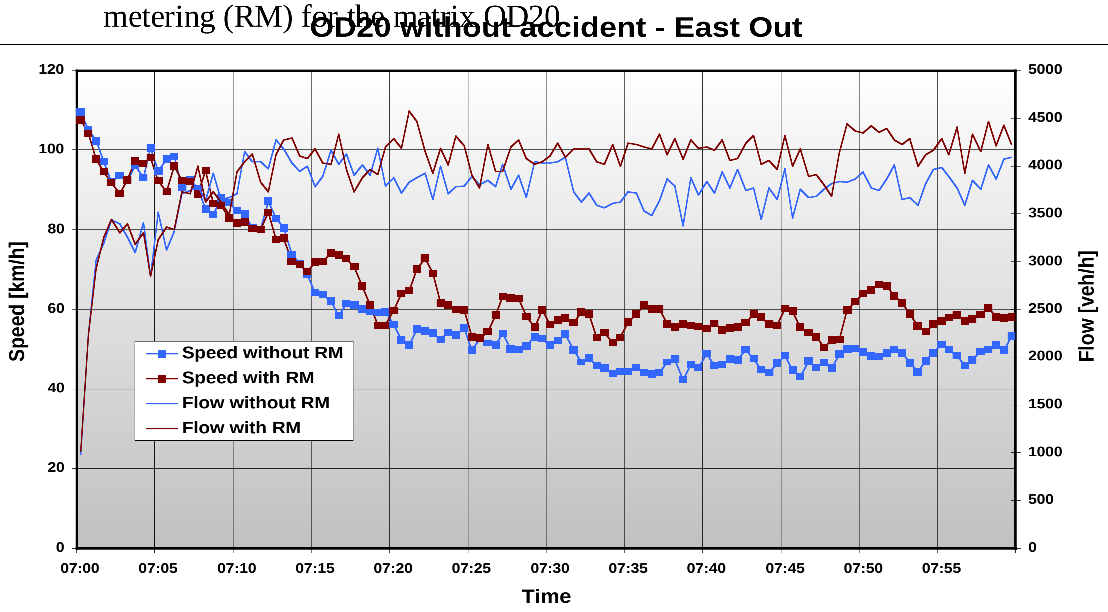


The positive effect of the ramp metering is also shown in Figure 9. The improvement is clearly visible in the second half of the simulation, where the difference between the two speed graphs is obvious. At the end, this difference becomes even more noticeable, which could mean that the congestion period is finished. It would be interesting to see the evolution of the speed beyond 8h00 in order to compare the time necessary to reinstate a certain fluidity of traffic. Unfortunately this study is limited to the standard OD matrix based on measures between 7h00 and 8h00.

The evolution of the speed in the case with ramp metering also shows the effect of the reservoir being filled up and the green time being fixed to 30 seconds. This causes several “speed drops”, as the demand for entering the motorway is suddenly very high, as seen at around 7:28, 7:37, 7:51 and 7:57. A longer reservoir on the on-ramp might result in a quicker distinction between the two speed graphs. A closer look on this problem will be made in the next phase of the PAPABILES project.

The interpretation of the results issued from the matrix OD20 (Figure 10) is similar to the one of OD10. The global gain in travel time amounts to 34 seconds, decreasing the time loss due to congestion by 25 %. However, the loss in travel time for the vehicles entering at the Morges East junction is getting important compared to the global gain (Factor 1.4, compared to a factor 1 for OD10).

Figure 10 Average speed and flow after the Morges East junction, with or without ramp metering (RM) for the matrix OD20



The positive effect of the ramp metering is visible sooner (from around 7:20), but the "speed drops" due to saturation of the reservoir are more frequent, due to higher traffic demand. This also explains the lower performance of the ramp metering compared to the case of OD10. The increase of the flow is also clearly visible in this case. This has the effect that congestion is resolved faster and the travel time is reduced as well.

5.2.2 With accident

The congestion can be caused not only by exceeding capacity, examined until here, but also by incidents causing the closure of one lane (and thus a capacity overload). In order to investigate such an event a roadblock was simulated on the right lane between 7:15 and 7:20, 300 m after the Morges East junction. The results in terms of travel time are illustrated in the following table.

