Freeway's Safety Ways: Rapid Flow and Intervention

Bergmeister K.
Autostrada del Brennero S.p.A.

Cattani M.
Trentino Parcheggi and Università di Trento

Francesconi S.
Autostrada del Brennero S.p.A.

Mauro R.
Università di Trento

Freeways are classified as a functional part of the primary road network, whose main function is to permit the transit of vehicles through across the territory. Freeways are generally characterised by a limited number of interconnections with other adjacent road networks. In the case of the Brenner Freeway, the interconnections with toll stations are located every 15 km.

For this reason, in the event of an emergency leading to the traffic stoppage, considerably long queues may form, with two main consequences. Firstly, drivers are forced to long waits, since they cannot change their itinerary route. Secondly, due to congestion, rescue and traffic assistance units can hardly reach the crisis spot, in order to start the emergency procedures.

On this basis, the Brenner Freeway is planning the realisation of safety ways, exit and entrance emergency slip roads, directly connecting the freeway to the adjacent roads. Interdicted to traffic under normal circumstances, safety ways will be equipped with barriers, only removable by the freeway's managers and by rescue and emergency units. They will have two main effects. On the one hand, they will channel out vehicles and in so doing ease the traffic jam. On the other hand, the access and intervention of rescuers will be simplified, as they won't be forced to use the emergency lanes or to make hazardous U-turns.

The realisation of such safety ways involves a preliminary study to quantitatively describe the traffic flow and to predict the evolution of its conditions in the system comprising the freeway and the roads affected by the outflow of vehicles from the principal axis. The re-arrangement of the infrastructures involved will allow the safety ways to drastically reduce the frequency and severity of traffic congestions.

In this paper, the principal measures to be taken for the re-adaptation of such infrastructures are described, and the modelling approaches for the system's design and management are analysed.

Freeway's Safety Ways: Rapid Flow and Intervention

PREFACE

Freeways represent the most important infrastructures of the European transport network. The increase of road haulage over the past decades is markedly higher than that of any other form of transport. Only the sea freight transport trend is comparable, but this form is convenient only for very long distances. There are three factors involved in such a huge increase of road haulage:

- the speed and the reliability of modern trucks;
- the comfort and extension of the road-networks;
- the possibility to optimise the management of different cargoes.

Table 1 and Figure 1 compare relative performances by mode of transport of goods in Europe. Table 2 gives an overview of the modal performance split of transport of goods through the years.

Table 1: Performance by mode of transport of goods in the EU-15 (values in billion tkm) [1]

	Road	Rail	Inland Water-ways	Pipe-lines	Sea	Total
1970	488	282	102	64	472	1409
1980	720	290	106	85	781	1982
1990	976	255	107	70	923	2332
1991	1010	235	106	79	955	2385
1995	1144	221	114	82	1070	2632
1997	1214	237	118	82	1124	2775
1998	1283	240	120	85	1142	2870
1999	1344	236	120	85	1197	2983
2000	1378	250	125	85	1270	3108
2001	1395	242	125	87	1254	3102
1991-2001	**+ 38%**	**+ 3%**	**+ 18%**	**+ 10%**	**+ 31%**	**+ 30%**

Table 2: Modal split of transport of goods in the EU-15 (%) [1]

	Road	Rail	Inland Water-ways	Pipelines	Sea
1970	34.7	20.0	7.3	4.5	33.5
1980	36.3	14.6	5.3	4.3	39.4
1990	41.9	11.0	4.6	3.0	39.6
1991	42.4	9.8	4.4	3.3	40.1
1995	43.5	8.4	4.3	3.1	40.7
1997	43.7	8.5	4.3	3.0	40.5
1998	44.7	8.3	4.2	3.0	39.8
1999	45.1	7.9	4.0	2.8	40.1
2000	44.3	8.0	4.0	2.7	40.9
2001	45.0	7.8	4.0	2.8	40.4

