COST-BENEFIT ANALYSIS OF TEMPORARY HARD SHOULDER RUNNING IN AUSTRIA

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ABSTRACT

The national Austrian motorway operator Asfinag is considering toinstall temporary shoulder lane usage on a motorway as already done in the Netherlands, Germany and the UK. This paper presents the methodology and results of a recent cost-benefit study for a two-lane motorway including two interchanges and two exits/entrances. The cost of reinforcement of shoulders, widening ramp ingress and egress, setting up emergency refugee areas, extending the existing dynamic speed control system and installing a surveillance system is being compared with the benefit of improving the service level and its impact on safety. The benefit is justified by decreasing travel times, improving traffic flow reliability and reducing traffic emissions. Numerical analysis of microscopic traffic flow simulation indicate that the cost of temporary shoulder running can be justified if current volumes will increase by 5% to 25% during peak periods. Forecasts on the safety impact rely on observed data at German motorways with marginal decrease of accident rates due to speed harmonization as speeds will be reduced from 130 km/h to 100 km/h. The shoulder lane use has to be extended through interchanges as congestion will build up. Otherwise only the origin of bottlenecks will move. While these figures are site dependent, the general approach and methodology is transferrable.

1. SHOULDER LANE USAGE TO RELIEVE CONGESTION

In several countries hard shoulder lanes on motorways are temporarily opened during periods of high demand to increase capacity. In Germany, the Netherlands and the UK temporary shoulder lane usage is part of national Active Traffic Management schemes. However, the implementation of such schemes varies with respect to legal restrictions, design guidelines and operational requirements. This paper is intended to provide some methodological insight in evaluating such schemes as very little is published in English about this topic.

1.1. Active Traffic Management

In response to growing demand of traffic on motorways many countries have an overall strategy to approach congestion management. Besides adding new roads and widening existing roads several measures are taken to relieve congestion. For example the state of Hessen in Germany established a motorway operation program with a strategy management. The strategy includes a) dynamic speed operation, b) dynamic lane allocation, c) incident management, d) network optimization, e) dynamic traffic information and f) construction site management. Within the pro-active system the impact of these strategies is continuously evaluated using traffic simulation and benchmarked by a comprehensive traffic data management system [9]. Speed harmonization and hazard warning by variable message signs are quite common on European motorways, while flexible usage of the given road space is not applied as general.

1.2. Temporary shoulder lane usage in Europe

In order to relieve congestion the shoulder is made available on several motorways in Europe for travel use rather than for emergency refuge only. Depending on national conventions this is either called *Temporary Hard Shoulder Running* or *Temporary Shoulder Use*. We will stick to the first terminology in accordance with US-terminology [11]. The usage of the hard shoulder by regular traffic movements contradicts legally with most national traffic regulations. In Austria the StVO §2, 6a (road traffic regulation act) defines the shoulder as a paved area next to the road, which is either available for broken vehicles to be left temporarily or for emergency vehicles. Therefore, road safety organizations warn that opening shoulder lanes for through traffic will make motorways more dangerous. Nevertheless, in Germany in the late 1990´s, some shoulders were temporarily opened for general purpose traffic during peak periods. A dedicated sign operated as VMS as in figure 1 has been introduced in 2002. The shoulder lane running is accompanied by a speed limit indicated by VMS as well. Some German states like Bavaria also impose restrictions on trucks to pass while the hard shoulder running is under operation. For safety reasons the shoulder operation has to be verified by a visual inspection to ensure the affected shoulder is clear of stalled vehicles. The verification is usually done by strategically distributed CCTV-cameras. Lembke [7] investigated accident rates and accident severity in 3 year before-and-after studies. If geometrical design and operation is done according to the new German recommendations safety will improve on the links but additional risks occur at the entries and exits. Therefore the weaving sections require particular attention to eliminate accidents during lane changes. In an investigation on different motorways Geistefeldt [4] affirmed little changes in accident rates on the motorway section under operation but reductions in accident rates upstream of the section. While the safety impact is vague, the capacity is increased greatly without the same investment cost of adding a new lane. Therefore, over 200 km of the German motorway network are already operated with temporary hard shoulder running (table 1).

Figure 1 - 3-lane plus shoulder opened with Variable Message Signs near Munich, Germany


Figure 2 - 2-lane plus shoulder closed in the Netherlands;Source: Rijkswaterstaat

In 2003 the Road Administration in the Netherlands implemented temporary hard shoulder running as part of a larger program to improve use of the existing infrastructure [3]. The ministry Rijkswaterstaat faces two traffic-related core tasks – ensure save and unimpeded movement of traffic and construct, maintain and operate major roads in the Netherlands.

Traffic operation is improved by monitoring and trying to control mode, route and lane choice. Managing lanes is one option of tackling commuter traffic which is an increasing problem in a densely populated country like the Netherlands. During rush hours the shoulder lane is available for through traffic at a reduced speed. The system is operated by time-of-day and not traffic actuated as in Germany. Due to rigid speed limits during operation and capacity increase, incidents as well as accidents have been reduced and temporary hard shoulder running is well accepted on Dutch motorways.