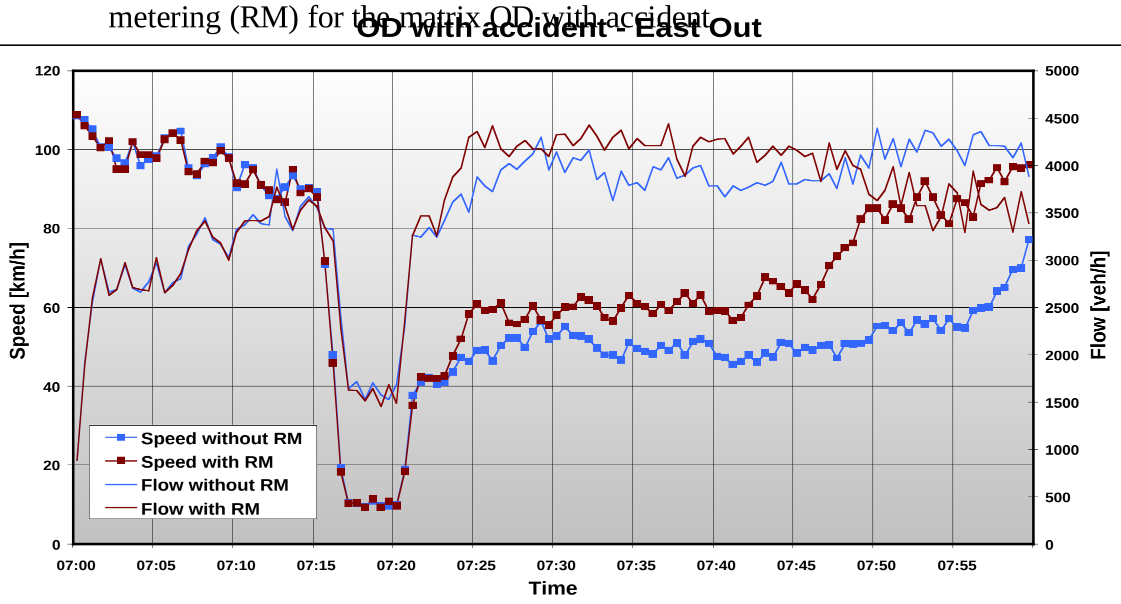
Table 4 Gain in travel time with or without ramp metering (RM) in the case of an accident

	Standard OD			OD 10			OD 20		
	Current	With RM	**Gain**	Current	With RM	**Gain**	Current	With RM	**Gain**
Global travel time [sec]	381.4	343.4	**38.0**	463.8	432.5	**31.3**	521.2	497.7	**23.6**
Travel time from origin 3 (Morges East) [sec]	247.1	278.7	**-31.6**	250.6	299.8	**-49.2**	252.1	278.7	**-26.6**

For the standard OD matrix the travel time is 102 seconds longer due to the accident (see also Table 3). Using the ramp metering system the time loss caused by the accident is reduced by 38 seconds. As the standard matrix does not cause a capacity overload, all of this time is won as a result of the ramp metering and we can determine the time gain at 37 % (38*100/102).

Figure 11 shows that, immediately after the accident, the graphs of speed and flow with ramp metering rise further than the ones without. At 7:50 the flow graph with ramp metering drops below the one without. This is due to the fact that congestion has disappeared and that the flow returns to the actual demand, which the rising speed graph confirms. Unfortunately, it is not possible to see at what time smooth traffic is reinstated without ramp metering. The time loss of the vehicles on the on-ramp is reasonable compared to the global time gain, the factor being less than 1.

Figure 11 Average speed and flow after the Morges East junction, with or without ramp metering (RM) for the matrix OD with accident



For the OD10 matrix (Figure 12) the two causes of congestion, accident and capacity overload, take effect at the same time. The ramp metering is able to improve the situation, but only to a limited extent. In fact, the increase in global travel time compared to the OD matrix without accident is 185 seconds, of which 31 (or 17 %) can be regained with the ramp metering. The factor between on-ramp time loss and global gain is now a high 1.6.

