CONTINUUM TRAFFIC FLOW MODELLING INSIDE THE MONT BLANC TUNNEL*

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Abstract

The problem considered in this paper is modelling the distances between vehicles in the Mont Blanc tunnel and evaluating the effect on traffic of a system enforcing spacing rules. Though the problem is basically of microscopic nature (individual distances), the paper shows that a continuum model, associated to a wave-tracking resolution method which provides accurate waves trajectories, may capture various motorists behaviours concerning vehicular spacing and describe into some details the effects of an enforcement system. The interest of such an approach is to avoid calibration difficulties always met with a microscopic modelling, explicit consideration of the stochastic aspects for which no measurements exist in the Mont Blanc tunnel, and thus to result in practical conclusions with a minimum measurement effort.

1 Introduction

In the long road tunnels crossing the Alps Mountains, traffic control and enforcement have taken an increased importance after the Mont-Blanc accident in 1999, which resulted in 39 fatalities. Speed control has been implemented for long, together with a flow control at the tunnel entrances, but it is only now that technology makes it possible to control and enforce the vehicle spacing regulations which have been decided after the 1999 accident.

The vehicle spacing control raises several issues:

- What is the impact of the flow control at the entry of the tunnel on the effective interdistance inside the tunnel? Or, conversely, what is the impact of this spacing regulation on the capacity of the tunnel? What is the maximal entering flow that makes it possible for drivers to comply with the spacing regulation?
- What can be the effect on traffic flow of a local spacing enforcement system if spacing rules are not respected upstream (congestion inside the tunnel)?

In order to investigate those issues without involving huge studies or experiments, it has been decided to develop a very simple traffic model.

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2 Description of the model

2.1 The choice for a continuum traffic flow model

Since the flows inside the tunnel are very sparse the first idea was to use a microscopic car-following model, able to take account of the vehicles diversity and to represent accurately the motorists behaviour with respect to spacing rules.

Unfortunately, calibrating such models is not easy, especially considering the fact that motorist behave in a special way inside tunnels, so that classical parameters could not be used. It was then decided to use a completely different approach, based on a simple macroscopic model.

The model used is a mere Lighthill-Witham-Richards [5, 8] model. The first interest of such a model is that the phenomenology of traffic is totally described by a flow/density (or speed/spacing) relationships and that it is thus easy to represent various user compliance with spacing rules. The second interest is that extensions have been made to this model to represent the interaction of the flow with moving obstacles [4], which happens to be the main modelling question in tunnels like the Mont-Blanc: most traffic perturbations are caused by vehicles having lower acceleration possibilities and causing traffic accumulation behind them.

These two points will be explained in the next part and some results given.

2.2 The flow density diagram

It is agreed by the tunnel operators that speed limits are mostly respected. The maximum speed is 70 km/h in the tunnel, and there is a minimum cruising speed of 50 km/h.

The spacing rules assume that vehicles must keep between them a distance of 150 m and 100 m when stopped (note that this safety distances are not related to collision prevention, but to fire security). The flow density diagram corresponding to a perfect compliance with these rules is depicted on the left side of fig. 1.

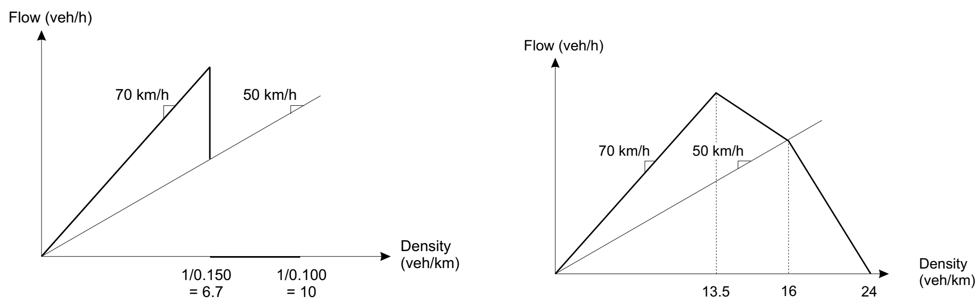

Figure 1: Fundamental relationships corresponding to the regulation (left) or to the observed behaviour of drivers (right).

From a user survey conducted at several long road tunnels [6], the following observations have been made:

- About one third of the users comply with these rules,
- One third respect spacing of about 40–50 meters, decreasing when the flow speed is low,
- One last third use very short distances, even at maximum speed.

The corresponding diagrams are triangular diagrams with different values for critical and maximal densities. The combination of the three types of users yields to the fundamental diagram depicted in the right hand side of fig. 1.

Other different combinations are possible and provide various types of compliance with the spacing rules. This makes it possible for instance to represent a stricter compliance in the vicinity of a spacing control system.

We will consider that in the whole tunnel, the traffic follows the "observed" fundamental diagram while, inside (or at the vicinity) of a control zone, it follows the strict regulation diagram.

2.3 Influence of slow vehicles

Some vehicles in the flow have a special behavior and their speed is not restricted by traffic itself, but rather by their mechanical caracteristics. Those "slow vehicles" are not necessarily constrained in speed (and may be fully capable of reaching the speed limit of 70 km/h) but may have some poor acceleration capabilities so that at the entry of the tunnel their speed is particularly low. Therefore they behave like a moving bottleneck.

