Traffic in the Netherlands 2014

TrafficQuest

CENTRE FOR EXPERTISE ON TRAFFIC MANAGEMENT

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Foreword.

The task we have set ourselves as TrafficQuest can be summed up in one sentence: the collection, analysis and dissemination of knowledge and expertise in the field of traffic management and traffic information. In the last few years, we have taken up that task in a serious and energetic manner. We have written a series of reports, articles and memos to serve the field in general and our partners Rijkswaterstaat (part of the Dutch Ministry of Infrastructure and the Environment), Delft University of Technology and TNO in particular.

In our state-of-the-art publications we have always focused on specific themes such as human factors, coordination of measures, incident management, network management from traffic control centres, cooperative systems and so on. This allows us to meet a demand – have all knowledge on the subject in a single report – however, it always concerns a part of the traffic domain. What do you observe if you zoom out, as it were, and consider the state of affairs and the development of ‘traffic in the Netherlands’? This question is important for a large group of professionals, from policy makers to operators in traffic control centres. As TrafficQuest we have therefore decided to publish a booklet that provides an overview, in addition to the specific reports on different topics. Because we want to update this annually, we speak of an Annual Report on Traffic in the Netherlands.

You are now looking at the first edition, the 2014 version. What can you find in this Annual Report? We will first discuss the traffic performance on Dutch roads. We will discuss the developments and trends and try to interpret them based on social developments. But we will also discuss the ‘hot topics’ of the moment: the issues policy makers, researchers and the industry are excited about. We will specify the new research themes that should be addressed according to TrafficQuest. We will provide an overview of must-have read papers. And finally, we will provide an overview of important pilots worldwide in which traffic management and traffic information measures are tested in a real-world environment.

Those who still want to zoom in after this overview will benefit from the references to the research themes, papers and pilots. We have also organised these links and downloads on our website www.traffic-quest.nl/en/traffic2014.

As a result, the Annual Report is not just an overview, but also a starting point for searches for more information on trends, measures and research groups.

Traffic management and traffic information are fascinating knowledge domains with a great social importance. We have worked on this Annual Report with great pleasure, and we sincerely hope that with this publication we have fulfilled our task of collecting, analysing and disseminating knowledge in an appropriate manner and this way contribute to the development of our field!

The **TrafficQuest team**, *December 2014*

Quotes from the Supervisory Committee

Dr. ir. André van Lammeren, *Director of Accessibility and Infrastructure at Rijkswaterstaat:*
'For me, the network of TrafficQuest is of great importance: a small group in which the knowledge of dozens of professionals come together in the field of traffic management!'

Prof. dr. ir. Bart van Arem, *Head of the Transport & Planning Department at Delft University of Technology:*
'The new Annual Report of TrafficQuest puts the development of the traffic in an expert perspective and provides directions for further development!'

Dr. ir. Michiel Jak, *Innovation Director Mobility at TNO:*
'It strikes me that the Netherlands is in the heart of the international knowledge ecosystem and is leading in a number of large-scale pilots.'


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Traffic statistics in the Netherlands.

Obviously, no annual report is complete without looking back. How has the performance of traffic developed in the Netherlands in recent times? What is the current situation with regard to travel times and travel time reliability? How are road safety and air quality developing? In this chapter, we will list the key facts. In addition, we will create some order in the sometimes chaotic jungle of data sources and indicators.

1.1. Data sources for traffic statistics

In the Netherlands we collect tens of terabytes of traffic data every year. In many places in the road network sensors have been installed, which collect data on the volume, speed and composition of the traffic and forward them to a control centre, where they are processed and redistributed. Traditionally, the road authorities provide these basic data. They use these data for their own purposes, for example, to provide the (political) authorities with the correct information or for planning studies. Since 1996, the road authorities also make the basic data available to service providers who use them to prepare traffic information. In recent years, service providers also collect data themselves to improve and expand their services to travellers.

The main parties and products

When it comes to obtaining traffic data, Rijkswaterstaat is still the main source. Thanks to the development and implementation of the motorway traffic management system and the corresponding sensor network with detection loops, a substantial part of the national road network has been well measured for years.

One of the products for which Rijkswaterstaat uses the collected traffic data, is the *Public Report on the National Road Network*. This report, which is published three times a year, presents the overall traffic trends on the motorway network, such as distance travelled, amount of congestion and total network delay. Other topics such as disruptions caused by road works, satisfaction of road users and the proportion of freight traffic are also addressed in the report.

Rijkswaterstaat archives its data and makes this historical data partly accessible via the *Network Management Information System* (NIS). Figure 1 includes an example of the development of the congestion severity* for the period of spring 2012 to summer 2013.

The data of Rijkswaterstaat are also included in the *National Data Warehouse for Traffic Information* (NDW). NDW was founded in 2007 and currently consists of 24 authorities: the government, the provinces, regional partners and the four major cities. They cooperate in the collection, storage and distribution of road traffic data in order to manage traffic and to keep road users well informed.
The NDW database offers insight into the current and historical traffic conditions on motorways, main roads and urban roads of the participating authorities. These data are distributed to road authorities and traffic information providers.

Two of these providers are the Royal Dutch Touring Club (ANWB) and the Traffic Information Service (VID). Based on NDW data and partly on their own data – the VID, for example, operates Bluetooth sensors – they prepare the traffic information they distribute via websites and other media.

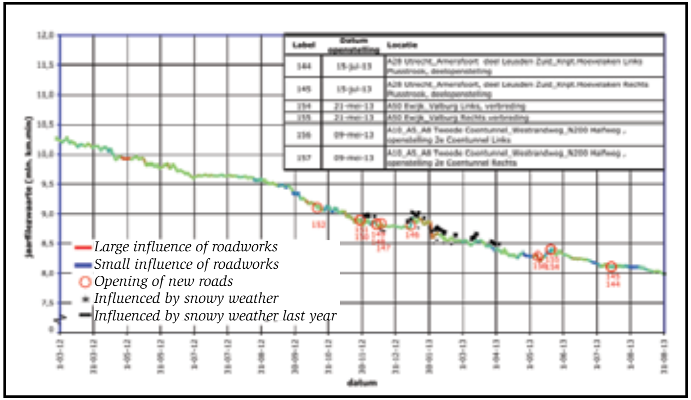

Figure 1: *Development of the congestion severity on the motorway network (source: Rijkswaterstaat, 2013).*

In addition, they regularly publish reports on the trends in congestion in the Netherlands, using the above-mentioned congestion severity indicator. These reports are about the relative changes compared to the previous period. However, the ANWB and VID also publish their own *Traffic Congestion Top 50*, using absolute congestion severity figures (kilometre-minutes). Table 1 shows an example of a part of the Traffic Congestion Top 50 of the VID for 2013.

* The congestion severity is the measure used to assess congestion. It is a product of the length of the traffic jam and the time the traffic jam lasts. This means that a 60-minute traffic jam of 1 kilometre is equally severe as a 1-minute traffic jam of 60 kilometres.

2013							2012
#		km.min	road	main direction	congestion starts at	#	km.min
1	▲	217.901	A20	Hoek van Holland → Gouda	Terbregseplein	2	238.915
2	▼	130.799	A50	Arnhem → Oss	Ewijk	1	281.427
3	▲	124.559	A20	Hoek van Holland → Gouda	Moordrecht	16	87.171
4	▲	119.452	A16	Breda → Rotterdam	Terbregseplein	8	109.299
5	☼	114.116	A9	Alkmaar → Amstelveen	Badhoevedorp (knp.)	-	30.284
6	▲	105.085	A27	Gorinchem → Breda	Merwedebrug	15	90.097
7	=	104.148	A13	Rijswijk → Rotterdam	Kleinpolderplein	7	111.499
8	▲	99.880	A1	Amsterdam → Amersfoort	Eembrugge	12	99.880
9	▼	86.370	A15	Rozenburg → Ridderkerk	Vaanplein	3	159.978
10	▲	81.120	A20	Gouda → Hoek van Holland	Rotterdam-Centrum	19	75.788
11	▼	80.937	A1	Amsterdam → Amersfoort	Bunschoten	10	101.677
12	▲	76.937	A1	Amersfoort → Amsterdam	Eembrugge	20	73.869
13	▲	73.277	A12	Utrecht → Den Haag	Malieveld	25	62.490
14	▲	73.267	A8	Zaandam → Amsterdam	Zaanstad-Zuid	46	37.981
15	▼	72.859	A27	Utrecht → Almere	Bilthoven	9	104.553
16	▲	69.561	A20	Gouda → Hoek van Holland	Nieuwerkerk aan den IJssel	22	67.655
17	▼	68.159	A27	Almere → Utrecht	Bilthoven	13	96.589
18	▼	64.207	A10	De Nieuwe Meer → Coenplein	Coenplein	5	134.572
19	▼	63.829	A8	Zaandam → Amsterdam	Coenplein	17	86.494
20	☼	58.761	A28	Amersfoort → Utrecht	Rijnsweerd	-	19.971

Table 1: *The top twenty traffic jams from the Traffic Congestion Top 50 (source: VID).*

TomTom and INRIX are also providers of traffic information and they publish figures on the amount of delay. To this end, they use data from ‘fixed’ measurement points (in, above and along the road) as well as floating car data. They provide their current traffic information to other parties - the ANWB, for instance, uses TomTom data - and directly to road users.
To provide insight into the development of traffic congestion, TomTom publishes reports of so-called *Traffic Indices*: a comparison of travel times during and outside rush hour periods. TomTom calculates this index for 120 metropolitan areas in the world, about half of which are located in Europe. INRIX uses the INRIX Index to compare traffic in cities and countries. This is based on the same principle as the Traffic Index of TomTom: a measured speed is compared to a free speed for all road segments. Then a variety of operations is performed to come to an index for a city or a country. Figure 2 shows an example of such a scorecard.
Data from various sources were merged for the creation of the *Traffic Monitor* (TNO, 2013) for the regions that participate in the ‘Beter Benutten’ programme*. It involves data from the historical database of NDW, supplemented by data from local traffic control systems, travel time cameras and Bluetooth measurement stations as well as travel time data based on telephone data. The data are imported, assessed for reliability and data availability in time and space, and aggregated to routes based on established calculation rules. This may be routes on the main road network, but also routes on the urban or provincial road network, or on different road networks. Based on these data, four indicators are always calculated: total network delay (in vehicle hours), traffic performance (kilometres driven), travel time and average speed. Incidentally, the Traffic Monitor calculates the total delay slightly different than Rijkswaterstaat. However, since the Traffic Monitor determines this indicator the same way every year, it is no problem to make a relative comparison of the traffic-related indicators.