Figure 12 Average speed and flow after the Morges East junction, with or without ramp metering (RM) for the matrix OD10 with accident

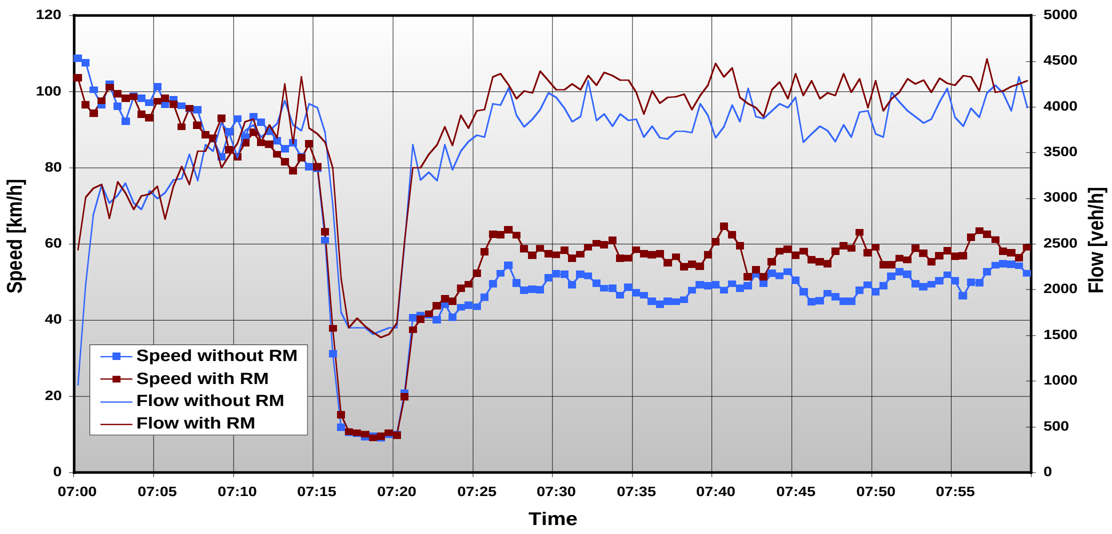
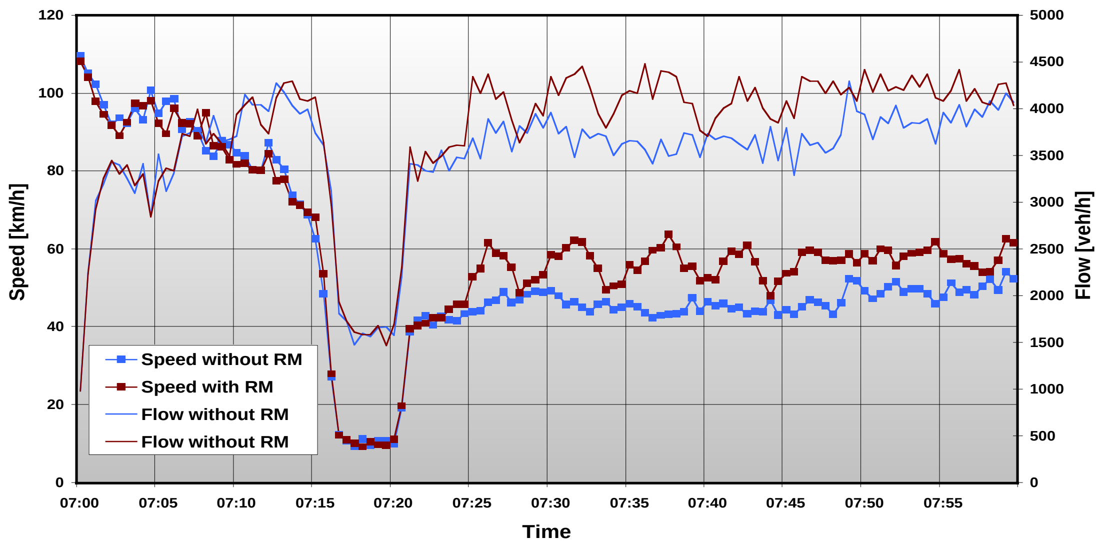


Figure 13 illustrates the efficiency of the ramp metering, clearly noticeable after the end of the accident. It also displays the difference between the speed and flow graphs with or without ramp metering. At the end of the simulation the speed graphs are almost identical, which represents the lower performance level at higher demand. However, the flow graphs show a certain difference, which indicates that more vehicles have passed the junction before the end of the simulation. This allows the conclusion that at 8:00 the length of the congested zone is less for the case with ramp metering than for the one without.