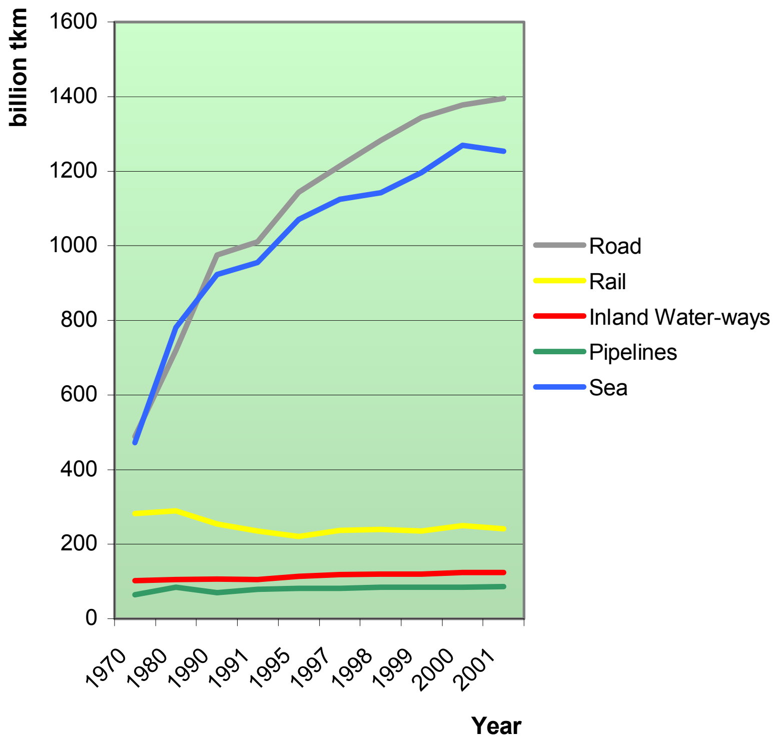

Figure 1: Performance by mode of transport of goods in the EU-15 (values in billion tkm) [1]

The strong dependency of the European economy on the road network calls for high efficiency and the reliability of its structures. This is even more imperative as regards freeways, which represent the main element of the road network, since there is often no alternative for long-distance international transports.

The increasing welfare of the European population brings with it rising consumption. Nowadays, commodities are exchanged all across Europe and beyond. In order to meet this massive demand for goods, we need an efficient transport system. Speed of delivery, is indeed the first parameter for the evaluation of a transport company. In this sense, every delay due to inadequacy of the infrastructures cause economic damages to the freeways' users. Therefore, freeways' managers and operators should guarantee the fastest possible connections.

In case of serious accidents, where the intervention of emergency units is required, efficiency can be vital: the units must reach the place of the accident as soon as possible, to activate the emergency procedures and the operations to bring back to order the traffic flow. This is often difficult on freeways, constituted by one-way carriageways, where U-turns are not allowed. Therefore, long queues can form behind the stopping place: vehicles are forced to stay on the carriageway having no possibility to change their route. What's more, in order to overtake queuing vehicles, rescuers must use the emergency lanes at a high risk for imprudent drivers walking on the carriageway.

SAFETY WAYS

In order to rapidly clear the carriageway from queuing vehicles the Brenner Freeway will realise a series of safety ways which will be used only in case of emergency. The safety ways will be supplied with lay-bys for rescue vehicles, with SOS buttons and CAU (Users Assistance Centre) telephones.

Mobile barriers will be also put in place, which will be only removed by the freeway's staff and by the emergency and rescue teams. Moreover, infrastructures designed for the rapid installation of mobile toll-booths will also be realised on the ramps. Therefore, they will be connected with the electric system and the optical fibres of the toll system. The mobile stations will consist of gates for automatic vehicles detection and recognition (GPRS systems, Telepass, etc.) that can be moved by trolley.

Safety Ways' Positioning
The optimisation of the safety ways' location is a crucial concern. On deciding their location, one must consider:

- the proximity of a main road,
- the distance from toll stations,
- the presence of flyover,
- the presence of special or dangerous stretches.

The proximity to a road with adequate capacity is, of course, the first requirement for the realization of a safety way. The road must be able to absorb the sudden flow of vehicles from the freeway. Therefore, its size and layout must cope with heavy lorries traffic and its original traffic load must be not excessive, since this would cause the stop of both the freeway and the ordinary road. Both these issues will be further explored in a later section.

In order to be very effective and beneficial for a larger number of vehicles, safety ways should be realised at an equal distance from the preceding and the following toll station. On the Brenner Freeway, 21 toll stations are distributed along the 314 km of freeway. This means that the average distance between toll stations is 15 km. An optimised distribution of safety ways would lead to about 7,5 km of competence for each safety way. Considering an average of 8-10 m of leeway for a vehicle in a queue, a safety way would allow the clearing from the stopped freeway of more than 1.500 vehicles.

INFRASTRUCTURAL AND OPERATIONAL ISSUES

Experiences made in the surrounding of the city of Vienna [2] show that the realisation of safety ways along the freeway implies the construction and adaptation of complementary infrastructures, like flyovers, ordinary roads, variable message panels, and the analysis and optimisation of the procedures. The most important interventions and procedures to be realised are listed below.

Flyovers

In the event of an emergency situation where the activation of a safety way is necessary, the related flyover becomes fundamental. Therefore, the structure must be dimensioned so as to stand the typology and quantity of traffic flowing out of the freeway. Some of the actual flyovers of the Brenner Freeway are outdated. For this reason, already in the year 2000, the Company has advertised a competition open to all European applicants and concerning the design and construction of new flyovers. The aim was to create a series of first-rate design solutions, realised by internationally known professionals from the European Union. 56 projects have been presented, all highly competitive on both a functional and aesthetic level. Some of them will then be realised on the Brenner Freeway as complementary infrastructure for the safety ways.

Ordinary Roads on Alternative Routes

The realisation of the safety ways implies a preliminary traffic absorption study for the roads involved in the eventual transfer of vehicles flowing out of the freeway. The ordinary road net and the new structures must be able to cope with any occurrence. Should they fail to do so, the roads will be properly renewed, for example by increasing the radius of curvature of the curves, in order to allow the traffic of lorries.