Finally, Statistics Netherlands (CBS) collects data on infrastructure, vehicle fleet, personal mobility and emissions from road traffic and makes these data available (CBS, 2013).

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In the ‘Beter Benutten’ (Optimising Use) programme of the Ministry of Infrastructure and the Environment, the government, regions and industry work together to improve the accessibility by road, water and rail in the busiest regions.

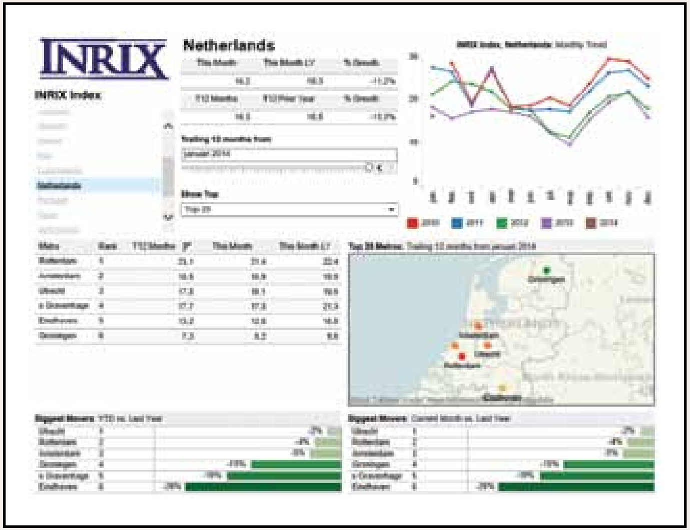


Figure 2:
Example of an INRIX scorecard for the Netherlands (source: INRIX).

1.2. Traffic statistics in figures

There are a lot of data available. However, the sources always describe a part of the traffic situation, and this makes it difficult to get a complete picture of traffic in the Netherlands.
Therefore, we now focus on the following questions: which indicators do the different sources use? For which network and for which period are they valid? And what does a comparison of the indicators amount to?

In Table 2 we have listed the available sources and the indicators that can be derived from them. Some sources provide multiple indicators and more detailed information for each period, but this review is based on the main indicators and annual figures.
This table shows that the different indicators cannot be compared indiscriminately. One indicator describes the situation from the perspective of the road authority (congestion severity), the other from that of the road user (travel time). Some sources only cover the motorway network, while others also include the secondary road network. And then there is the difference in scale: the entire country or only certain regions or cities.

Below we will discuss a number of the indicators more in-depth and let the figures on the traffic situation in recent years speak for themselves.

The congestion severity on the motorway network
Rijkswaterstaat, ANWB and VID all use the congestion severity indicator for the motorway network. In their reports, ANWB and VID emphasise the relative difference compared to the previous period. The percentage increase or decrease can also be calculated from the Rijkswaterstaat data. The data of all three sources over the past six years are shown in Table 3.

The table shows that the figures are fairly close together, although the differences between the figures of the ANWB and Rijkswaterstaat are greater than those between the figures of VID and Rijkswaterstaat. Especially the figures for 2012 show a significant difference: ANWB speaks of -20.1%, while Rijkswaterstaat says -16.2% (VID: -16.0%). The fact that the actual figure lies closer to those of Rijkswaterstaat and VID is supported by the INRIX Index. This index gives a difference of -15.6% for 2012 compared to 2011, although this relates to both the motorway network and the other road networks combined. For 2013, the differences between the sources are negligible.

The table also properly reflects that the congestion severity strongly decreased in recent years, with the exception of 2010. This decrease is also visible in the measured traffic delay, as indicated in Figure 3. It is remarkable that the number of vehicle kilometres on the motorway network does not decrease but still increases, even though

the increase in recent years is smaller than before. The traffic delay (and also the congestion severity) has indeed decreased sharply, and in 2013 it dropped below the level of 2000. This decrease is mainly due to the expansion of the infrastructure in the form of rush-hour lanes on a large number of routes in 2011 (59 % more kilometres of rush-hour lanes than in 2010) and in 2012 (14 % more kilometres of rush-hour lanes than in 2011). The slight increase in traffic delay in 2010 is due to the many roadworks carried out that year and the relatively large number of days with adverse weather.

The congestion severity on the motorway network by cause

For the motorway network, the causes of the traffic jams are well-recorded. This provides opportunities to zoom in a bit more on the congestion severity indicator. For the sake of readability, the causes of the traffic jams have been clustered into four categories: *Bottleneck*, *Disruption* (incidents and

	Road network	CBS	RWS	ANWB	VID	TomTom	INRIX	Traffic Monitor
Road length	NL	●						
	HWN	●	●					●
	OWN	●						●
Distance travelled	NL	●						
	HWN	●	●					●
	OWN	●						●
Congestion severity	NL							
	HWN		●	●	●			
	OWN							
Total delay	NL							
	HWN		●					●
	OWN							●
Travel time	NL							
	HWN		●					●
	OWN							●
Congestion index	NL						●	
	HWN					●		
	OWN					●	●	

NL = whole of the Netherlands, HWN = main road network, OWN = other road networks

Table 2: Overview of indicators and their sources. Note that some sources cover the entire country (CBS, for example), while other sources focus only on specific regions (like the Traffic Monitor).

Source	2008	2009	2010	2011	2012	2013
Rijkswaterstaat	-1,9 %	-14,9 %	+ 5,3 %	-23,9 %	-16,2 %	-8,0 %
ANWB	-1,4 %	-14,0 %	+ 9,0 %	-25,0 %	-20,1 %	-8,0 %
VID	-1,7 %	-14,5 %		-24,1 %	-16,0 %	-8,0 %

Table 3: The congestion severity for the main road network: relative difference compared to the previous year for the sources Rijkswaterstaat, ANWB and VID.

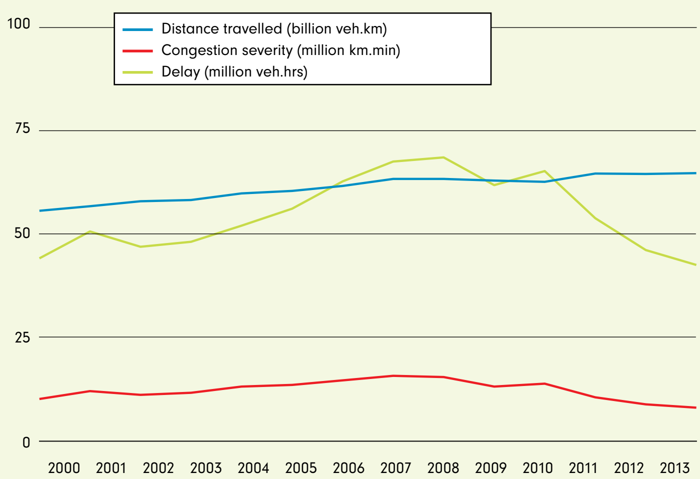


Figure 3: Congestion indicators for the main road network (source: Rijkswaterstaat).

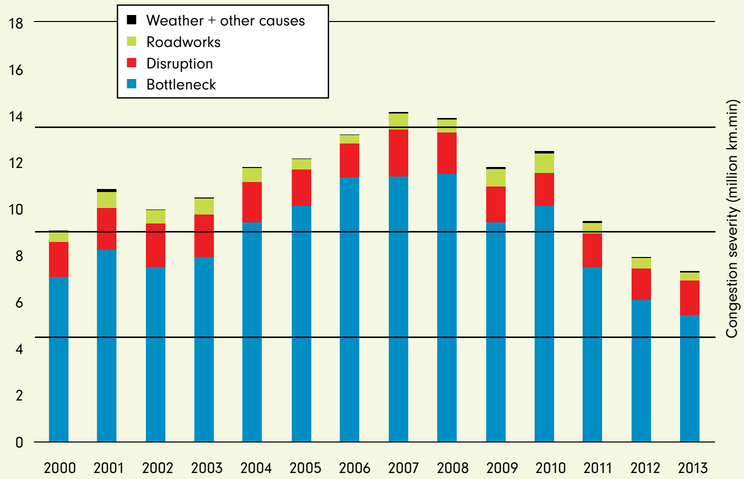


Figure 4: Congestion severity by cause, absolute (source: Rijkswaterstaat).

events), *Roadworks* and *Weather + other*. The amount of congestion for each category is displayed in Figure 4, and the relative contribution of the different categories is shown in Figure 5.

It is clear that the reduction of the congestion severity in recent years was most significant in the category Bottlenecks. This is where we gained the most. Partly due to this, the relative magnitude of the cause Disruption increases to approximately 20% in 2013, even though in absolute numbers it decreased from 2.2 million kilometre-minutes in 2007 to 1.6 million kilometre-minutes in 2013.