In 2006 the shoulder lane of the M42 near Birmingham was made available for through traffic on a 17 km segment, if volume exceeds thresholds and speed drops under a minimum. This is part of a nationwide initiative to manage congestion on critical parts of the motorway network. Special attention has been given to safety issues. Therefore dedicated refuge areas have been installed including emergency call boxes. The speed is limited to 50 to 60 mph during operation. It is not allowed to continue on the shoulder across entrances. Currently only one additional motorway (M6) is operated with temporary hard shoulder running but the Department of Transport is planning for more than 200 km [10]. The plans include also sections which were previously envisaged to be widened with additional lanes.

Table 1 - Applications of hard shoulder running in Europe
Figures from personal interviews in 2009

Country	Motorway network in [km]	Hard shoulder running in [km]
Germany	12,700	210
Netherlands	2,360	225
England	3,500	28

1.3. Capacity analysis of current installations

Capacity increase is the main purpose of temporary hard shoulder running. All reports on capacity analysis of existing systems prove capacity increases, however at very different levels. Table 2 illustrates findings by different studies.

Table 2 - Increase in capacity due to temporary hard shoulder running

Motorway	**Location**	**Lanes**	**Capacity without**	**Capacity with shoulder**	**Capacity increase**
A4	Cologne (Ger)	2	4.300	5.200	21%
A1	Hamburg (Ger)	3	6.110	6.680	9%
A94	Munich (Ger)	2	4.080	5.100	25%
A99	Munich (Ger)	3	5.500	7.000	27%
A3	Offenbach (Ger)	3	5900	8000 - 8500	
A5	Bad Homburg (Ger)	3	6.700	8.100	21%
M42	Birmingham (UK)	3	6.045	6.610	9%

In most cases in Germany more than 20% increase were measured using a stochastic capacity analysis method. In Hamburg the increase is lower since only figures of measured maximum volumes were provided. The true capacity of 3 lanes plus shoulder may be higher but was not observed. The M42 in the UK has a lower increase in capacity due to different operation. Since the hard shoulder running stops at each entrance vehicles on the shoulder have either to exit or change to regular lanes which about halves the capacity increase.

2. ITEMS TO BE CONSIDERED WHEN SHOULDER RUNNING IS INTRODUCED

If temporary hard shoulder running will be introduced in a country, a number of issues have to be considered.. First the appropriate laws have to be checked and adjusted to allow hard shoulder running. Second the geometrical design specifications for shoulders have to be adjusted to cope with temporary running. Third it has to be checked that structural regulations fit with the additional loads on shoulders imposed by running traffic. Furthermore operational issues will be addressed in this chapter. In this paper we will take Austria as an example. The same issues have to be addressed if another country may consider the introduction of hard shoulder lane running.

2.1. Legal issues

By law (StVO §46) it is not allowed to drive on the hard shoulder of a motorway unless the vehicle belongs to road maintenance or rescue services. In case of emergency or broken vehicles the shoulder can be used for deceleration and acceleration only. Furthermore §9 prohibits to pass solid lane markings. Since a solid line divides the shoulder from the remaining lanes, a dedicated sign 223 was introduced in the German road regulations (STVO §41,9). If sign 223.1 or 3 is active (Figure 3), it is allowed to cross the solid line of the shoulder lane. Sign 223.1 also regulates to continue a trip on the shoulder lane.

Figure 3 – sign 223.1 allows shoulder lane usage, 223.2 no use of shoulder and 223.3 leave shoulder

According to the EU Directive 85/337/EEC an assessment of the effects of certain public projects on the environment (EIA) have to be made. This regulation applies in the case of adding new lanes to motorways but should not apply to a different usage of an already existing road space. This is one good reason to favour temporary hard shoulder running in case of urgent remedial measures since EIA´s may take years.

Shoulders on motorways serve broken vehicles and provide roadspace for emergency vehicles in case of congestion. If the shoulder lane is also blocked by queued vehicles, a rescue alley has to be guaranteed so that emergency vehicles have enough space to reach their site of operation. This alley is recently required by the road regulation act in the middle between two lanes or between lane 2 and 3 on 3 lane motorways.

2.2. Geometrical design of hard shoulder running

In Austria there are some motorway sections without a permanent shoulder lane with rescue areas every 2 km at the latest. This maximum distance is not appropriate in dense traffic during the operation of the hard shoulder running. Since no space is available for broken vehicles to stop safely rescue areas should be provided with closer spacing. Table 3 illustrates some examples. The shoulder lane has to have a minimum width which is equivalent to the regular lane width on motorways. A minimum of 3,50 m is recommended since the lane will be used by trucks in particular. Sight distances have to be checked, especially in case of noise barriers in right corners.

Table 3 - Design and operational characteristics of existing installations

	Distance between refuge areas	Shoulder width	Speed limit during operation.	No overtake for trucks during operation	Activation condition of shoulder operation
Bavaria 3 lane (Ger)	500 – 1.000m	3,50m	100 km/h or 120 km/h	yes	5.500 pcu/h or v > 95 km/h and 70 veh/km
Hessen 3-lane (Ger)	About 1.000m	min 3,25m, planned 3,50m	120 km/h	yes	5.500 pcu/h
L. Saxony 2-lane (Ger)	500 – 1.000m	3,50m	100 km/h	no	3.300 pcu/h
Utrecht 2-lane (NL)	Max 1.000m	Min 3,25m, mostly 3,50m	100 km/h	yes	3.000 – 3.600 pcu/h
Birmingham 3-lane (UK)	about 500m	3,30 to 3,70m	96,6 km/h (= 60 mph)	no	4.500 pcu/h

The design of exits and entrances is the most critical part. If the capacity of the through traffic has to be increased rather than the segments between entrances, the shoulder lane should be extended past the exits and entrances. Continuous running requires adaptations of the weaving sections at on- and off-ramp.