The results using OD 20 show that the positive effect of the ramp metering in terms of gain in travel time is diminishing (9 %). The double effect of accident and high demand causes a frequent filling of the on-ramp reservoir and the nearly constant draining does not allow the system to fully develop its potential.

The instability of the speed graph for the case with ramp metering, due to the frequent opening of the ramp, is clearly visible. This significant variation in speed reveals a safety problem. The gain in travel time should not be made causing a higher risk of accidents due to a frequent variation in speed.

Figure 13 Average speed and flow after the Morges East junction, with or without ramp metering (RM) for the matrix OD20 with accident



5.3 Conclusions

Generally, the ramp metering is not sufficient to avoid the appearance of congestion. However, such a system allows draining more quickly the congested area and, consequently, causes a decrease in global travel time. Nevertheless, this lower travel time is only possible by increasing the waiting time of the drivers on the on-ramp. Under normal conditions, when congestion is a result of capacity overload, the ramp metering helps limiting the increase in global travel time by 30 % and 25 % for OD10 and OD20 respectively. For the standard matrix no notable difference in travel time could be observed, as no congestion appeared.

In the case of an accident after the junction, which is rather frequent in reality, the ramp metering allows decreasing in a significant way the rise in global travel time due to congestion, as long as the demand does not exceed the capacity limit of the junction. This can be assured for the matrix OD, for which an improvement of 37 % can be observed. For a higher demand the double cause of congestion decreases the performance of the ramp metering. This is mainly due to the limited reservoir of the on-ramp, causing a repeated draining.

The question is whether the performance of the ramp metering could be improved by making longer the reservoir. This could be achieved by displacing the acceleration lane downstream using the hard shoulder of the motorway. However, it is important to notice that increasing the gain in global travel time also means increasing the waiting time of the vehicles on the on-ramp. In an extreme case, this might cause drivers to avoid the motorway and to reach their destination taking another path.

This reservoir problem could also be resolved by using a more sophisticated algorithm, which takes into account the evolution of the queue length, in order to fix the entry flow for the next time step.

6. General conclusions

This second phase of the PAPABILES project has allowed finding the following results:

The calibration parameters used for modelling the traffic on the section allow an excellent correlation between the measures made in reality and the ones issued from the simulation. However, it would be preferable to rely on more than only one sample for calibrating the model.

The construction of a 3rd lane starting at the Morges East junction allows improving traffic conditions on the studied section by two cumulating effects. Firstly, the 3rd lane allows a better traffic fluidity, which causes a decrease in travel time, even at high demand. Secondly, the congestion problems due to the introduction of traffic at the Morges East junction disappear, only to resurface at the Morges West junction, but at a higher demand. This displacement towards the Morges West junction allows increasing the demand by 17 %, after which the network is again confronted with systematic congestion. This gain in performance, together with an increase in traffic fluidity between the Morges East junction and the Ecublens interchange, allows a 27 % increase of the demand before having the same average speed as the current configuration.

The installation of a ramp metering does not avoid the appearance of congestion at the Morges East junction. Nevertheless, ramp metering allows reducing its importance and duration. For the standard OD matrix no improvement was observed, as there was no congestion. The decrease of the loss in travel time was quite significant for OD10 and OD20. This gain in global travel time is however obtained with a certain waiting time (which is taken into account for the global gain) for vehicles on the on-ramp.

Table 5 Number of congestions (of ten replications) at the Morges East and Morges West junctions

	Morges East			Morges West		
	2 lanes ME	3 lanes ME	Ramp metering ME	2 lanes ME	3 lanes ME	Ramp metering ME
OD00	0	0	0	0	0	0
OD05	5	0	2	0	0	0
OD10	7	0	9	1	1	0
OD15	10	0	10	7	1	3
OD20	10	0	10	10	2	7
OD25	10	0	10	10	6	10
OD30	10	0	10	10	9	10
OD35	10	0	10	10	10	10
OD40	10	0	10	10	10	10

In the case of an accident right after the Morges East junction the ramp metering allows a significant gain in time as long as the demand does not exceed the capacity of the junction. This is the case using the standard OD matrix, where a 37 % improvement of the global time loss due to the accident was observed. For the two other matrices OD10 and OD20 the combination of the accident and the capacity overflow does not allow the ramp metering to function properly anymore. The junction is saturated to the point that the on-ramp queue regularly reaches the queue detector and thus opens the motorway entrance for 30 seconds. This frequent draining is the cause of the rather deficient functioning of the ramp metering system.