The congestion index for urban road networks

Both INRIX and TomTom define their own congestion index for (a number of) urban road networks. In Figure 6, we compared the two variants for Amsterdam, Rotterdam and The Hague, over the years 2010-2013. Note that TomTom provides no data on 2010 and that

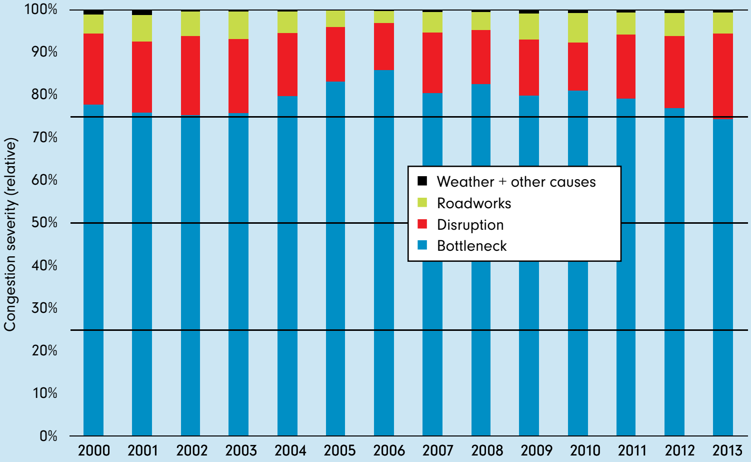


Figure 5: Congestion severity by cause, relative (source: Rijkswaterstaat).

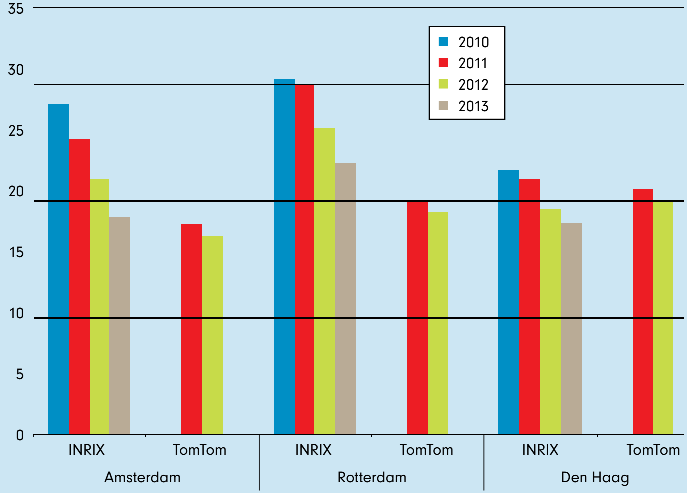


Figure 6: Congestion index for urban road networks (source: INRIX and TomTom).

their data on 2013 were not yet available at the time of writing this annual report.

The figure clearly shows that the congestion also decreases in urban road networks. The indices of INRIX and TomTom do not quite match, although they show the same downward trend. The difference can be explained by the way in which the indices are calculated: the size of the corresponding road network, the amount of data used and the cleaning thereof are all slightly different between INRIX and TomTom.

The indicators of the Traffic Monitor

The Traffic Monitor for the regions participating in the "Beter Benutten" programme, uses various indicators to monitor the (main and other) road networks. Currently, the Traffic Monitor includes data from September 2011 onwards. An example for the other road

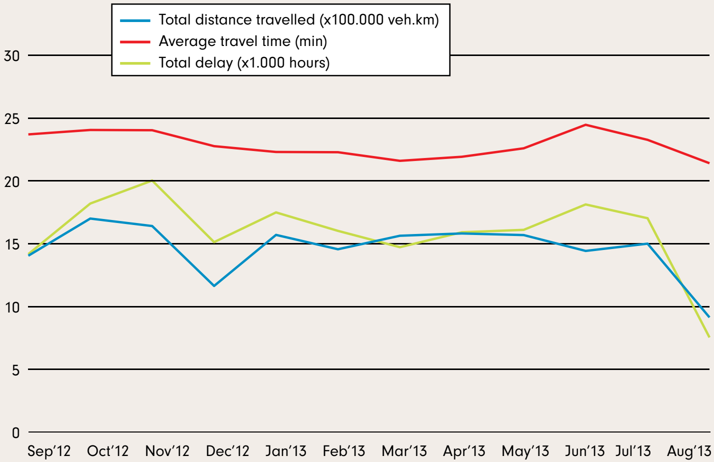


Figure 7: Traffic performance on the urban route Kleinpolderplein-Vaanplein for an average evening rush hour (source: TNO).

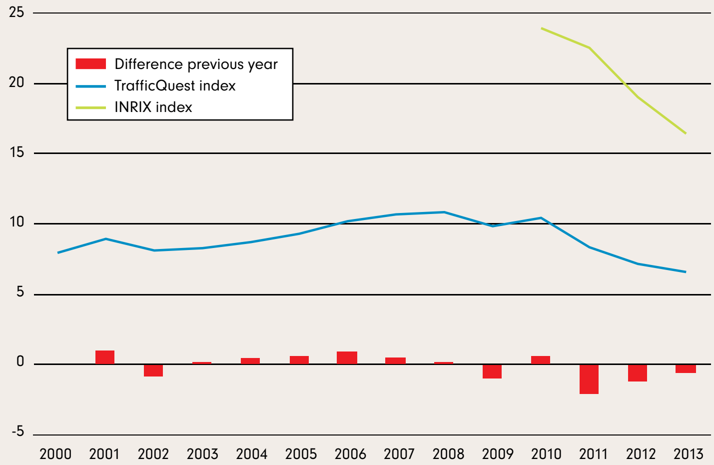


Figure 8: Travel time index on the motorway network (source: RWS and INRIX).

networks is included in Figure 7. It concerns the development of a number of performance indicators for the average evening rush hour (15:00 to 19:00 hours) on the Maastunnel route in Rotterdam (Kleinpolderplein-Vaanplein) over the measurement period of September 2012 to August 2013. For the other road networks, the indicators that are derived from the measured *flow*, such as vehicle kilometres driven and network delay, are more indicative in nature. The number of measurement locations is still too limited to draw firm conclusions.

This is different on the motorway network: on busy routes, there are, on average, loop detectors every 500 metres. Furthermore, the number of entrances and exit locations is limited, which results in better flow measurements.

TrafficQuest-travel time index

The indicators we have discussed so far, put a strong emphasis on what happens during rush hours. After all, in case of congestion se-

Figure 9: Travel time and travel time reliability on the motorway network, relative (source: Rijkswaterstaat, adaptation by KiM).

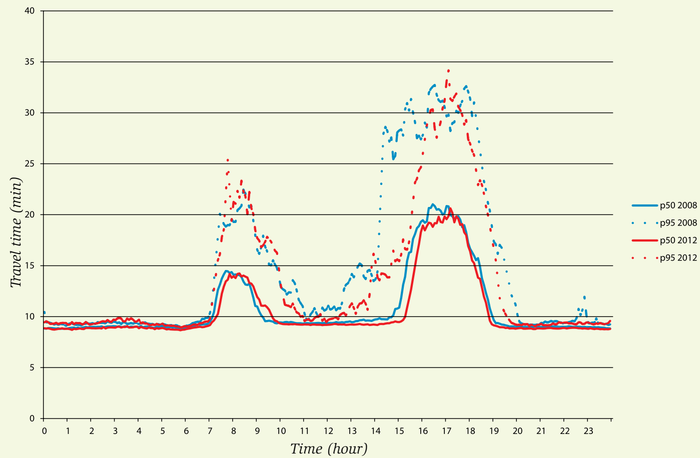


Figure 10: Travel time percentiles for Thursdays in 2008 and 2012 on the A13 towards Rotterdam (source: Rijkswaterstaat, adaptation by TNO).

verity and delays, it is mainly about (the size and the consequences of) congestion, and this occurs mainly during rush hours. To broaden the focus somewhat, TrafficQuest has calculated how much extra time a road user, travelling at *any* time, loses on the motorway network.* To determine this so-called travel time index, the indicators *kilometres driven* and *delay* were used. Based on these data, we compare the observed travel time to the travel time required when a speed of 100 km/hour can be reached.

The blue line in Figure 8 shows the travel time index as of 2000. For 2012, this index is 7.1%, which means that on average, a ride that would take 60 minutes in light traffic (100 km/h), took a lit-

* Unfortunately, insufficient data from the other road networks are available to do a similar calculation for such networks. We also still do not know (measure) enough to perform a calculation for the entire country.

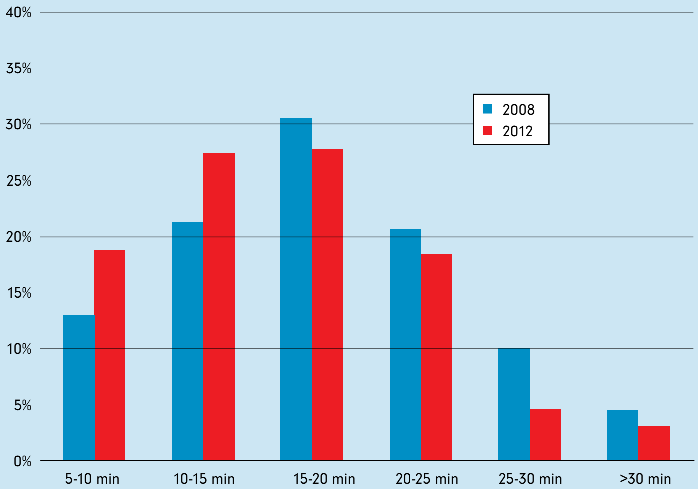


Figure 11: Travel time distribution for Thursday rush hours in 2008 and 2012 on the A13 towards Rotterdam (source: Rijkswaterstaat, adaptation by TNO).

tle over 64 minutes (= 107.1% of 60) in 2012. From 2003, the travel time index gradually increases until 2009, when it started decreasing again, with the exception of 2010, which is completely in line with the other indices. The decrease does, however, gradually slow down from 2011 onwards. This figure also includes the difference with the previous year as well as the INRIX Index for the Netherlands as a whole during rush hours (from 2010 to September 2013). This INRIX line shows a sharper decline. The explanation for this is that the delay during rush hours decreases relatively stronger than outside rush hours. The line is higher, because this index also includes the traffic on the secondary road network. The higher value can be explained by the larger percentage difference in speed (and travel time) on the national and urban road networks in combination with the greater length of those road networks. Incidentally, the INRIX Index uses a travel time measured under traffic-free conditions as a reference.