Figure 4 – interrupted (left) and continuous (middle) shoulder running marked green on a 3-lane motorway and a continuous shoulder running on a 2-lane motorway (right) on A7 in Lower Saxony; photo provided by Landesbehörde für Straßenbau und Verkehr, Niedersachsen Germany

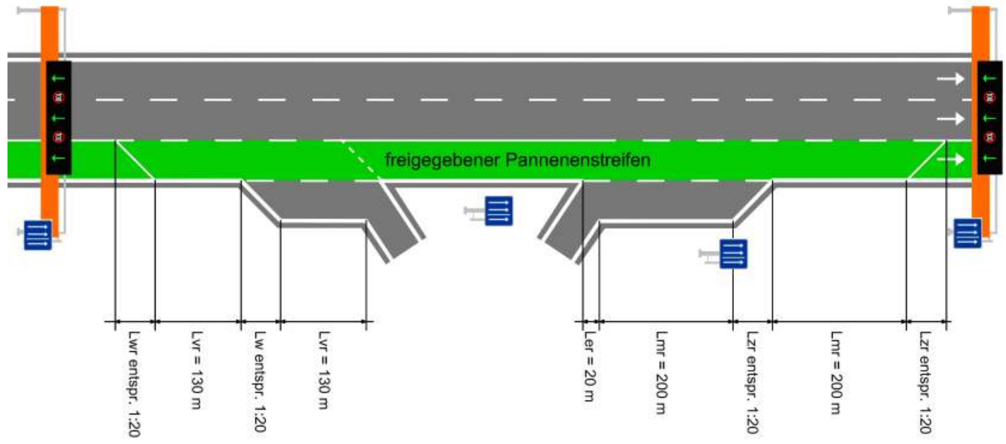

Figure 5 – length of weaving sections for deceleration and acceleration with continuous shoulder running

2.3. Structural issues of hard shoulder running

The bearing capacity of the shoulder should be identical to the major road. This is the case on most Austrian motorways. If the bearing capacity of the shoulder is lower, substructure and pavement have to be increased in case of hard shoulder running due to trucks with high axle loads.

There must be a continuous crossfall between regular road and shoulder without a buckling. Furthermore drainage of the shoulder has to be guaranteed. If the crossfall is changed the drainage has to be checked again.

2.4. Operational issues

Most temporary hard shoulder runnings in Europe are operated in a semi-automated mode. The hard shoulder is operated only if traffic demand requires additional road space. A threshold of traffic volume is marked by radar or inductive loop detectors. An operator in a traffic control centre is alarmed by exceeding thresholds. He then checks the clearance of the shoulder usually by looking at Closed Circuit TV cameras. A system of multiple surveillance cameras are mounted so that the total length of the shoulder lane can be observed by zooming, panning and tilting. Since automatic incident detection via image processing and pattern recognition is not yet mature, manual checking is still required before activating hard shoulder running. More sophisticated algorithms as in Bavaria provide thresholds for activation based on a combination of volume, density, speed and truck ratios.

If hard shoulder running is activated the speed should be limited to 100 km/h or even lower. The main purpose of hard shoulder running is to increase capacity. This is in accordance with common guidelines as the maximum capacity can be observed between 70 and 90 km/h depending on location and driving behaviour.

There is no common view on limiting truck overtaking under hard shoulder running. If truck rates are very high it is not advisable to keep trucks on a single lane, but truck overtaking usually interrupts speed harmonization needed to increase capacity. Therefore individual studies should be made to define the maximum capacity either with or without trucks overtaking.

The signalling should be done by VMS. The dedicated sign - shoulder running activated – should be placed right and left at the gantries supplemented by dynamic speed limits via lane specific VMS-signs as seen in figure 1. If the shoulder lane is blocked, the lane assignment should indicate the blockage as in figure 2.

Road maintenance becomes more difficult in case of hard shoulder running. First maintenance should be done at low traffic volumes during periods of no operation. Secondly winter maintenance will require additional effort as snow and ice has to be removed from the shoulders. This is a problem on some Austrian motorways as noise barriers block space needed to store the snow.

3. CASE STUDY ON A4 NEAR VIENNA

3.1. Site description

There are some 2-lane motorway sections in Austria which should be upgraded to 3-lanes due to increased travel demand. However budget restrictions and constraints by the environmental impact assessment make hard shoulder running a viable option. One of the most appropriate sections will be on the A4 between the south-east side of Vienna and the airport in Schwechat. This is a section of about 7 km between the motorway interchange Prater and the interchange Schwechat with two entrances in between (Alt Simmering and Simmeringer Heide). The A4 has lately been equipped with a full surveillance system including cameras, traffic sensors, dynamic speed signalling and a sufficient number of gantries.