Moreover, on the basis of the existing roads and their conditions, for each safety way alternative routes must be identified and studied for traffic driving in both directions. The alternative routes have to be chosen taking into account the capacity and geometry of the involved roads, the proximity to residential areas, the time needed to drive them, the presence and typology of intersections (signalised or not, roundabouts, etc.). The definition and organisation of alternative routes may create problems, which can be solved only through important interventions. The requirements for the roads forming the alternative route are better stated in a following chapter. The net's traffic absorption is also a subject widely discussed in a next part of the paper, where the effects on the ordinary road net generated by the safety way's opening are considered.

Communication Systems

Especially during emergencies, but the argument should not be confined to extreme situations, the first concern of the administrators is to transfer information to the users and to communicate with them, in order to indicate how to properly behave so as to reduce negative consequences. By designing safety ways and their connected infrastructures this becomes even more important, since they will only be accessible for real emergencies, and since they represent something new for the users of the freeways. Therefore, a road-signalling must be meticulous and the interconnections with the ordinary viability could be equipped with traffic lights. Variable message panels will be placed before and at the inception of the safety ways, in order to inform the users about what happened, how to best handle the situation and the alternative route to follow after leaving the freeway. The messages to be displayed on the panels will be studied and prepared beforehand, in order to be readily available under any circumstances

Barriers and Mobile Toll Stations
The safety ways, under normal traffic conditions, will be closed. Only the managers of the freeway and the emergency and rescue teams will be allowed to open the ways. Therefore, removable but locked barriers will be installed at their accesses. In case of emergencies, mobile toll stations mounted on trolleys will be quickly transported and installed at the safety way. The toll stations will be equipped with portals for the automatic detection and recognition of the vehicles (GPRS systems, Telepass, ...) and directly connected with the tolls recording system of the freeways network. The system is still being developed.

Emergency procedures and infrastructures
The intervention of safety and rescue teams and of the police in case of emergency has to be as fast and effective as possible. Rapid and efficacious interventions after an accident are of the essence and can drastically reduce the gravity of the consequences. For this reason, emergency procedures, must be set up well in advance in order to be ready to face whatever crisis. All the personnel involved in the operations must be properly coordinated and instructed as regards alternative routes and facilities available to drivers (e.g. barriers, mobile toll stations, variable message panels).

GEOMETRY OF THE SAFETY WAYS

The safety ways' design must consider the function that such services provide, i.e. exit ramps diverting the freeway traffic, in case of carriageway block. The capacity of these ramps is clearly lesser than that of the whole carriageway. Therefore, in the majority of cases, their opening - accompanied by the closing of the freeway's next section - will lead to a queue, growing upstream the safety way. Coming from a congested situation, the vehicles will then proceed slowly through the safety way. However, we cannot exclude the case the safety way's capacity might exceed the freeway traffic demand (for example in case of accidents happening in the night hours). In this circumstance, the drivers' behaviour on the ramp won't differ from that of drivers on an ordinary freeway exit ramp, save the greater speed reduction, forced by the particularity of the situation, the police's presence, etc.

As a result of these considerations, the geometric requirements of the safety ways to be similar to those of ordinary freeway exit ramps, in terms of curvature radii, gradients, and cross-sections. Some possible layouts, indicating the geometric features, are shown in Figure 3 and Table 3.