Travel time reliability

The decrease in congestion also has implications for the (un) reliability of travel times, according to the calculations of the Netherlands Institute for Transport Policy Analysis (KiM, 2013). The Institute defines the unreliability of travel time as the extent to which the travel time is longer or shorter than the travel time expected by the traveller. This definition, expressed in the standard deviation, comprises the structural, daily variations as well as the incidental, minor and major disruptions. Travel

times longer than the average plus twice the standard deviation are called extreme travel times. The relative development between 2001 and 2012 (in 2000 these data were not yet available) is shown in Figure 9. Unreliability has clearly decreased significantly in recent years.

To illustrate the development of the travel time (un)reliability, we have made a comparison in Figure 10 of the situation in 2008 on the A13 route Rijswijk-Rotterdam with that of 2012. These travel times relate to weekdays (Thursdays). In 2012, the travel time varies from approximately 8 minutes under free-flow conditions to a peak in the 95th percentile (red dotted line) of nearly 35 minutes during the evening rush hour. This is more than four times the free-flow travel time. The median travel time during this peak is approximately 20 minutes in 2012, which is still more than twice the free-flow travel time. Compared to 2008, the median travel time in 2012 is practically the

Road	Road section		2009	2012	Ranking
15	Kp Ridderkerk 1	Hendrik Ido Ambacht	239.728	239.400	01 (02)
4	Kp Prins Clausplein	Delft Noord	241.269	239.200	02 (01)
4	Hoofddorp	Kp De Hoek	208.287	215.800	03 (04)
10	Kp De Nieuwe Meer	Amstelveen S108	202.591	213.000	04 (06)
12	Utrecht	Nieuwegein Noord	220.652	208.500	05 (03)
10	RAI S109	Kp Amstel	184.724	200.400	06 (13)
16	R'dam Centrum	Kralingen	198.062	200.100	07 (07)
16	Kralingen	Prins Alexander	205.098	197.100	08 (05)
10	Amstelveen S108	RAI S109	188.115	196.000	09 (10)
4	Kp Badhoevedorp	Vlvd Schiphol	181.294	190.500	10 (14)
4	Kp De Nieuwe Meer	Sloten	181.163	189.100	11 (15)
4	Kp Badhoevedorp	Sloten	189.347	187.900	12 (09)
27	Kp Rijnsweerd	Kp Lunetten	190.652	183.800	13 (08)
4	Hoofddorp	Nieuw-Vennep	186.089	178.400	14 (11)
1	Muiden	Muiderslot	184.964	169.600	15 (12)

Table 4: Overview of the road sections in the Netherlands with more than 180,000 vehicles per 24 hours (both directions combined).

same, but the rush hour travel times vary less. Figure 11 also clearly shows this development in the travel time distribution.

Number of busy road sections

The fact that there is less congestion does not mean that the motorway network is less travelled. We had already seen this in Figure 3, but it also shows from the overview of the road sections with a traffic load of more than 180,000 motor vehicles per 24 hours (in both directions). This overview is included in Table 4 for the years 2009 and 2012.
The table shows that some road sections have become less busy, while others have become busier.
Based on counting data, we can also conclude that the motorway network in the Netherlands is heavily used. While there are fifteen road sections with a traffic load of more than 180,000 motor vehicles per day in the Netherlands, there are only seven in Belgium, five in England and two in Germany – see Table 5 (VV, 2011; VV, 2013; DfT, 2013; Bast, 2013). Incidentally, these foreign road sections have also become busier on average.

Country	Road section	2010	2012
Belgium	R1 Antwerpen: Borgerhout – Berchem	259.984	269.869
	R1 Antwerpen: Berchem – Antwerpen-Zuid	232.019	238.829
	R1 Antwerpen: Borgerhout – E313	240.660	236.832
	R1 Antwerpen: Deurne – Antwerpen-Oost	205.177	210.492
	R0 Brussel: Zaventem – Machelen	–	202.382
	R0 Brussel: UZ Jette – Wemmel	181.325	199.360
	R0 Brussel: Zaventem-H. – St-Stevens-Woluwe	–	183.107
England	M25 – M4-Heathrow	185.633	207.485
	M25 – Heathrow-A30	195.360	196.279
	M60 – A572-M602	184.002	190.044
	M1 – A414 (Junction 7/8)	155.662	186.726
	M25 – M3-A317	176.150	181.764
Germany	A3 AD Heumar – Köln	183.869	185.422
	A100 Dreieck Funkturm – Kurfürstendamm	186.100	169.422

Table 5: Overview of the road sections in neighbouring countries with more than 180,000 vehicles per 24 hours (both directions combined).

1.3. Road safety in figures

Road safety in the Netherlands has been at a high level for years. Figure 12 shows the trends in the figures for traffic-related fatalities (total in the Netherlands and on the motorway network) and traffic-related injuries (total in the Netherlands) per billion kilometres driven for the period 2000-2012. The figures used are from Rijkswaterstaat, the Institute for Road Safety Research (SWOV) and CBS. It can be seen that the number of traffic-related fatalities is flattening, while the number of injuries, both relative and absolute, has been increasing since 2006. Fortunately, 2013 once again shows a decrease due to the significant decrease in the number of traffic-related fatalities. Figure 13 shows what it looks like if we place the Netherlands in an international perspective. This overview is based on data from 2011 about the number of traffic-related fatalities per billion kilometres driven (IRTAD, 2013). With a seventh position, the Netherlands is still doing well on an international level. Even if we express road safety in the number of traffic-related fatalities per million inhabitants, we remain at the top: in Europe we take the fourth place with about 40 traffic-related fatalities per million inhabitants (average over the years 2009-2011), after Malta, Sweden and the United Kingdom (SWOV, 2013).

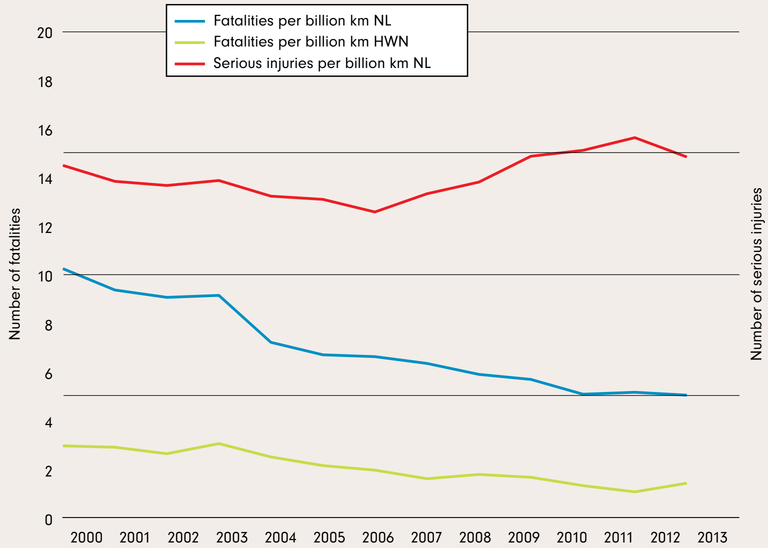


Figure 12: Road safety in the Netherlands (source: Rijkswaterstaat, SWOV and CBS).

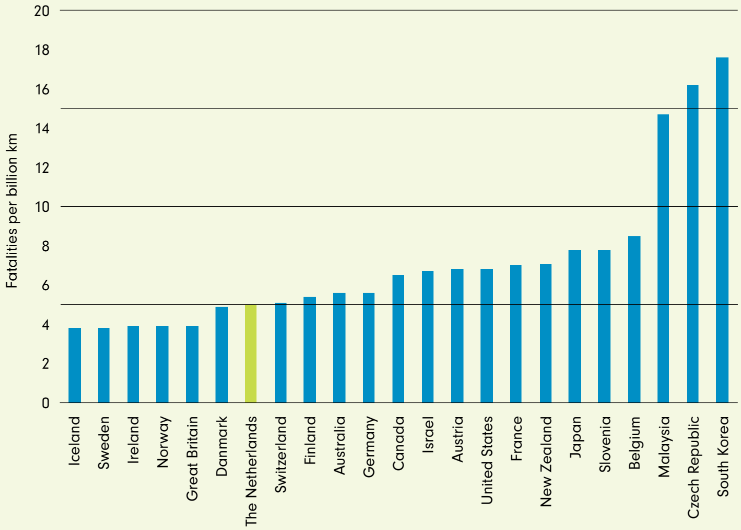
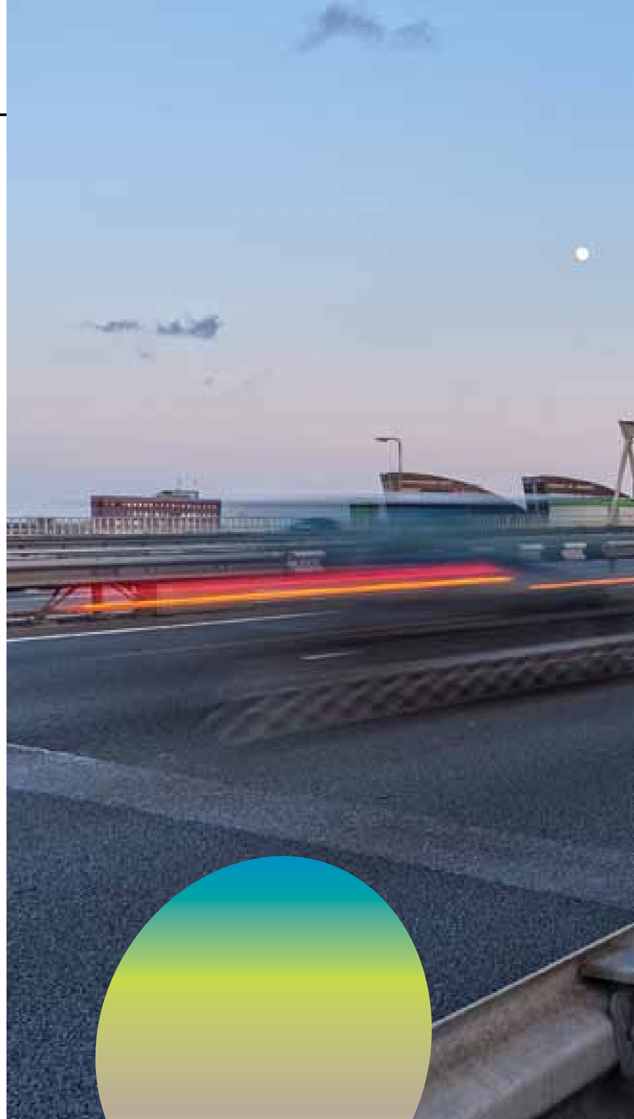


Figure 13: Road safety in an international perspective (source: IRTAD).