The idea of the proposed model is to represent exogeneously the trajectory of those "slow" vehicles while the remaining traffic is described by the LWR model.

Note that since the tunnel has only one lane per direction, no overtaking is possible.

2.4 Wave tracking resolution method

The resolution method that was chosen for this study is the *wave tracking* method. It differs from classical finite difference schemes since it does not need a space-time discretization grid and is based on the explicit handling of waves in their different stages: generation, propagation and collision with other waves.

This method has been applied to the LWR model in [1] and extended in order to take account of different types of boundary conditions such as stationary [2] as well as moving bottleneck [3]. When considering piecewise linear fundamental relationships like the ones we use here, the method calculates the exact solution of the LWR model.

3 Traffic modeling at the entry of the tunnel

It is straightforward to see that the maximal flow for which the vehicles can comply with the spacing regulation is given by the regulation itself: $Q_{\max} = \frac{70\,\mathrm{km/h}}{150\,\mathrm{m}} \approx 460\,\mathrm{veh/h}$. Thus the interval between two vehicles at the entry of the tunnel should be at least of approximately 8 s.

But beyond this simple reasoning we must also take into account the fact that some vehicles (like trucks, for example) have poor acceleration capacities and cannot reach instantaneously this 70 km/h limit. Indeed, in the case of such slow vehicles, a platoon is forming behind them with a higher density (see fig. 2). This perturbation disappears after a few seconds (point C on the diagram), depending on the entering flow.

In order that such a perturbation do not diverge it is important that another slow vehicles does not move off too early. Hence the maximal number of trucks that can enter the tunnel is limited by this dissipation time. Given the total entry flow, a maximal truck flow can thus be calculated. This result is represented on Fig. 3 in two different ways, corresponding to two possible management strategies:

- Given a total flow, what is the maximal number of trucks that can enter the tunnel? The extra number of trucks will be queued while cars will fulfill the gaps between trucks.
- On another hand, if we do not want to separate flows and make trucks wait longer than individual cars, what is the maximal entering flow, given the proportion of trucks?

NB: Calculations have be made with a $0.2\,\mathrm{m/s^2}$ acceleration for trucks but the numerical results should to be handled with care since this acceleration value is only a mean value obtained from

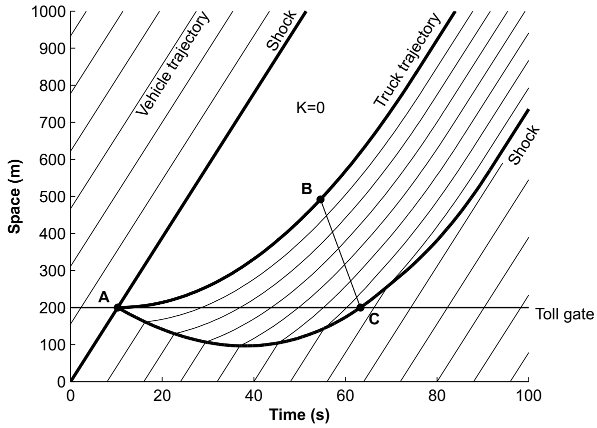

Figure 2: Space-time diagram representing the entry of a slow vehicle inside the tunnel after its stop at the toll gate

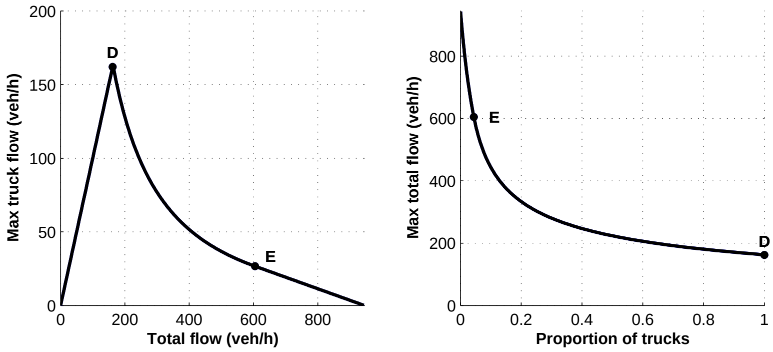

Figure 3: Capacity of the tunnel considering slow vehicles

a not up-to-date study [7] and because of the hypothesis of the LWR model (average behaviour, etc.).

4 Traffic modeling at the vicinity of a spacing control zone inside the tunnel

Since the speed limit is well respected by drivers, as soon as a truck and the platoon behind it reaches this speed limit, the geometry of this platoon will not evolve and the interdistance between vehicles will not change. Actually this is only true while there is no spacing control and as long as the "observed" diagram can be applied. In this section we will see what happens when such a platoon arrives near a spacing control zone.