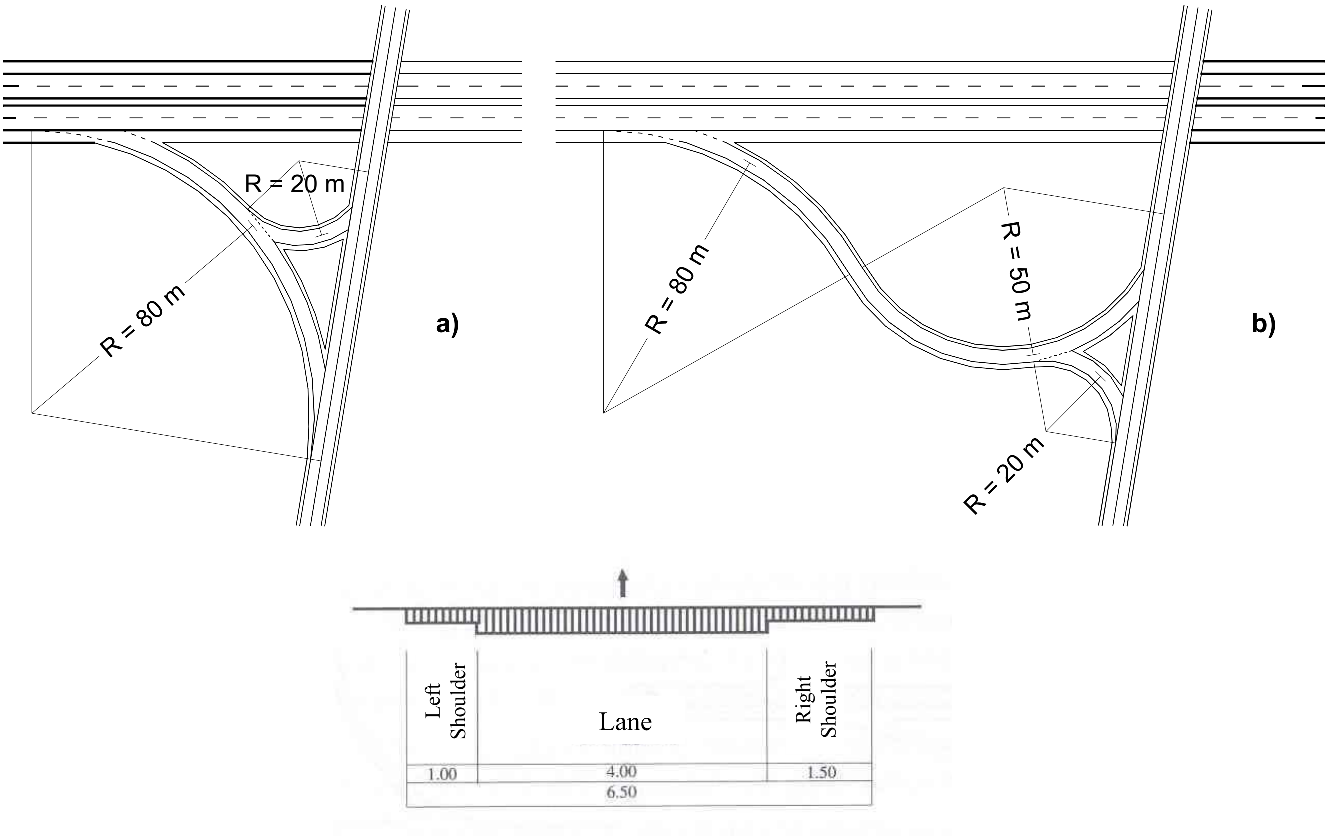

Figure 3: Geometry and lay-out of the safety way

Table 3: Geometric indications for safety ways

Design speed	<= 50 km/h
Minimum radius	80 m (v = 50 km/h) 50 m (v = 40 km/h)
Maximum longitudinal gradient	6 - 8%
Crest vertical curves	1000 - 1500 m
Sag vertical curves	500 - 750 m
Cross gradient	min 2.5% - max 5%
Minimum visibility distance	35 - 50 m

Part a) of the Figure 3 presents the simplest case, where a direct ramp can be used. Part b) shows the case where the alternative route through ordinary roads requires a left turn at the safety way's exit. Here the second curve can have a smaller radius than the first, but this must measure at least 50 m. An even smaller radius (around 20 m) can be introduced for secondary directions, i.e. for those manoeuvres that are unnecessary on alternative routes.

These safety way's layouts provide a smooth flow of vehicle, also bearing in mind that the police will probably request drivers on the ordinary road, to which the safety way is connected, to give way to vehicles coming from the freeway. A quantitative evaluation of the safety way's capacity is not easy, because of the distinctiveness of this factors and the conditions of its opening to the freeway flow. During congestions, the safety way works pretty much like a signalised intersections lane: the vehicles start from an almost standstill, leaving the queue that leads to the provisional freeway exit. In ideal conditions, the capacity of a lane with green light at a signalised intersection is 1900 pcu/h, following HCM indications [3]. The conditions in which the safety way operates are slightly different, due to the presence of provisional road signs, police control, a path unfamiliar to users, etc. Thus, a more realistic appraisal of the maximum flow passing through the safety way will involve a smaller figure, arguably about 1500 pcu/h.

REQUIREMENTS FOR THE INFRASTRUCTURES FORMING THE ALTERNATIVE ROUTE

The opening of the safety way causes the transfer of all freeway's vehicles to the ordinary road network. This issue should be considered when defining the alternative route, which leads from the safety way's end to the next freeway station, providing a by-pass to the traffic block. Even taking into account that the transit on the alternative route is limited to emergency situations, the involved roads and intersections need to meet some basic requirements. As usual, for safety reasons, the transit of heavy vehicles calls for the selection of roads with a minimum lane width of 3.00 m. This allows the transit of two heavy vehicles heading in opposite directions.

Furthermore, intersections must enable drivers of heavy vehicles to turn. Generally, it is safe to say that National and Provincial Roads do not present difficulties. The possible presence of critical points (for example narrow passages) can be managed with the help of police, considering the exceptionality of the situation.

As regards strength performance, the infrequent use of ordinary roads as freeway's escape ways is sufficient guarantee that this won't constitute a problem. In fact, low volumes do not lead to any fatigue problems.

CRITERIA FOR CHECKING THE OPERATIONAL EFFECTS ON THE ROAD NET

Ensuring the geometric requirements to the alternative route for the freeway traffic could not be sufficient for the implementation of such a project in case of a freeway block. The operational conditions need be kept in constant check, considering the part of road network affected by the opening of the safety way. We should consider the worst case scenario in which the transferring of the freeway traffic might cause the traffic jam to simply be pushed into ordinary roads. Worse still, drivers not using the freeway would be delayed as well.