1.4. Air quality in figures

Statistics Netherlands (CBS) also publishes data on the emissions of pollutants from road traffic (CBS, 2013). We have converted these data into CO_2, NO_x and PM_{10} emissions per distance travelled. For CO_2, this is kilogram per thousand kilometres travelled, for NO_x kilogram per hundred thousand kilometres travelled and for PM_{10} kilogram per million vehicle kilometres. The different distances are used so the development of the emissions can be presented in a single diagram. The results for the Netherlands as a whole (NL) and the motorway network (HWN) are shown in Figure 14.

It is clear that all emissions have been reduced in recent years. Between 2000 and 2012, this decrease was the smallest for CO_2 with 2% for the entire country and 6% for the motorway network. The decrease in the amount of NO_x was significantly larger, 45% and 48%, respectively. The PM_{10} emissions also decreased significantly, by 61% for the Netherlands as well as for the motorway network.

According to the European Environment Agency (EEA), the vehicle fleet is quickly getting cleaner. In the Netherlands, the emissions of the new car fleet is the lowest in Europe. The emissions of new cars in 2013 are 8% lower than in 2012.

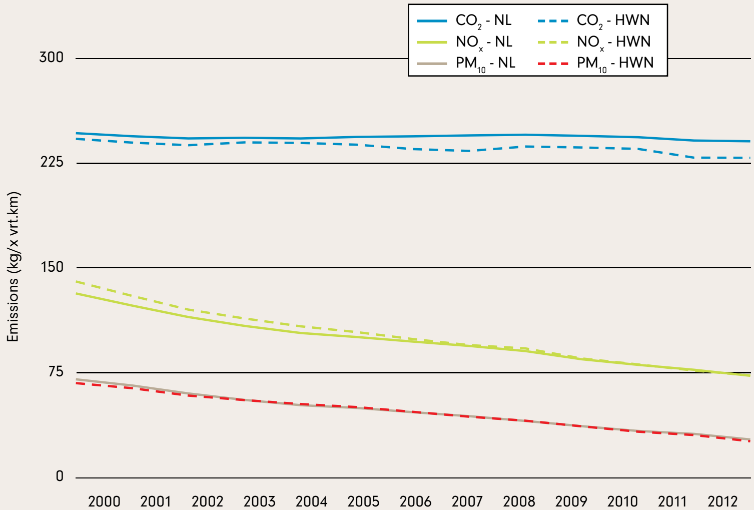


Figure 14: Emissions from road traffic (source: CBS, adaptation by: TrafficQuest).

1.5. Summary

All in all, the conclusion can be drawn that the traffic situation in the Netherlands keeps improving. The delay on the motorway network has been reduced to approximately the level of 2000, although the number of kilometres driven has increased. We know less of the other road networks, however, they too show a decrease in traffic delay. It is encouraging that the number of traffic-related fatalities continues to fall and that the emissions of road traffic also slightly decrease (in case of CO_2) or have been reduced greatly (in the case of NO_x and PM_{10}). The only indicator which goes against the trends is the number of injuries on Dutch roads: this number has increased in recent years.

2

Traffic congestion explained.

**After having recapitulated all the data on accessibility in the Netherlands, we can now focus on the meaning of these data.
How can the trends of recent years be explained? What factors played a role? And also: what does this tell us about the near future?
What developments outside the traffic domain – (socio)economic, social and demographic changes – will have an impact on traffic in the Netherlands in coming years?**

2.1. Trends in road traffic

In the previous chapter we also addressed the urban and provincial road networks, partly with the aid of the overviews of TomTom, INRIX and the Traffic Monitor. In this chapter we will confine ourselves strictly to the motorway network. Not because the other road networks are less interesting, but purely because insufficient information is available about the intricate and very diverse urban and provincial networks to retrieve any general, Dutch trends from them. The trends in mobility, accessibility and reliability we will discuss below are therefore based on data from the motorway network. The section on road safety, however, does relate to all road networks.

Trends in mobility and accessibility

The development of congestion on the motorway network in the Netherlands shows an erratic pattern: until 2007, there is a clear increase in congestion severity and total delay due to congestion, from early 2008, the congestion severity decreases annually. Currently, the congestion severity and the travel time delay are both at a level (well) below that of 2000. The corresponding traffic demand, however, is some 16% higher – see Table 6.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Performance	100	102	104	105	108	109	111	114	114	113	113	116	116	116
Travel time	100	103	104	105	108	110	113	117	117	115	115	117	115	115
Delay	100	115	106	109	118	127	142	153	155	140	148	122	105	96
Cong. severity	100	119	110	115	130	134	145	155	152	130	137	104	87	79

Table 6: Development of traffic performance (kilometres travelled), travel time and delay (vehicle hours) on the motorway network, 2000-2013 (source: Rijkswaterstaat and TrafficQuest).

Relationship between supply and demand.

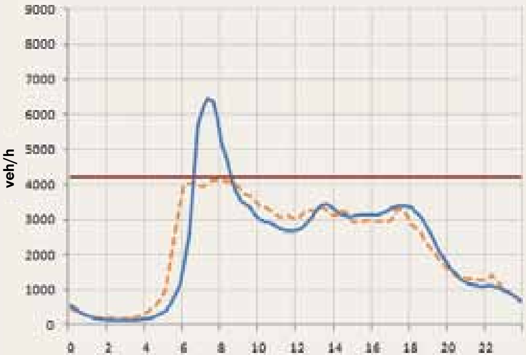
Insight into the relationship between traffic demand and supply (capacity) is very important to road authorities. In particular the question: by how many vehicles should the traffic load on a specific bottleneck be reduced in order to get the travel delay to an acceptable level? If you know the answer to this question, you will know exactly what needs to be done in traffic and demand management. The amount of traffic to be removed is also called the X-factor.

In 2011, this X-factor was determined with a model for the fifty largest bottlenecks in The Netherlands (Transpute, 2011). The acceptable level to be reached by the calculations was a delay of 10 minutes. The reduction in total network delay and the economic benefits generated by the X-factor were also calculated.

The chart on the next page shows the example of the A10-West in the southern direction. The traffic demand (blue line) was determined based on measured data. The figure shows congestion: after all, the demand is larger than the measured flow (orange line). The chart also clearly shows that the traffic, as a reaction to the structural congestion, moves to the outer limits of the rush hours. For this bottleneck, the X-factor determined through simulation comes to 2,080 vehicles in the morning rush hour on an average working day. If this number was removed from the morning rush hour, for example through traffic management and demand management, it would result in a gain of 8,830 lost vehicle hours per average working day. This calculation does not take into account blocking back effects and a ‘back-to-the-rush-hour’ effect.

The average X-factor for the bottlenecks in the Top 50 in the morning rush hour is significantly lower and comes to 4.4% of the total number of vehicles that passes the relevant bottlenecks during the morning rush hour. For the evening rush hour, the X-factor is 2.2%. The above example of the A10-West in the southern direction is therefore an outlier with 11.8%.

- - - Flow (measured)
- - - Traffic demand (estimated)
—— Capacity



The traffic demand calculated for the A10-West in the direction of junction De Nieuwe Meer (source: Transpute, 2011).

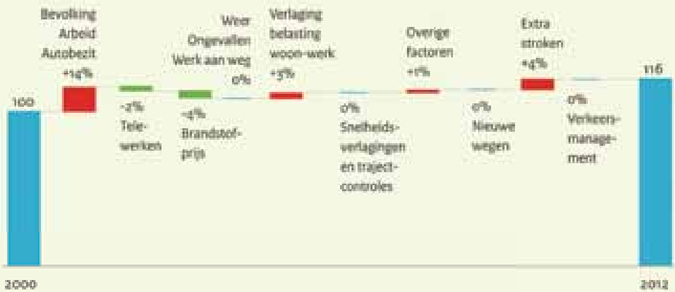


Figure 15: Causes for the changes in the volume of traffic on the motorway network between 2000 and 2012 (source: KiM, 2013).

Figure 16: Causes for the decrease in delay on the motorway network between 2008 and 2012 (source: KiM, 2013).

Both the traffic demand and the traffic supply are responsible for the decrease in the congestion severity and the travel time delays. In the Mobility Report 2013 of the KiM, several factors have been mapped on the basis of extensive data analysis. The most important ones are displayed in Figure 15.

The figure shows that there was a significant increase in the volume of traffic (16%) on the motorway network in the period 2000-2012. The main factor that contributed to this growth is Population-Employment-Car Ownership (+ 14%), meaning the population growth, employment participation and car ownership and use.
The supply side also contributed to the growth: the construction of additional lanes resulted in a 4% traffic increase.