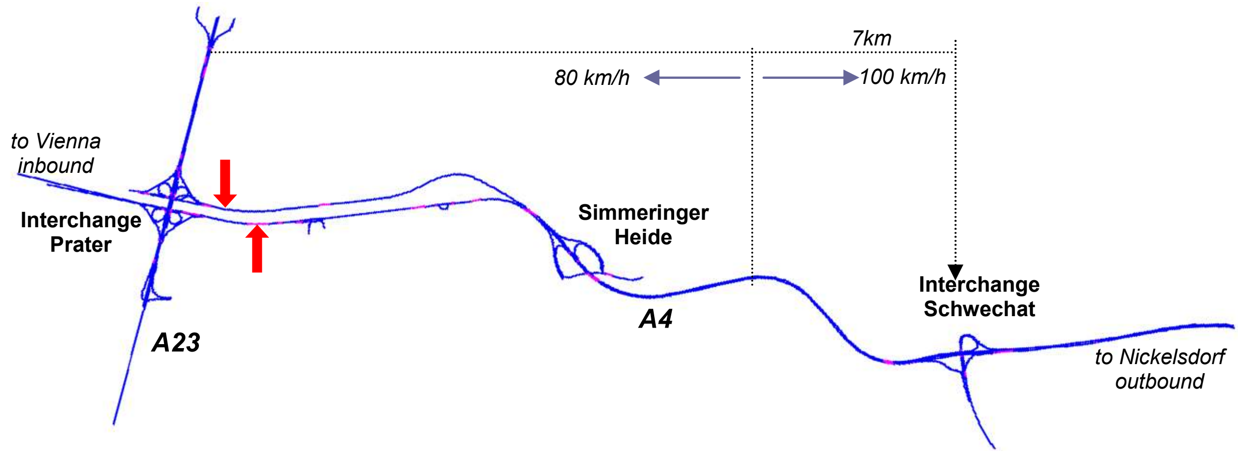

Figure 6 – motorway A4 with 7 km hard shoulder running; measurement points of figure 9 marked in red

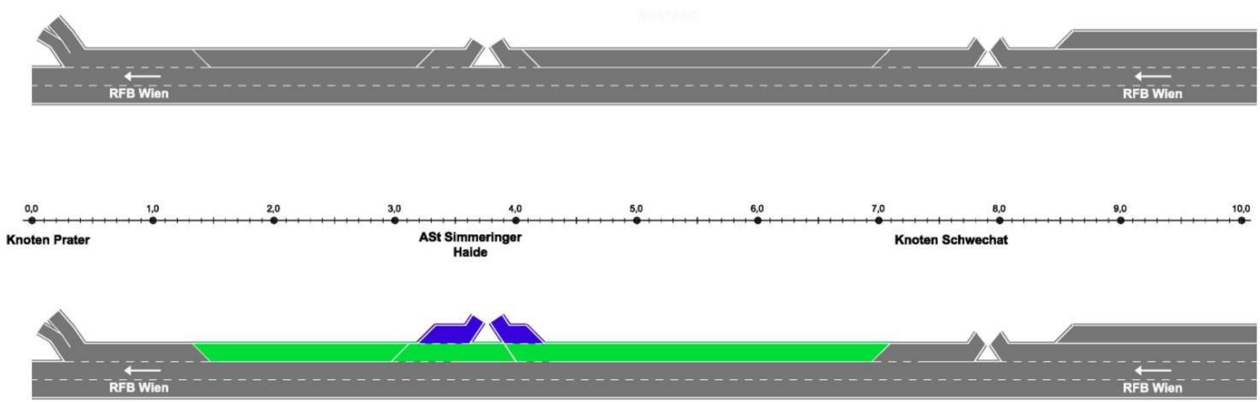

Figure 7 – A4 inbound (towards Vienna) with current situation top and hard shoulder running (bottom) marked in green; blue parts indicate extensions to the ramps with new weaving sections

The hard shoulder running has to be installed on a 5.8 km segment inbound between the merge at Schwechat and the Prater interchange (figure 7). There are already three lanes available upstream. There is no extension needed downstream as many vehicles divert on the two lane ramp interchange at one of Austria´s busiest interchange A4/A23 at Prater. The merge is currently operated from 2 lane with a 900 m long 3 lane diversion zone to two times 2-lanes. By having continuously 3 lanes before the diversion vehicles can select the suitable lane at an earlier stage which will relieve congestion due to extensive lane changes. The exit and entrance ramps at Simmeringer Heide have to be rebuilt since the deceleration lane of about 200 m and the acceleration lane of about 300 m have to be added outside of the existing shoulder lane section. The bearing of the shoulder lane is sufficient for continuous usage by cars and trucks as well, so that the overall additional construction measures are minor.

The shoulder running on the outbound section is slightly longer (6,2 km as in figure 8). Also more construction is required as two entrances and exits have to be rebuilt.

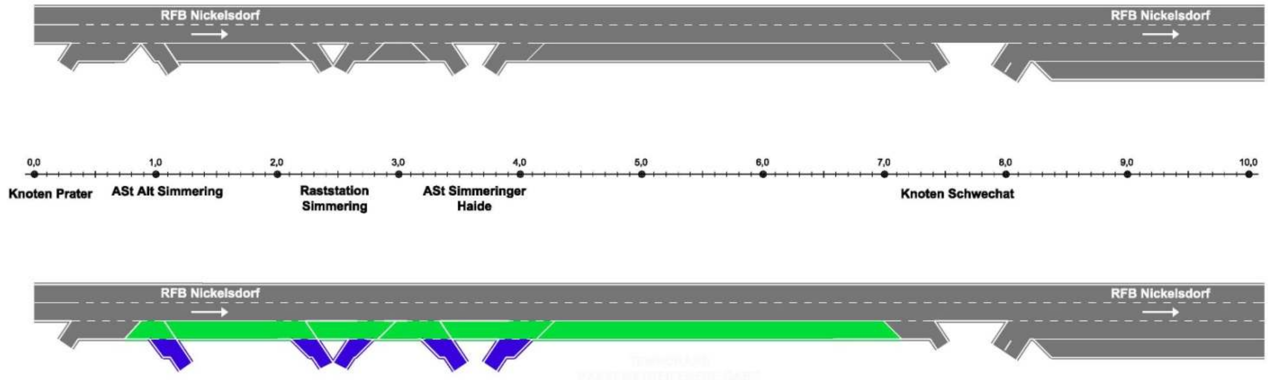

Figure 8 – A4 outbound (towards Nickelsdorf/Schwechat) with current situation top and hard shoulder running (bottom); blue parts indicate extensive extensions to the ramps