The evaluation of the freeway flow deviation's effects into the ordinary road network is neither a simple nor a systematic operation. There are in fact many variables: the volume of the traffic diverted from the freeway, the traffic volumes travelling on the ordinary road network, and the peculiarities of the route to the next freeway station, which can vary in terms of length, number of intersections, and type of areas it crosses, that is, suburban or rural.

A procedure to evaluate the operational effects of the safety way's opening consists of the following steps:
1) definition of the route for the detour, that is to say, from the safety way to the station where the vehicles are expected to get back to the freeway;
2) evaluation of the traffic volumes on the portion of road network under scrutiny;
3) calculation of the network performances, especially focusing on the intersections, as these are the system's critical points;
4) overview of the operational conditions, together with a comparison of minimum threshold values (Levels of Service and total delays are among the parameters that can be used).

Route Definition
Before building a safety way along the freeway track, the Brenner Freeway managers will identify a link route, leading from the safety way to the next station, where the traffic will be channelled back into the freeway. This route must be clearly indicated to drivers who will be assisted by the police. In accordance with the requirements previously defined, the identified route should be as short and straight as possible, so as to facilitate the traffic flow. The route's identification allows the definition of a part of the road network, which will be controlled with respect to measure's effects. An example is shown in Figure 4.

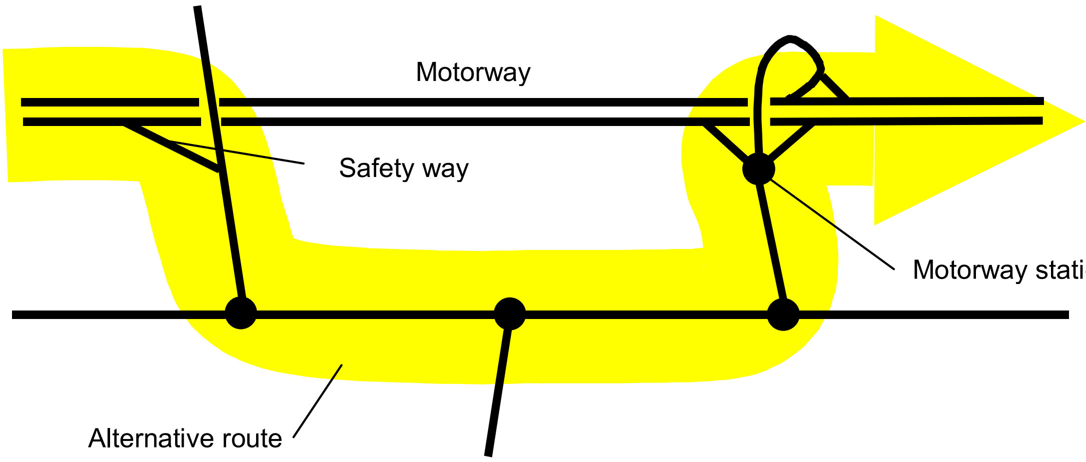

Figure 4: Sections and knots forming the road network part of interest

Network Volumes' Estimation
This is the most complex part of the procedure. The traffic volumes on the network vary appreciably, depending on the hours, the day of the week, and the season. Therefore it's not possible to foresee the traffic volumes on the network when opening the safety way, in order to check its operational conditions during emergency phases.

The problem can be by-passed through the identification of some typical network traffic conditions throughout the year. Subsequently, the designer can assess the effects of a design detour volume in such diverse circumstances. An alternative and more accurate method is applicable if real time traffic data are available: in this case, the network expected performances can be thoroughly assessed, according to the actual traffic conditions. This continuous monitoring of the ordinary road network is not, at least for the time being, an activity contemplated by the Brenner Freeway.

The network's traffic volumes, regardless of the network's actual load, can be calculated simply by adding the diverted flow for every section of the alternative route (see following diagrams). We can arguably ignore a possible traffic redistribution on the network, because the safety way's opening is exceptional, unpredictable, and only provisional.