Table 6 also shows that the delay increased until 2008 and then decreased again. If we look at the causes of this decline for the period 2008 to 2012 – Figure 16 – then the decrease in delay of 32% appears to be mainly the result of the construction of additional lanes (-34%) and the application of traffic management (-3%).

In 2013, road works were responsible for approximately 5% of the congestion severity on the motorway network (also see Figure 5). Since the number of major roadworks will decrease, this percentage is likely to continue to fall. As a result, the share of congestion caused by incidents will increase proportionally. This will require additional attention in the coming years.

It is also striking that although mobility has been growing steadily since the seventies, since 2005 we observe a flattening in the growth of car use. In 2012, there was a limited reduction in the number of vehicle kilometres on the motorway network for the first time (a decrease of 0.2% compared to 2011), but 2013 showed a small increase (+ 0.3%). It is unclear whether it is a structural decrease or an accidental reduction that fits within the 'natural variation'. The figures seem to point towards a stabilisation of the number of kilometres driven.

Research by the KiM shows that the following factors play a role in the observed flattening of the growth:

- Decrease of (car) mobility of young adults in both the number of trips and distance travelled (since 1995). This is possibly caused by a decrease in the number of employed young adults, lower car ownership and increasing urbanisation.
- Developments in employment participation: stabilisation among women since 2008, a decline among men.
- An increase in international mobility and the occurrence of saturation (in regard to car ownership and having a driving licence). This factor only seems to have a limited impact on the flattening.

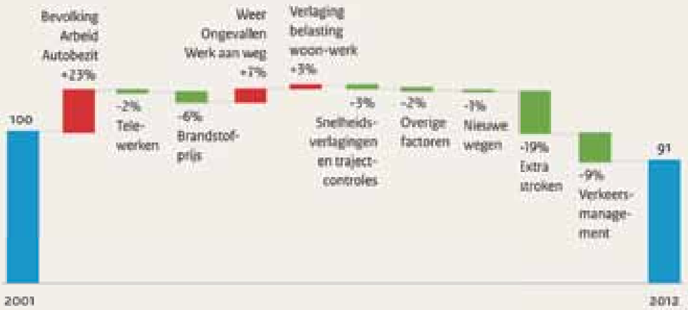


Figure 17: Causes for the change in the travel time unreliability on the motorway network between 2001 and 2012 (source: KiM, 2013).

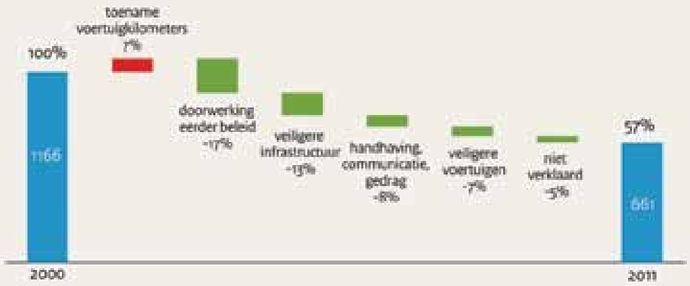


Figure 18: Causes for the decrease in the number of traffic-related fatalities between 2000 and 2011 (source: KiM, 2012).

The factor we cannot properly determine is the influence of the Internet society. One of the problems is that it has both a limiting influence (less work and shopping-related travelling) and a stimulating influence (home delivery).

Trends in travel time reliability

Figure 9 in Chapter 1 showed how the reliability of the travel time has evolved over the years. It is striking that the average travel time has remained fairly stable since 2006, while reliability has increased on average (or, in the terminology of Figure 9: the unreliability decreases). The combination of the construction of additional lanes and rush-hour lanes, and traffic management made for an increase in reliability by 28%, as visualised in Figure 17.

Trends in road safety

Figure 12 showed us that the number of traffic-related fatalities has been falling gradually since 2000, though in recent years the decline is slowing somewhat. The decline is explained in Figure 18.

The factor ‘Past Policies’ relates to the Sustainable Safety measures that were drawn up and implemented from the year 2000 onwards, and to measures taken to increase road safety for young people. ‘Safer Infrastructure’ relates to the introduction of 30 km/h zones, the construction of roundabouts and the introduction of the speed limit of 60 km/h on country roads. In addition, the vehicles themselves have become safer, while communication campaigns proved to be effective.

What is worrying is that the number of injuries has increased in recent years. No research has been conducted into the cause of this.

2.2. Relevant developments

Obviously, traffic is not an isolated phenomenon. As we observed in the preceding pages - see Figures 15 and 16, for example - there are also plenty of 'non-traffic-related' factors that influence the situation on the road. These include employment, population, societal changes and so on. To gain some insight into how traffic will develop in the future, it is useful to consider the trends in the 'context' of traffic. This mainly relates to the economy, society and technology.

Economy

The growth of the domestic (car) mobility has been flattening for several years. The logical question is: will this trend continue in the future? This depends mainly on three factors: car ownership, population size and employment.

In 2012, the CPB (Netherlands Bureau for Economic Policy Analysis) said it would be unlikely that economic development will fall outside the bandwidth of the Prosperity and Environment Scenarios 2002-2040 (WLO, 2006) and that as a result, the WLO-growth scenarios do not require adjustment (see Figure 19). Partly based on this, the KiM expects that in the future, the development of (car) mobility will move within the bandwidth of the most recent estimates (NMCA*, 2011). In light of the recent flattening of the growth of (car) mobility and the current economic downturn, there is a good chance

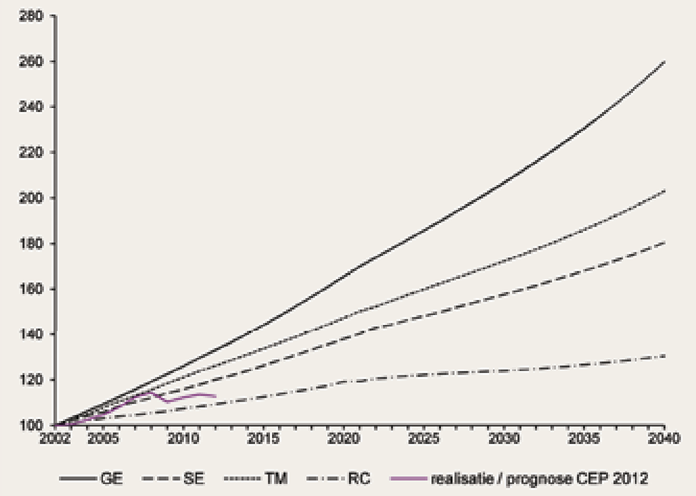


Figure 19: Realisation Gross Domestic Product 2002-2012 and the WLO scenarios (source: CPB, 2012).

* NMCA stands for the National Market and Capacity Analysis, an analysis of the bottlenecks in the Dutch roads, railways and waterways. The analysis is performed using the four Netherlands Regional Models (NRM), which in turn are based on the Welfare, Prosperity and the Living Environment (WLO) scenarios of the Dutch planning offices.

that the development of the mobility will remain close to the lower end of the indicated bandwidths.

The way the environment and car use will change in the future, will also have an impact on the development of congestion. For 2013, the KiM expects a decrease in congestion on the motorway network, but for the period from 2014 to 2017 traffic volumes, and thus congestion, are likely to grow again due to the recovering economy and a slight decrease in fuel prices. The road capacity is still increasing, which will accommodate a part of the increased traffic load, but this will be to a lesser extent than during the period 2010-2013.

It is important to continue to closely monitor the economic development. After all, the calculations for future bottlenecks (NMCA) are based on economic (growth) scenarios.

Social changes

Social media play a major role in the lives of young adults, who are also known as Generation Y or the Net Generation. If and how this will affect car use, however, is difficult to say. Recent German research (Autoscout24, 2012) shows that the number of physical encounters among young people is not yet declining. Furthermore, the car is still considered a status symbol. 32% of Generation Y agree to the statement 'Cars are an important measure of success', compared to nearly a quarter of all respondents. That young people are still sensitive to the status of the car also appears to apply to the Netherlands. Only 64% of Generation Y agreed to the statement 'To me, a car is nothing more than a means of transport', compared to 85% of the generation from the sixties and seventies. So for the moment there are no clear indications that the status of car ownership among (Dutch) young adults is decreasing. KiM does not expect that the previously identified reduction in car use by young adults will continue (KiM, 2013).

Demographic changes

The developments in the age structure of the population – the proportion of the elderly, see Figure 20 – will also play a role in the development of mobility. The 65+ age group is responsible for almost half of the growth in mobility.

The aging population will also affect the performance of the driving task. Older drivers have limitations in how they process information and their reaction time. Developments in the field of driver assistance will therefore be especially important in the near future.

Socioeconomic changes

Socioeconomic changes also affect mobility. Figure 16 showed that 'Teleworking' ('Work Smart, Travel Smart', The New Way of Working) is responsible for a 2% decrease in mobility in recent years. Various rush hour avoidance projects have contributed to a reduction of approximately 5% of the congestion at regional bottlenecks. A financial incentive was used in many of these projects, such as a fee for each time the rush hour was avoided. Research shows that some of the participants continue the desired behaviour even after the compensation was no longer given. The percentage of participants

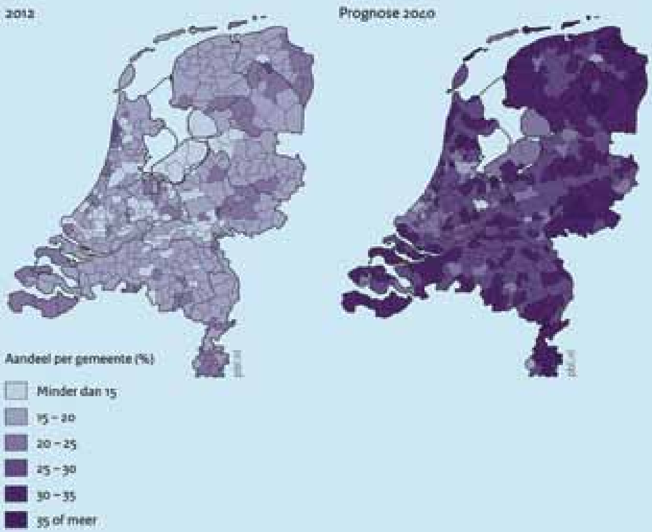


Figure 20: Share of 65+ in 2012 and 2040 (source: CBS/PBL).

showing a permanently changed behaviour strongly depends on the local situation: the urgency to avoid the rush hour is mainly determined by the level of congestion at those locations.
Several of the rush hour avoidance projects are continued in the 'Beter Benutten' programme.