4.1 Control zone = capacity reduction

In fact such a control zone is nothing but a modification of the fundamental relationship from the observed diagram (outside the control zone) to the official one (inside the control zone), so that it will have the same impact as a bottleneck. In particular, since the platoon behind a slow vehicle is higher than the capacity of the control zone a congestion will be generated upstream the control zone and will take some time to disappear. This corresponds to the fact that each car in the platoon has to wait till the distance with the vehicle in front of it is far enough to comply with the regulation

The exit of the control zone is not a capacity reduction so that the new platoon behind the slow vehicle will pass this discontinuity without being changed. This means that the interdistance between vehicles keeps complying with the regulation. This latter point is made possible since the speed limit is respected everywhere in the tunnel so that vehicles in the platoon cannot accelerate and get closer to the truck.

The conclusion is thus twofold:

- A control zone is a good way of regulating the spacing between vehicles when combined with a good compliance with the speed regulation. Indeed vehicles keep complying with the spacing regulation after the control zone.
- But such a control zone also creates a congestion inside which vehicles comply less with the spacing regulation. From a security point of view, this feature is not very positive.

4.2 Towards a better efficiency of the control zone

In order to avoid this counter effect of the control zone which actually generates higher violation of the regulation, we can imagine some *progressive* adaptation of the spacing between vehicles rather than a crisp discontinuity of the fundamental relationship.

Indeed, we cannot suppose that drivers will know precisely the position of the control zone and they will unlikely change they behaviour abruptly at this position. Furthermore, it is of interest for the traffic manager to help drivers to smoothly adapt their spacing in order to comply with the regulation at the entry of the control zone. That can be simply done for example by message signs giving the distance ahead of the control zone such as "Spacing control in 300 meters".

Thus, if information is provided in a proper way to drivers, the crisp discontinuity of fundamental diagram can be replaced by a smooth one. We do not precisely know what would be the reaction of drivers to such information, but we can model it by a simple linear transition between the two diagrams inside a transition zone of a given length. Figure 4 depicts space time diagrams for three different values of the flow entering the tunnel.

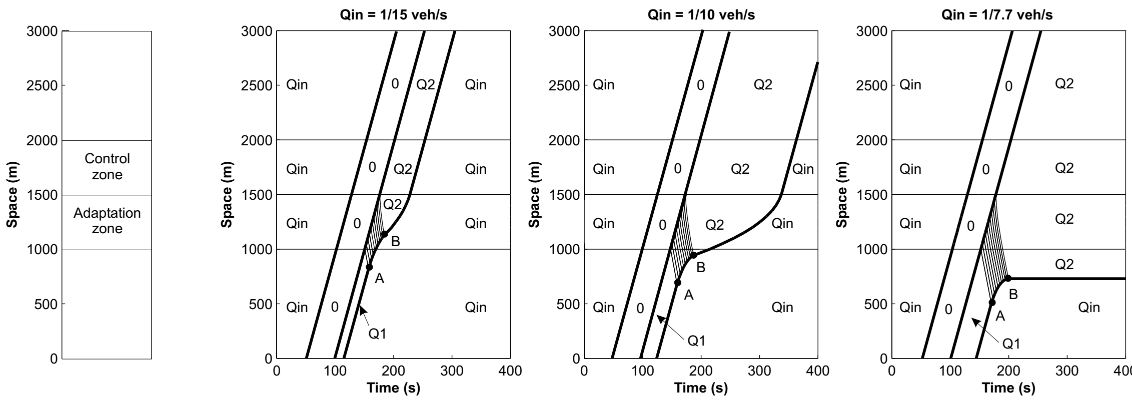

Figure 4: Effect of an adaptation zone before a spacing control zone for different flow values of the entry of the tunnel

This smooth adaptation of the spacing replaces the high density congestion of the crisp control zone by a wider congestion zone but with lower density values. Thus it is made possible to diminish the severity of the regulation violation by providing information to drivers. Of course, this goes in a higher security direction.

The highest density is observed at point B, which corresponds to the intersection of the constant flow characteristic originated at the entry of the truck in the control zone and the shock wave at the end of the platoon. It is thus possible to calculate the "optimal" length of the adaptation zone with simple hypothesis on the possible entry flows and slow vehicles acceleration.

5 Conclusions

This short study has shown that several interesting conclusions could be drawn from a macroscopic modelling of traffic inside tunnels, in spite of the sparsity of considered flows.

Indeed, even if numerical values have still to be handled with care, the qualitative results are:

- The capacity of the tunnel is limited because of the acceleration limitation of trucks and the theoretical maximal flow of 460 veh/h, corresponding to maximal speed and minimal spacing is hardly achievable.
- A spacing control can be efficient when combined with speed control but results in a more severe violation of the security rules when applied abruptly.
- This violation can be soften by a proper information given to drivers upstream the control zone.

The main interest of this study is to show that using a mere first order continuum model with only a few input data makes it possible to capture in some details individual behaviours and their effects over traffic flow. It is presumable that using a microscopic model to solve the same problem would have made it necessary to make a number of hypothesis (distributions etc.) and would thus have resulted in more questionable results. The results obtained here are necessarily approximate, but there is a direct and explicit connection between the few hypotheses made and these results: any additional information coming from empirical observation could thus easily be integrated into the model and improve the accuracy of the results.

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