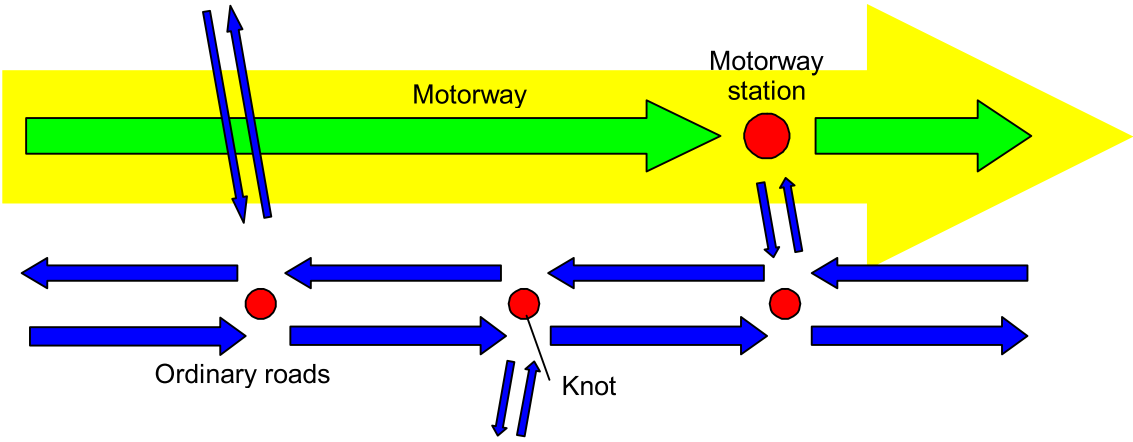

Figure 5: Network standings with normal freeway operation

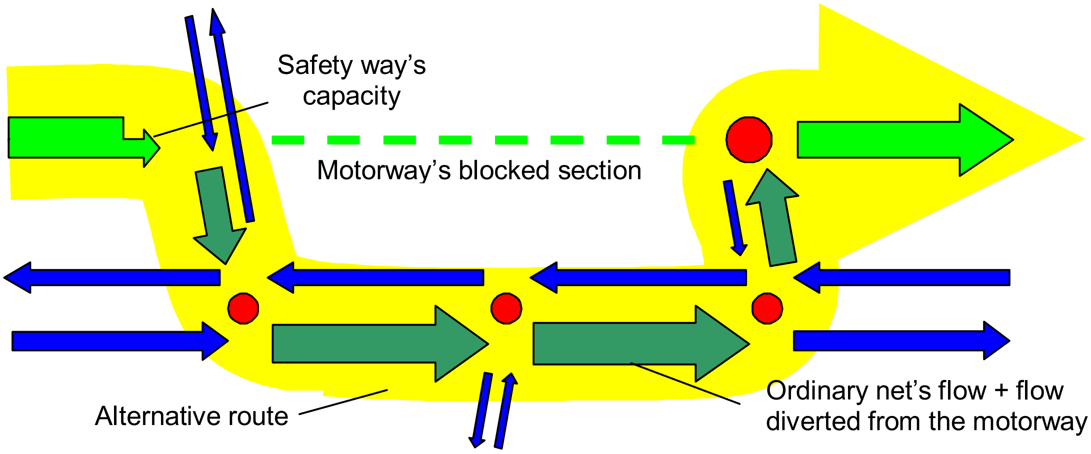

Figure 6: Network flows after the safety way's opening: the freeway traffic is transferred to the alternative route

Network Performances' Calculation
Once the traffic volumes are defined, ordinary traffic engineering methods can be applied to the different parts of the road network (sections and knots) that experience the effects of the safety way's opening.

The methods for the traffic quality assessment in uninterrupted flow conditions can be applied to the road sections, if they are of a sufficient length. The results are expressed in terms of mean travel speed for the considered section (from which we derive the Level Of Service), depending on the traffic volume and the geometry of the road.

For the knots, suitable procedures for the typology of specific intersection should be employed. If necessary, the intersection's rules can be modified, with police's assistance. In fact it can be argued that the stream coming from the freeway must be given priority, even though this rule is not applied to all roads that are part of the alternative route. The procedures for the appraisal of the quality of circulation of the intersections consider the geometric layout, the traffic regulations concerning junctions, as well as the volumes of traffic to estimate the capacity and then the delays affecting each manoeuvre.

By using the abovementioned methods, the designer can determine travelling times and delays, carrying out a "with/without safety way" comparison. This question will be dealt with in the next paragraph.

By iteration of these calculations, it is also possible to determine the maximum flow leaving the freeway that can be endured by the ordinary road network, without causing excessive congestion.

Considering the performance of the whole system, what should not be overlooked - alongside the possible delays in the ordinary road network - are the delays caused to freeway's users by the queues that might take place on the freeway upstream the safety way.

Operational Conditions' Check
Needless to say, it is of central importance that it be ascertained whether the opening of the safety way to the freeway traffic actually attains the desired goal,. The assessment of the safety way's functioning will be determined through the comparison between fixed threshold values of opportune parameters.

A control parameter could be the total travelling time of the detour, with a minimum length of 100 km. If the figure is lower than a specific value, corresponding to a speed which is considered acceptable, then the traffic diversion is a viable option. Otherwise, it is not worthwhile.

Another possible parameter is the Level Of Service. If for any traffic stream the LOS is too low, the measure will be judged negatively. Such a criterion proves difficult to apply, because of the complexity of including in a synthetic index such as the LOS the operational conditions of different elements like sections with uninterrupted flow and intersections.

A more accurate evaluative methodology is the cost-benefit analysis, which entails the calculation of the costs of the delays experienced by all drivers, including those on the ordinary roads used for the detour. On the plus side are delay reductions for the freeway's users, who can by-pass the block instead of waiting until its cause is removed. A balance between these delays - on the one hand imposed, on the other hand reduced - eventually keeping into account different categories of users (given that for some categories time is more precious than for other), leads to a rational assessment of the opportunity to open or not a safety way, depending on the traffic conditions on the road network.

The presence of an already existent overpass is a generally good requirement for placing safety ways. This because it permits to realise two safety ways in the same location, one per carriageway. In fact, independently of the stopped carriageway, vehicles could be turned in both directions of the crossing road using the overpass, as shown in Figure 2.