Smartphones and (mobile) internet

Smartphones offer users the opportunity to inform themselves 'anytime, anywhere' on the current situation on the road as well as for planning a trip. The strong rise of the smartphone certainly contributes to a better use of the road.

For pre-trip travel information the Internet – fixed and mobile – is the most important source of information with a share of over 50%. For on-trip travel information, this is currently still the car radio (41%) followed by navigation systems (24%). However, recent research (I&O Research, 2013) shows that apps (17%) and the Internet (12%) together are already being used more than the information on the variable message signs (14%).

Intelligent vehicles

Within ten years, approximately 60% of the Dutch fleet will be connected continuously, via the driver and/or via equipment in the vehicle. This trend is expected to continue: within a period of fifteen to twenty years, virtually the entire fleet will be connected with other vehicles or with online services (Connekt, 2013). Automated vehicles will also appear on the road in the longer term. In October 2013, a prototype of such a vehicle was demonstrated on the road at the Innovation Relay by the Dutch Automotive Vehicle Initiative (DAVI), a collaboration between TNO, TU Delft, RDW and Connekt.

These developments will have a major impact on the fields of traffic management and traffic information. In particular, there will be changes in how traffic information reaches the road user. This transition is the core of the action programme Better Informed on the Road, now renamed Connecting Mobility. The underlying transitions that are foreseen are shown in Figure 21.

Figure 21: Transitions in Traffic Management and Information from the action programme Connecting Mobility (Connekt, 2013).


3

The main themes of 2014.

The field of traffic management is continuously changing. Which themes are on the minds of colleagues? What are policy makers worried about and where do they see opportunities? In this chapter, we have made a selection of the 'hot topics', subjects that deserve our attention in the immediate future: coordinated network-wide traffic management, the integration of roadside and in-car cooperative systems and data fusion.

Coordinated network-wide traffic management, CNTM for short, has been the great promise in this field since the nineties of the previous century. This approach allows road authorities to implement their available traffic management measures much more effectively. The only problem is that this is theoretical – in practice, CNTM has hardly been able to prove itself in all these years.* This makes it even more interesting that CNTM has now been given a serious chance with the large-scale Practical Trial Amsterdam. On the following pages, we will outline the principles of CNTM and its capabilities, with a focus on the approach that was followed for Practical Trial Amsterdam.

3.1. Coordinated Network-wide Traffic Management

What is CNTM?

Coordinated network-wide traffic management is the coordinated use of roadside and/or in-car measures to optimise the traffic performance within a regional network. CNTM can also be used to improve the travel time reliability, safety and quality of life.

From the many studies into the effectiveness of local or isolated traffic management measures we can conclude that most of these measures are cost-effective (Taale & Schuurman, 2013). However, the effects are often much lower than we would expect based on the theory. For example, a ramp metering system should, in theory, prevent the so-called capacity drop, responsible for a decrease in capacity of between 10 and 15%. In practice, however, no ramp metering system is capable of achieving this. On the contrary, on a global level, the gain in (effective) capacity we can realise by using an ramp

* Also on an international level there are only a few successful practical applications of CNTM. One of them is the coordinated ramp metering system on the Monash highway near Melbourne (Australia).

metering system is between 0 and 5%, even if the algorithm is well-designed and tuned. The explanation for this is that ramp metering systems can only function properly if there is sufficient space available on the on-ramp for the resulting queue of vehicles (buffer space). And because on average the on-ramps are only a few hundred metres long in the Netherlands, the buffer space is limited and the effective metering time short.

But there are other explanations for the limited effectiveness of ramp metering systems and other dynamic traffic management measures. The four most important ones are specified in the box text on the next page. The first three items speak for themselves, but we will clarify the fourth item by using the example in Figure 22 (Taale, 2008). There are two origin-destination pairs in this simple network: from A to B and from C to D. The travellers going from A to B can choose between two routes, with route 1 intersecting only with the route for travellers from C to D. We assume that the situation is in balance: the road authority has adjusted the traffic lights in such a manner that the intersection is controlled with the least possible delay, taking into account the amount of traffic on both inbound arms of the intersection. Due to air quality problems, however, the road authority decides to reduce the speed on route 2. This makes route 1 more attractive to travellers so more travellers will select this route to drive from A to B. This increased traffic demand on route 1 will result in more delay on the intersection. Therefore, the road authority will make the adjustments in such a way that the local traffic

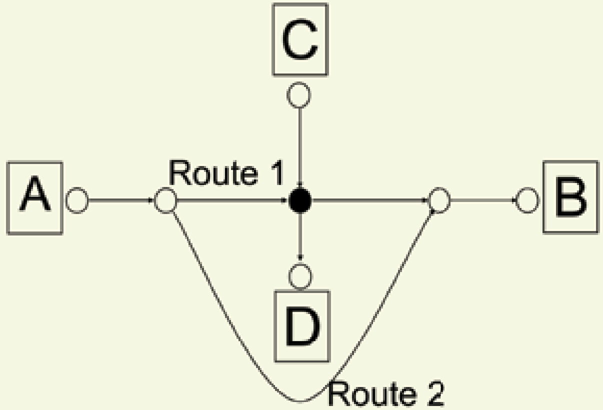


Figure 22: Example network.

throughput is once again optimised. This will be at the expense of travellers from C to D. Furthermore, the optimisation will make route 1 even more attractive compared to route 2, so even more travellers will select route 1 to drive from A to B. This process will repeat itself until a new balance is established.
However, this new balance proves to have significantly longer waiting times than the original situation. If we assume a speed limit of 100 km/h for route 2 in the original situation, and it is reduced to 80 km/r, the new balance will lead to approximately 30% more delay for this specific case. This example shows that if the road authority does not anticipate the reactions of the road users and just looks at the local situation (in this case: the situation at the controlled intersection), the use of the network is suboptimal.

Which methods are available?

The solution for these problems is – at least in theory – simple: opt for a network approach. This applies both to the design of the strategy for traffic manage-

Four reasons to opt for the network approach

1. **Due to policy constraints or location-specific constraints, the individual measures are often only implemented to a very limited extent (short periods).**
   Ramp metering systems, for instance, can only function if there is sufficient space available on the on-ramp for the queue (buffer space).

2. **The effect of a single measure is usually insufficient to solve a problem.**
   The gain in effective capacity that can be achieved with an individual ramp metering system, for example, is insufficient to prevent congestion on the main road.

3. **The effect of a single measure is cancelled out by problems elsewhere in the network.**
   A bottleneck downstream of the measure or heavy congestion on urban routes along which traffic is redirected, could, on balance, lead to no effect or an adverse effect.

4. **The reactions of travellers to the measure employed, (partly) neutralise the effects of the measure.**

ment and the implementation of the available measures. As far as strategy is concerned, methods such as ‘Sustainable Traffic Management Plus’ are available. Coordinated network-wide traffic management is the most suitable approach for its implementation.

The simple fact that we have been trying to think of ways to efficiently apply CNTM since the nineties, however, reflects the fact that the network approach is not easily deployed. Since then, science has mainly focused on the development of advanced, model-based optimisation methods, which allow you to determine which measure should be used at which moment. Such a method, which is often called *Model Predictive Control* (MPC), uses a traffic simulation model, such as METANET, FastLane, StreamLine, DynaSmart or DynaMIT to make a short-term prediction based on the current (measured and estimated) situation in the network. This prediction is dependent on the anticipated implementation of measures. Using MPC, we will then look for deployment of measures that would result in an optimal predicted traffic performance. It goes without saying that such an approach, especially for larger networks with multiple measures, is an enormous task from a computional point of view. This is why the last couple of years we see that researchers tend to focus on accelerating the computing processes, for example by simplifying the optimisation problem (MILP approach by Lin et al., 2011), or by using an intelligent reformulation thereof (LQR description by Le et al., 2013). However, we are still years away from the practical application of such optimisation methods.

Practice has meanwhile focused mainly on the development of methods that enable an approach based on so-called traffic management scenarios. A traffic management scenario describes which measures should be used under which circumstances. An important limitation is that no a-priori assessment can be given of the resolving power of a certain traffic management scenario for the prevailing situation. There is also the problem that it requires an enormous amount of traffic management scenarios to cover all possible situations in the network. The approach with the Scenario Coordination Module or SCM (Wang, et al., 2010), developed within the framework of the project Improving Throughput on the Ring Road A10, which is part of the FileProof (short term approach to congestion) programme, addresses this point by working on sub-scenarios (‘building blocks’) that are combined by the SCM. Because it could not be determined during the evaluation of SCM at which moments the module was operational (TrafficQuest, 2010), it was impossible to unambiguously determine the effect of the coordination. However, an estimate indicates that coordination with the SCM resulted in about 4% less delay on the A10, even though there was approximately 2% more traffic (DHV, 2012). This is on top of the 12.5% reduction in delay that was already achieved with the local measures without coordination (TrafficQuest, 2010).

CNTM and Practical Trial Amsterdam

The FileProof project ‘Improving Throughput on the Ring Road A10’ was followed up by the ‘Practical Trial Amsterdam’. Within the Practical Trial several aspects of the CNTM approach were

improved, including through the use of *proactive* and *sophisticated* control. By this we mean that the measures should be implemented as much as possible before the onset of congestion and that the level of implementation should be tailored accurately to the nature and severity of the problem. For metering on the on-ramps, this means that the right amount of traffic (not too little and not too much) should be stopped.