Table 5 compares the probability of congestion appearing for the two scenarios (3^{rd} lane and ramp metering). It confirms that the ramp metering is not able to avoid congestion, but limits its extent and duration, as congestion is less frequent at the Morges West junction, which shows that congestion does not develop as much upstream as for the case without ramp metering.

Figure 14 Average section speed in respect to the vehicle origin and the OD matrix

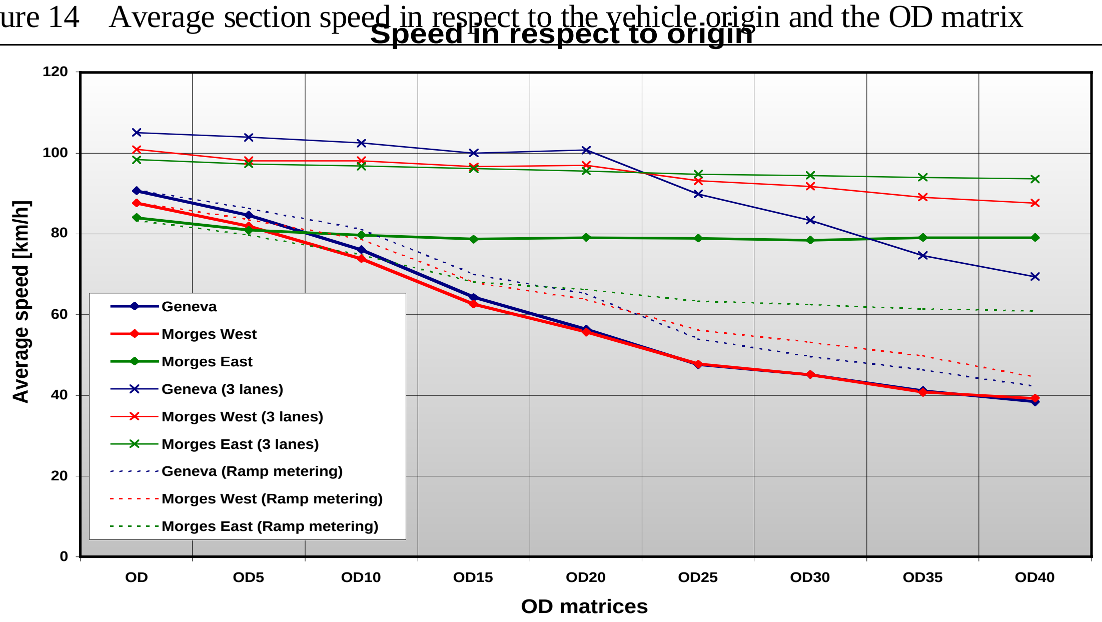


Figure 14, Figure 15 and Figure 16 show the difference in efficiency between the two studied scenarios in terms of average speed and gain in time. However, this comparison cannot be made without remembering that the goal and the expenditure are not the same for the two scenarios.