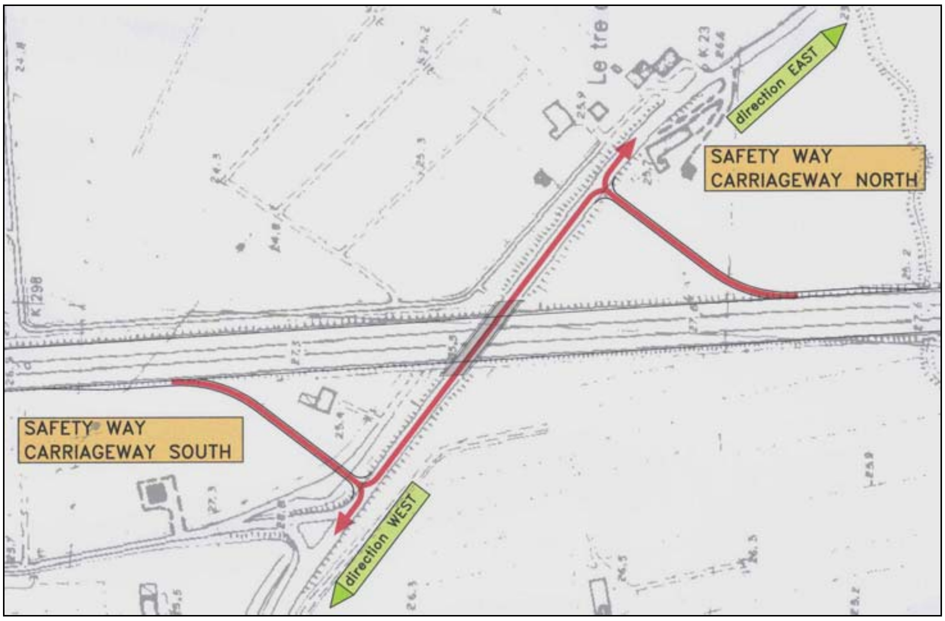

Figure 2: Example of safety ways in correspondence of a flyover

Finally, it is important to consider the presence along the freeway of particular and dangerous sections, like steep slopes, where heavy vehicles are driving slow and collisions are likely to occur, or sharp curves, where vehicles may skid. Accidents are not rare in such places, and therefore a safety way would be very effective and solve in many cases potential congestion situations.

CONSIDERATIONS ON THE SAFETY WAY'S FUNCTIONING

As explained in the previous chapter, the more general evaluation of the safety way's efficiency consists of a cost-benefit analysis. For a given traffic situation, the safety way's opening effects are cross-checked by comparing costs and benefits of two scenarios: the present scenario in which the roadway is blocked but no safety ways are in place and a virtual scenario in which safety ways are operative . If the benefits are greater than the costs, the measure is judged effective and the safety way's opening leads to an improvement of the whole circulation conditions.

The generalized benefits - i.e. the difference benefits-costs - can also be seen as a function of the traffic volume diverted through the safety way from the freeway to the ordinary road network. In this case, it is theoretically possible to maximize the positive effects of the safety way's use by controlling the flow rate that leaves the blocked infrastructure.

Diagrams of benefit vs. safety way flow can show three different scenarios (Figure 7).

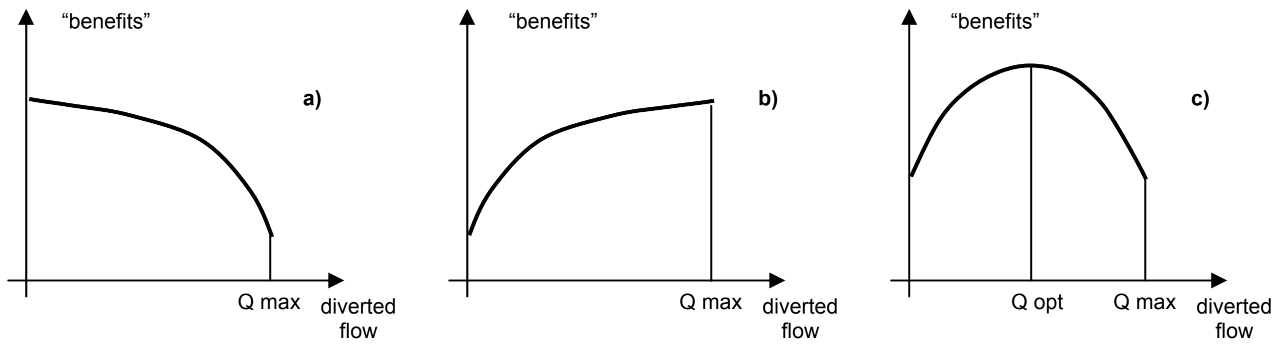

Figure 7: Possible "benefits" vs. safety way's flow diagrams

The first case (a) shows decreasing benefits as the flow increases. This situation reflects a rather busy road network, in which a traffic increase leads to a worse congestion than that of a scenario without safety ways.

On the contrary, case b) is typical of an essentially clear ordinary road network: the diverted freeway traffic does not cause congestion, and benefits grow together with the volume of traffic employing the safety way, whose use is thus advisable.