3.2. Volumes

On Friday afternoons an average hourly peak volume of 4.270 vehicles has been measured (figure 9). These hourly measurements were taken over a period of three months with an average truck rate of 7%. The afternoon Friday peaks exceed by far the capacity thresholds for 2-lane motorways according to design standards. The German guideline HBS, which is applicable in Austria, states a design volume of 3.800 veh/h on level 2-lane motorways located in metropolitan areas. With respect to the design guidelines Austrian car drivers can apparently manoeuvre at higher flow rates and densities remaining an average speed of about 80 to 90 km/h. This statement is in line with measurements taken on other sections of the Asfinag motorway network.

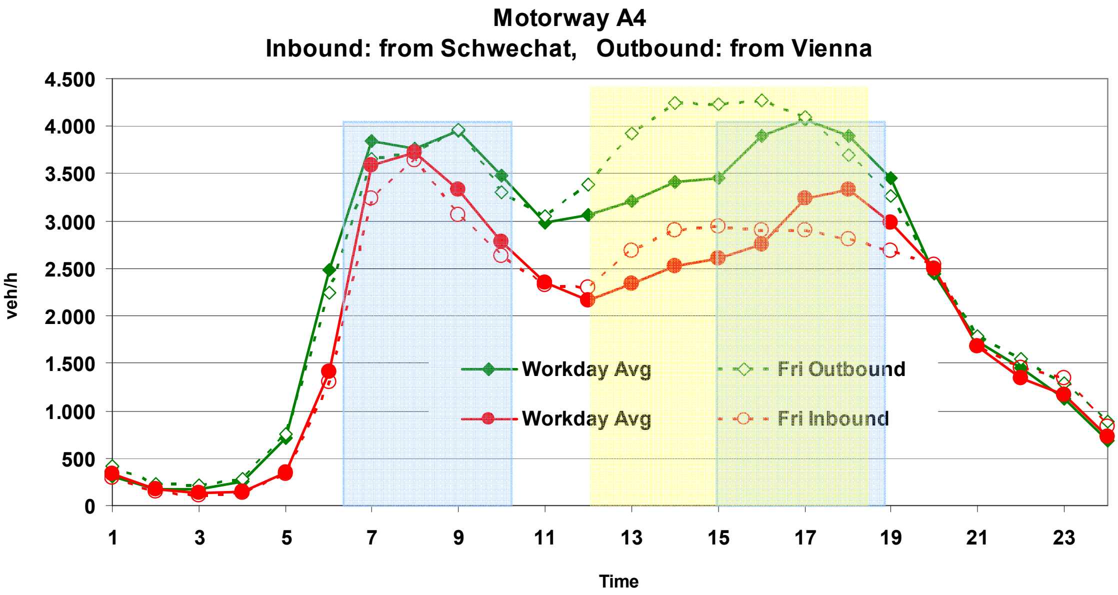

Figure 9 – traffic volumes on A4 as average over all working days (Mon-Fri) and Friday only; Periods of hard shoulder running are shaded in blue resp. yellow

Currently the section A4 is not facing congestion frequently. However, the metropolitan area of Vienna and the region next to the airport are growing and traffic demand is expected to increase as well. Recent time-series and growth rate projection indicate an increase of about 10 % in car and truck traffic over the next 5 years. This increase in traffic will not be manageable on a two lane motorway anymore. Especially the outbound direction to Schwechat and Nickelsdorf needs some measures to increase capacity for future traffic demand.

3.3. Flexible lane usage

Temporary hard shoulder running will increase capacity during periods of high demand. Traffic flow analysis identifies the appropriate thresholds to switch from 2-lane to 3-lane operation including hard shoulder operation. As indicated in the volume-speed chart of figure 10 the speeds will drop sharply if the volume exceeds 3.300 veh/h on a 2 lane motorway (blue measurements). At higher volumes the hard shoulder running with a total of 3 lanes is preferable with respect to harmonized speed levels and capacity. Figure 10 illustrates in red 3 lanes with 100 km/h speed limit although the A4 is partially operated with 80 km/h due to noise considerations. The volumes presented are based on 1-min volume counts which are substantially higher than 60 min averages. Maximum volumes of 4.400 veh/h on 2 lanes and 6.500 veh/h on 3 lanes are observed based on 1-min counts. Such high volumes require steady driving conditions with experienced drivers as being observed with experienced commuters knowing the site. The values are based on a 7% truck rate and a motorway without gradient.