Figure 15 Average global section speed in respect to the OD matrix

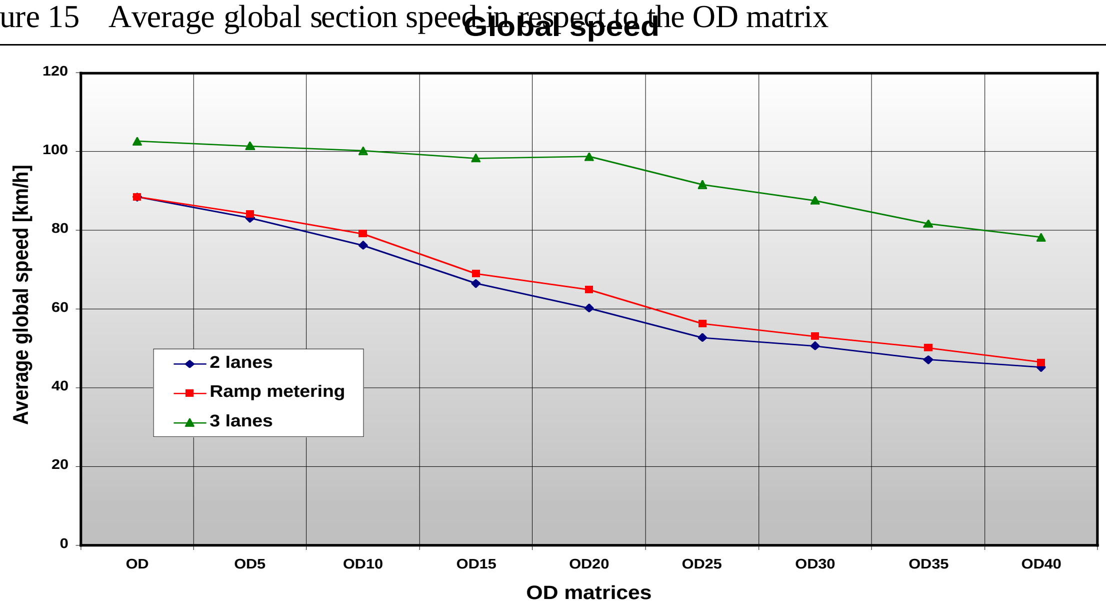
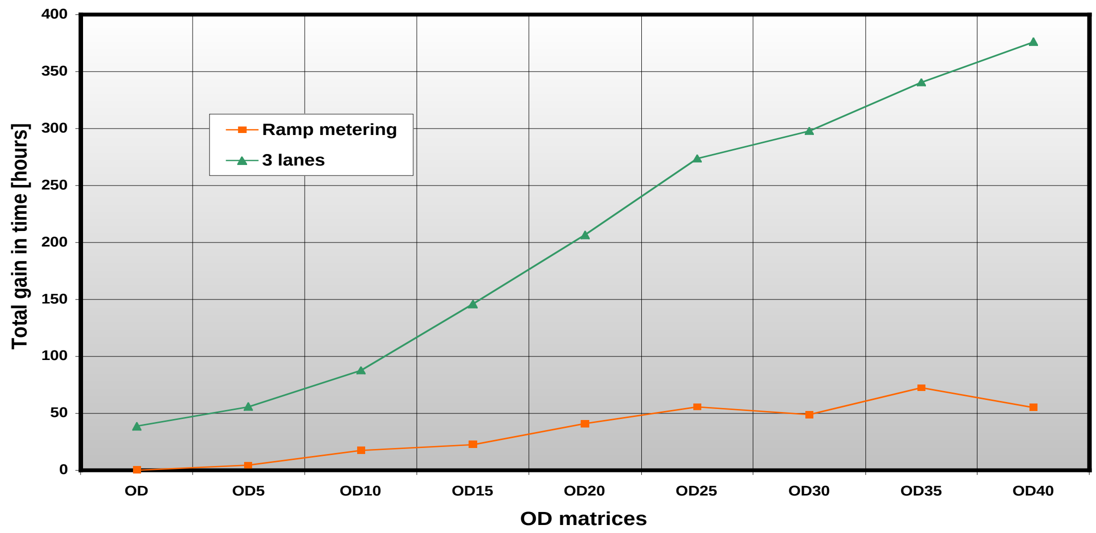


Figure 16 Total time gain in respect to the OD matrix



7. Research perspectives

Several times this study has exposed limits that do not make possible a complete interpretation of the results. It also revealed several points that would merit a more detailed analysis. Following points could be investigated in the future:

- Refining the calibration parameters using several samples
- Expand the study period from 6:00 to 10:00, rather than limiting it to one hour
- Improve the ALINEA algorithm in order to reduce the negative impact of a too short reservoir
- Expand the reservoir by displacing the acceleration zone downstream
- Modelling the intersection with the local road network in order to use the traffic lights and the selection lanes as an extension to the reservoir
- Install a ramp metering at the Morges West junction, with or without a correlation to the system at the Morges East junction
- Modelling the 3^{rd} lane from the Morges West junction already

All but the last point are planned to be examined in phase 3 of the PAPABILES project.

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