Case c) is an intermediary one. The detour towards ordinary roads leads to an improvement of the overall traffic conditions. However, if the flow is greater than the value Q_{opt}, its effect becomes negative, with an increasing congestion that reduces the benefits. Ramp metering can control such a situation. A control device - a simple traffic signal - is placed on the safety way and operated so as to give way to a more suitable rate of traffic, i.e. the rate Q_{opt} that optimizes the system's functioning.

Such a deep analysis can be hardly carried out when deciding the opportunity to open the safety way. However, the definition of these qualitative cases can lead to some general considerations. The safety way must not be opened in case of already saturated road network (as in the case a) of Figure 7). Its opening would have negative overall effects, with increased delays for all the users. Therefore, safety ways do not represent a solution in case of traffic peaks involving the whole road network, such as happens during holiday periods, or winter week-ends. The typical use of the safety ways will be for emergency events occurring on the freeway, such as accidents or other problems, not specifically related to high traffic levels.

Thus, the opening of the safety ways remains an exceptional event, occurring only in cases of real emergency. A criterion to establish the necessity to consider the opening of the safety way could consist of analysing the speed of the traffic, as shown in Figure 8. With normal traffic, a vehicle can cover 100 km in about 1 hour. If traffic is growing, the speed of the vehicles decreases, and the distance covered in the same time is strongly reduced.

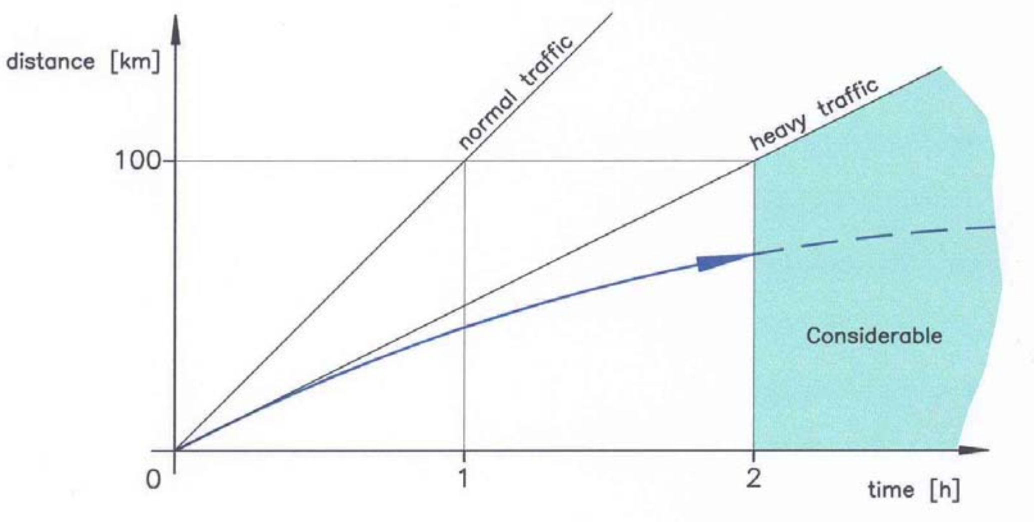

Figure 8: Example of distance covered by a vehicle on the freeway versus time. The blue region of the figure indicates where the opening of a safety way can be considered

The freeway managers will consider the possibility to open the safety ways when driving 100 km will take more than a Time Limit, for example 2 hours (blue curve on the Figure). Anyway, this Time Limit cannot be considered as an invariable. It depends on many parameters:

Time Limit = **f** (traffic typology, seasonal period, day or night, atmospheric conditions, working days or holidays, ...)

Moreover, it is not only the distance covered within a certain time that should be considered, but also changes over time. The shorter the distance measured in equal subsequent time-spans, the higher the emergency level for opening the safety way. As stated above, the final decision must consider the whole road net conditions. However, this criterion permits to pick out the crisis phenomena on the freeway, when the opening of the safety way could improve the traffic performance.

CONCLUSIONS

The freeway's efficiency becomes more and more fundamental, due to the continuous traffic growth on the European road network. Therefore, the Brenner Freeway has planned the building of safety ways between the existing toll stations, allowing the traffic diversion in case of blocks, mainly caused by accidents. In the paper both geometrical features and operational issues have been discussed. This has led to the definition of some basic requirements for such an element: its lay-out should be similar to the ordinary freeway slip roads; roads and intersections involved in the detours should be adequate, in terms of both size and capacity; the effects of the traffic flows diverted on the ordinary road network must be carefully considered. Taking into account these effects, together with the reduced delays for the otherwise blocked freeway's drivers, will lead to a rational decision about whether to open or not the safety way during a specific crisis phase.

REFERENCES

[1] European Commission (2003) – *EU energy and Transport in Figures: Statistical pocketbook 2003* – EU
[2] G. Luza, W. Hufnagel, H. Reiter – Die FLY Over-Rampe – Dilatationstausch unter Aufrechterhaltung des Verkehrs – Bauingenieur, Band 76, Dezember 2001
[3] Transportation Research Board (2001) – Highway Capacity Manual 2000 – Washington.