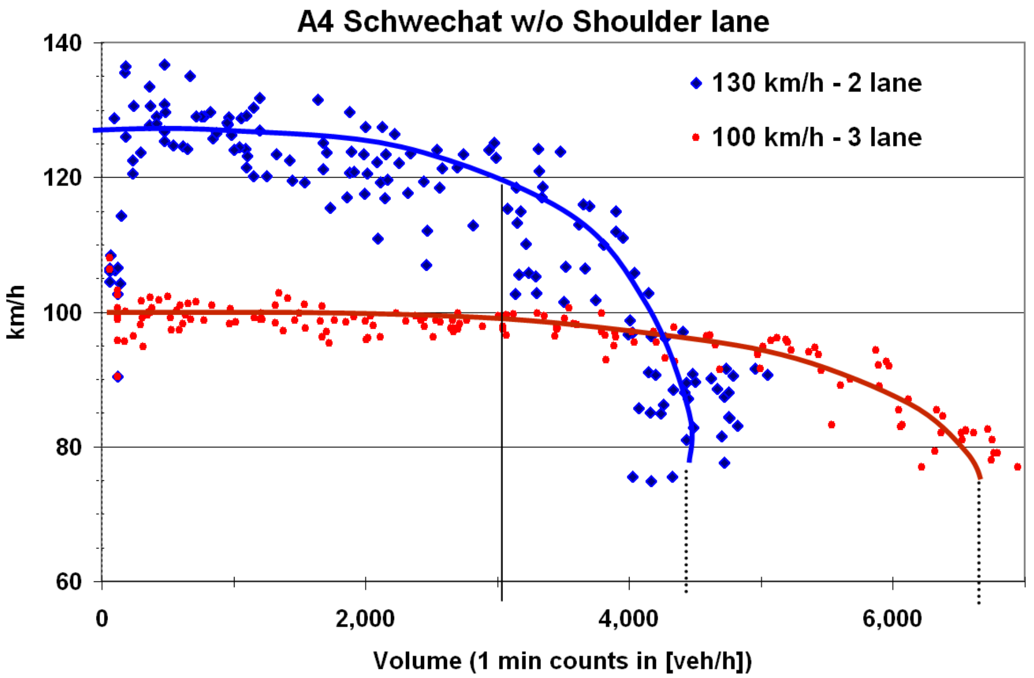

Figure 10 – Volume-Speed-Relationship for 2-lane standard and 3–lane hard shoulder running on A4 outbound (southbound)

In the volume profile (figure 9) the hard shoulder running should be operated for about four hours in the morning and about three hours in the afternoon. On Friday early afternoons this operation may be extended to five hours depending on volumes as indicated by the blue and yellow shaded time periods. A hysteresis loop with a threshold of 3.300 veh/h is taken to activate and 3.100 veh/h to deactivate hard shoulder running. One should add a minimum of 15 min for either type of operation as additional constraint. Hysteresis type of control and the constraints limit fluctuations between both operations.

The volume-speed relationship of figure 10 summarizes the principle of hard shoulder running quite well. Temporary addition of a shoulder lane allows congested roadways to have higher throughput at reduced speeds. However, the key to hard shoulder running is that the segment must extend through the roadway bottleneck [3].

3.4. Simulation study

The following studies are based on microscopic traffic flow simulation using Vissim [8].The network has been extended on both sides of the hard shoulder running in order to model potential queuing beyond the interchanges at Prater and Schwechat. The total network contains a length of 12 km.

The model has been calibrated using field data with particular emphasis of modelling merging zones [2]. If the number of downstream lanes is less than the sum of the upstream main lane and the lanes of the entrance ramp, vehicles have to merge and change lanes. In case of heavy traffic many drivers on the main lane are co-operative leaving gaps for single vehicles to merge. As this behaviour is rarely seen in micro simulation, a double cross setup of priority rules had been implemented giving priority first to the main motorway lane and second to vehicles trying to change lanes at the end of the acceleration lane. This gives an auxiliary chance for slow vehicles to change lanes at the very end of the ramp.

For reasons of the environment and noise the A4 has a rigid speed limit as marked in figure 6. The maximum speed is set to 80 km/h in the vicinity of the interchange Prater. Further towards Schwechat 100 km/h is currently mandated.

Separate simulation runs were carried out for the morning period (6am – 10am) and the afternoon period (3pm – 7pm) for average working days with volumes presented in figure 9. Since Friday afternoon traffic out of Vienna differs greatly from the other afternoons, the outbound traffic for Fridays had been modelled as a separate scenario for a peak period from 1pm to 5pm. The simulated volumes taken at the two measurement points marked red in figure 6 were matched with the counts. Path flows were used to receive realistic flow distributions across the interchanges. During the two peak periods a constant truck rate of 7 % was used. The simulation study was carried out for an average weekday.

Numerous simulation runs were carried out by changing the volumes. For both directions the flows were gradually increased in steps of 5% up to an increase of 25%. For each run two data sets were collected:

1. Segment analysis: the simulated links were divided in segments of 50m length and for each minute volume, average speed and density was recorded
2. Individual travel times were recorded between the two main interchanges Prater and Schwechat for each run

A graphical display of the segment analysis (contour plot) is an ideal form to present dynamic processes in a two-dimensional way. On the x-axis the time is shown, while the y-axis depicts the space. The average velocity per minute is colour coded classified by intervals of 20 km/h. Figure 11 illustrates a dramatic increase in congestion, if traffic demand will increase by 20%. Beginning from the entrance at Simmeringer Heide congestion starts at 07.10 pm and will last for about 2 hours. A shock wave will propagate up to the interchange Schwechat. There will be dense traffic - speeds around 60 km/h – between Prater and Simmeringer Heide. By introducing hard shoulder running traffic will travel with speeds close to the speed limit. Some distraction with slow-downs occur only during lane change next to the interchange Prater.

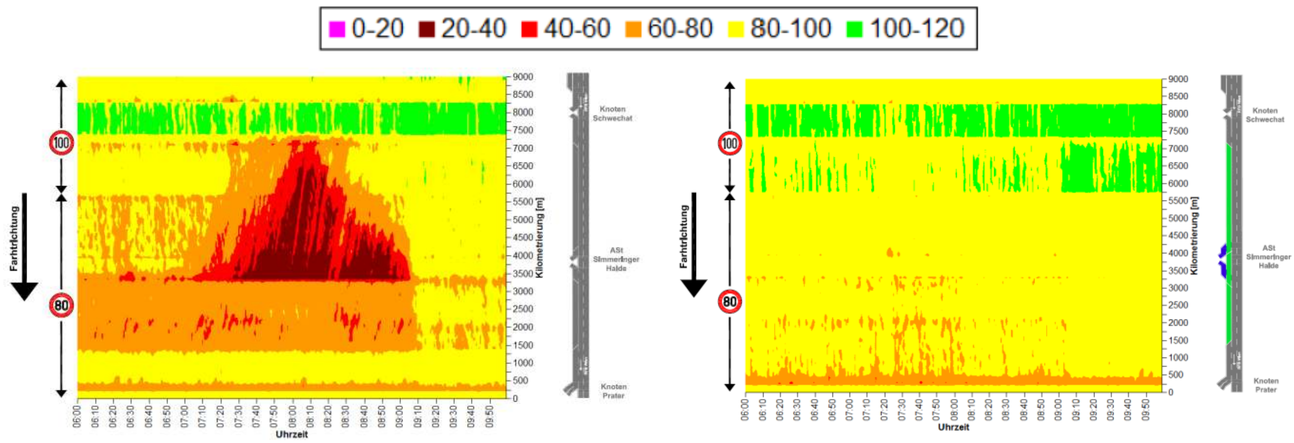

Figure 11 – Inbound traffic flow without (left) and with shoulder running (right) if demand increases by 20%; colour identifies the average speed at the particular 50 m segment and 1 min time period

4. COST-BENEFIT ANALYSIS

4.1. Methodology

The method presented in [1] takes all benefits related to hard shoulder running and compares these with the additional costs implied by the new operation. The benefits are calculated by taking indicators for the base case and the hard shoulder running case. Each indicator is valued by a price using price unit factors. The total value of all benefits is compared with the total cost.

The investment costs contain the effort for constructing additional ramp sections, refuge areas, gantries and reinforcing the shoulders. Signing and additional electrical equipment will add another one-third to the investment cost. The total investment cost is assigned to the economic life time of the system using a constant capital recovery factor. The annual depreciation of the system is usually the biggest cost factor. Furthermore, operation of such a system will produce annual costs such as energy and maintenance for additional Variable Message Signs and additional effort for winter service and road maintenance.

Indicators to quantify the benefit are:

- Travel Cost is calculated by taking the total travel time of the total demand and multiply it by the value of time
- For safety the cost of accidents involving fatalities and injuries are taken; accidents with vehicle damage only are not considered. Travel times for each time period
- Cost of fuel savings by harmonizing traffic flow
- Cost savings by less toxic pollutants as emissions are calculated for each traffic state (free, heavy, dense, congested) based on [6]
- Cost savings by positive effects on climate change; these costs are calculated separately from the fuel cost savings

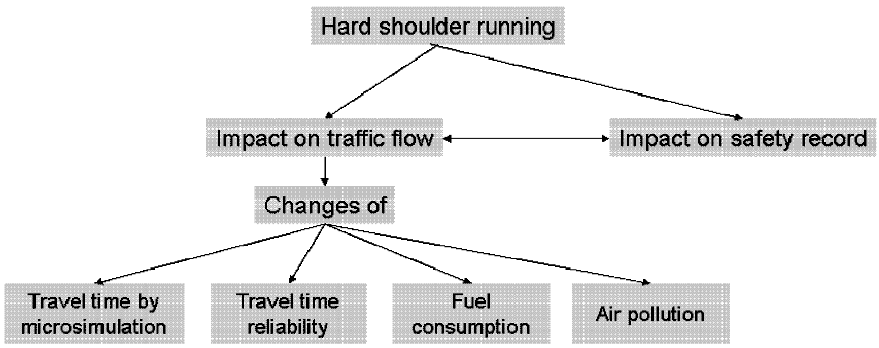

Figure 12 – Impacts of hard shoulder running based on [1]

While in [1] look-up tables are proposed to calculate travel time savings, micro simulation is taken in this study. Since the travel time impact is by far the most important factor justifying the need of hard shoulder running, the cost and travel time calculation should be done very carefully. Arnold [1] prepared volume-speed relationships for a set of different road types with and without refuge areas. His tables are based on measured sites. However specific configurations at motorway interchanges are not considered in look-up-tables which must be generally applicable. In this study we calculate the travel time of each vehicle within each period of 4 hours and multiply the delay with the appropriate travel cost according to table 4. Delay is defined as the observed travel time minus travel time if vehicles could travel with their desired speed not being influenced by other vehicles.

Table 4 - Value of time for different trip purposes based on RVS 02.01.22 (Austria FSV)

Trip purpose	Value of time [€/hour]	Rate of person trips with this activity on A4
Business trip	28,00	13%
Commuter trip	10,00	30%
Private activities (Leisure, eduction, shopping, …)	7,50	57%
Freight transport	25,00 [€/truck]	

The travel time reliability can be accounted for by taking the overall travel time and considering the variation in travel time as well. The variation is measured in the box plots using the 25 and 75% quantils. In the final calculation a certified measure was not agreed on as research on reliability of transport systems is still going on. However figure 13 indicates that the hard shoulder running makes travel time more predictable.

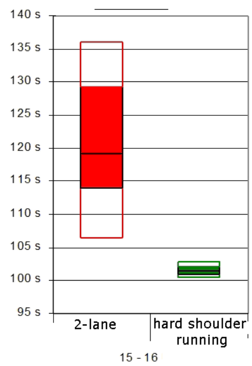

Figure 13 – Travel time outbound between Prater and Schwechat from 3pm to 4pm; travel time reliable and short in case of hard shoulder running (right)

4.2. Results

Based on the micro simulation the travel times of the hard shoulder running were subtracted from the case with 2-lanes. These travel time saving were multiplied with the values of time for each trip purpose as given in table 4. This exercise was carried out for different volumes starting with the year 2010 as base case and different growth rates. The travel time savings for the outbound direction are much higher than the inbound direction (Table 5).

Table 5 - Travel time cost savings with hard shoulder running for different volumes

Volume 2010	**outbound**	**inbound**	**Total**
2010	222,671 €/a	155,517 €/a	**378,188 €/a**
+5%	566,466 €/a	313,957 €/a	**780,423 €/a**
+10%	1,554,161 €/a	396,121 €/a	**1,950,282 €/a**
+15%	3,405,797 €/a	512,134 €/a	**3,917,931 €/a**
+20%	6,122,366 €/a	772,639 €/a	**6,895,005 €/a**
+25%	9,361,844 €/a	1,453,844 €/a	**10,815,688 €/a**

The travel time savings and the other benefits were compared with the cost of investment for the construction including additional electrical equipment and signs. The outbound direction needs more investment than the inbound direction, since it contains two instead of one entrance/exit. The examples, which were examined further, include a 5% and 10% increase in travel demand. This increase in demand is expected as overall average over the next 10 years.

Table 6 - Cost benefit analysis of hard shoulder running with two volume scenarios

		Outbound to Schwechat		**Inbound to Vienna**	
		+5% car, +10% truck	**+10% car, +10% truck**	**+5% car, +10% truck**	**+10% car, +10% truck**
Total Investment cost	[€]	4.115.900	4.115.900	2.333.700	2.333.700
Annual depreciation	[€/a]	482.509	482.509	273.581	273.581
Operation of hard shoulder	[€/a]	5.902	5.902	5.902	5.902
Travel time reduction	[€/a]	766.466	1.554.161	313.957	396.121
Change in accidents	[€/a]	0	0	0	0
Fuel	[€/a]	4.831	10.119	978	3.483
pollution	[€/a]	-66	28	-156	-145
Climate change	[€/a]	-35.165	-25.708	-42.984	-53.635
Total benefit	[€/a]	736.066	1.538.600	271.795	345.824
Benefit - Cost	[€/a]	247.655	1.050.189	-7.688	66.341
Benfit - Cost ratio		1,5	**3.2**	1,0	**1.2**

The investment and operation costs for shoulder running are independent of the increase in traffic volume. Since the segment of the A4 is not noticeable with respect to accidents there are little chances of improvement by speed reduction or speed harmonization. Due to the existing speed limit, differences are minor thus resulting in no evident changes in accident rates and severity. Fuel will be saved by operating at better speed levels – the lowest consumption is observed at speeds between 60 and 70 km/h with little acceleration and deceleration. This speed and harmonized traffic flow can be found after the introduction of the hard shoulder running accompanied by VMS. The pollution is slightly higher although these minor increase is hardly noticeable.

The benefit of the hard shoulder running is marginal at a 5% increase. The benefit becomes obvious as demand increases by 10%. The cost-benefit ratio is 3.2 for the outbound and still 1.2 for inbound traffic, which will justify the investment. The depreciation time for such a system should be rather short (10 years). If travel demand will increase furthermore, then widening the roadway will be required. If travel demand does not require additional road space, the hard shoulder lane can be removed after the 10 year period without a loss in investment.

CONCLUSION

In case of throughput problems hard shoulder running can increase capacity. The segments should not be too short. Furthermore hard shoulder running should also be extended through the bottleneck of the roadway. Entrances and exit within hard shoulder running have to be planned carefully. If these bottlenecks remain, additional traffic is just fed into the segment that is already running at capacity thus adding additional congestion. Hard shoulder running should be installed with VMS and an extensive CCTV-surveillance system to allow temporary usage when traffic demand requires additional capacity.

This paper provided some information to evaluate the impact of hard shoulder running using micro simulation supplemented by a cost-benefit analysis. As in the case study presented reductions in travel time are usually the biggest impact factor to justify hard shoulder running. The impact given by changes in fuel consumption and pollution are minor. Reduced average speeds but less stop-and-go traffic will be positive on climate change. This is the second biggest benefit in this study while safety impacts were not measurable. This motorway segment has no noticeable safety problem and a temporary hard shoulder running will not add new safety troubles.

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