A number of control principles have been formulated for the Practical Trial Amsterdam.

1. **The capacity drop should be avoided or postponed whenever possible.** Once congestion occurs, the capacity drops with percentage points at a time. Therefore, it is important to control proactively and influence traffic flows moving towards the bottleneck, so congestion (and hence the capacity drop) is avoided or at least delayed.
2. **A traffic flow in the network may not be hindered unnecessarily.** The approach is to prevent blockages and blocking back effects at intersections and junctions. To realise this, traffic control measures are adjusted and the strength of the control measure is tailored to the current traffic situation.
3. **To the extent possible, a traffic problem should be resolved at the level where the problem occurs (is caused).** This can be achieved by controlling traffic in layers and by timely scaling up and by using the space in the network optimally, according to the current traffic situation.

‘Controllers’ were then developed based on these principles. An important feature of these controllers is the feedback structure, which means that the strength (scope) of the control measure is directly related to the (desired) effect.

As discussed earlier, the Roadmap of the action programme Connecting Mobility foresees a transition towards a more in-car oriented traffic management approach. Within the Practical Trail Amsterdam, tests are conducted in the so-called *in-car track* that should provide insight into the technical and traffic engineering possibilities of such an approach. The track focuses on the gathering of data and the provision of personalised travel and route information.

3.2. Integration roadside and in-car

In recent years there has been a lot of attention for the possibilities in-car technology provides for gathering information about the traffic performance and influencing this traffic performance. With regard to influencing, it primarily concerns technology that supports the 'strategic driving task', such as providing personalised travel and route advice. Secondarily, it concerns technology that can take over (parts of) the actual driving task.

There is a lot of international attention for the subject. In the United States, for example, they have launched the 'Connected Vehicle Research' projects, while the projects CVIS, eCoMove and Compass4D are in progress or have just been completed in Europe. This mainly concerns research projects, which primarily study the potential of such systems in small-scale pilots.

Transition and integration of roadside and in-car

The transition to a traffic management system based on in-car measures is expected to be gradual. This means that for a considerable period, roadside and in-car systems will be used side by side. The question is if, and if so, how, both systems can work together during the transition period. Will we keep the systems separated, for instance, with the market using in-car systems to inform the road user and the government playing a more intervening or guiding role using roadside systems? Or can something be gained from integrating both systems at an early stage? An option would be to share roadside and in-car data. An illustration of the possibilities: after an incident, road users are diverted by their in-car systems. The in-car systems share these recommendations with roadside systems, which, in turn, timely adjust the traffic control measures to facilitate the increased traffic demand on the alternative route.

It is expected that the combination of data from the roadside systems and the in-car systems also leads to an improvement of the quality of the data. This could include the use of 'floating-car traces' to better visualise the situation on the motorway, possibly with a reduced number of loops – see also the section on data fusion – or to improve the estimation of queue lengths on the urban road network. Another interesting option is the use of real-time origin-destination information or traffic flows on specific routes for network-wide traffic management.

What other issues are there in the deployment of in-car systems? An often-mentioned advantage of in-car systems is that they would increase the self-organising ability of the traffic, which reduces the need for outside intervention on traffic flows. If intervention is still desired, in-car technology also provides the ability to monitor and influence traffic flows in a much more refined way. However, actually exploiting these advantages requires more insight into the goals pursued with in-car technology – the focus – and their consequences. At the moment, in-car services are mainly focusing on improving the situation of the individual driver and less on improving the system performance. This has to do with the fact that in-car

systems are usually managed by the market parties and for them it is most important to serve their customers as well as possible. For in-car technology to become a full-fledged traffic management tool, it is key to find a mode in which the so-called system optimum is leading – and not the user optimum – at the moments that this is required.

A final point to note is that in-car measures do not increase the effective capacity of the road, unlike roadside measures such as ramp metering. In other words, with the current generation of in-car systems, the available capacity in the network can be utilised, but not increased. This will only change in the longer term, when advanced applications such as platooning are introduced. We may then see a real shift, with in-car measures being used for guidance and intervention.

An outlook on the new role of existing roadside systems

Whatever the outcome of the transition, and no matter how the aforementioned points are addressed, it is clear that the traditional roadside technology will continue to play an important supporting role in the coming decades. The role of the roadside measures will, however, gradually change into a more cooperative one, in which roadside and in-car systems will operate as one.
Below we will discuss the consequences this will have for the main roadside systems. We will first look at the traffic-related functions the relevant roadside measures are currently fulfilling, and then discuss how in-car systems can contribute to them.

- **Ramp metering systems**

The use of ramp metering systems normally has two traffic-related objectives. The first one is *restricting the inflow of traffic onto the main road*, to ensure that the flow on the main road does not reach the critical threshold. This will prevent or at least delay a capacity drop. The second objective is *to facilitate the merging process* by better spreading the merging traffic in time. This prevents abrupt merging actions from disturbing the traffic flow.

The restrictive function of the ramp metering system will not be replaced by in-car technology in the short term. However, in-car technology can provide an important contribution to supporting the merging process. There are two sides to the merging process, that of the on-ramp and that of the mainline. As the name indicates, a ramp metering system only intervenes in the traffic on the on-ramp, one side of the 'zipper'. In-car technology offers the possibility to influence both sides of the zipper at the same time in such a way that the positioning of the vehicles relative to each other can be determined. A prerequisite for successful application of such a 'merging assistant' is that sufficient vehicles, both on the motorway and on the on-ramp, are equipped with the in-car technology.

If one measure is not sufficient to solve an expected traffic problem, a combination of measures can be used. In case of a ramp metering system, the situation may arise that the queue on the on-ramp threatens to block the underlying road network. By sharing the load with on-ramps located further upstream, the risk of blocking back

(or: the necessity to turn off the system due to this impending blocking of traffic) can be prevented. This form of coordination is now being tested in the Netherlands as part of the Practical Trial Amsterdam within the so-called roadside track. A disadvantage of this ‘remote traffic management’ is that a part of the traffic that is stopped on an upstream on-ramp, may not have had plans to travel past the bottleneck. Information from the vehicles can then be used to better estimate how much traffic should be metered, but also to determine whether the delay for traffic that will not travel past the bottleneck location is acceptable. In addition, in-car systems can inform users of an upstream on-ramp about the reason of the metering. This helps to reduce the number of times the red light is ignored – road users will better respect the red light if it is clear why they should wait – and may render the currently necessary red light cameras redundant.

In-car systems can also be used as a support measure by timely informing road users about the upcoming bottleneck on the main road or on-ramp, so that the road user can choose a different route, should one be available. This has advantages for both the road user in question and for the traffic that does not have the possibility of choosing a different route.

• Traffic signal controllers

The purpose of traffic signal controllers is to safely and efficiently handle traffic at an intersection. Traffic lights allow the control and the distribution of the crossing moments, so they are ‘fairly’

distributed among the road users. Traffic signal controllers also allow road authorities to prioritise specific target groups, such as emergency services and public transport.

A more efficient handling of traffic at an intersection can be achieved by making better use of the green time of the traffic lights. From the roadside perspective, this can be done by providing the traffic control installation with sufficient information, so it can determine an optimal distribution of the green times of the traffic lights according to the nature and size of the conflicting traffic. As long as the penetration rates of in-car systems are still low, this information will be provided by roadside sensors. However, in-car information such as approach speed, selected direction at the intersection and position in the queue can be used to further optimise the distribution of the green times. Smartphones of pedestrians and cyclists can also be used to determine their numbers. This measurement method is more accurate than the method based on traditional roadside sensors.

A better use of green times is also possible from the side of the vehicle. Once the green times and the expected moment of passing the stop line are known for the vehicle, it can be determined in-car how the traffic lights should be approached. For example, by adjusting the speed, which allows the vehicle to pass the stop line at the highest possible speed and without stopping, or by releasing the gas pedal earlier if the green light cannot be made anyway, thus saving fuel and the environment.

If a clear main direction of the traffic flow passing a number of consecutive intersections can be distinguished, it may also be useful to realise a 'green wave' for the traffic on the main route. In this case, the advantages of a green wave for the main direction outweigh the disadvantages for the other road users. We do, of course, already have green waves in the 'roadside form'. However, based on in-car information the flows on a section of a route can be monitored real-time, while the added value of a green wave can also be determined in real-time. It is also possible to calculate the travel times between intersections, which can be used to better coordinate the green time windows of consecutive intersections.

• Variable message signs

As a rule, variable message signs giving route information (travel time) are used to improve the distribution of the traffic over the network. In determining the text to display, the question is always what message is expected to be most effective given the (final) destination and other properties of the traffic passing at that moment. The message on the variable message signs thus serves the greatest common divisor of the traffic passing the relevant panel. In-car systems can be used to determine this greatest common divisor, and thus increase the effectiveness of the variable message signs, in particular for that portion of the traffic that does not make use of an in-car navigation system. For the traffic that does use an in-car navigation system, tailored information can be offered, meaning personalised information based on the destination, route preferences and so on.

- **Automatic incident detection**

Automatic incident detection using overhead signs was designed to promote road safety and throughput by timely warning road users of abrupt changes in downstream speeds. By using the overhead matrix signs to close lanes, road workers and stalled vehicles can be ‘safeguarded’. The latter is not possible with in-car technology. This would require all vehicles to be equipped with in-car technology, which is not realistic in the short term. Warning for abrupt changes in downstream speeds, however, works well. A relatively small percentage of equipped vehicles already suffices to realise a gradual speed adjustment for the entire traffic flow.

Automatic incident detection can also be used to slow down the growth of a traffic jam, allowing it to dissolve more quickly. If you depend on roadside systems for this, the space required for an effective implementation of such a measure becomes a limiting factor. Because traffic is normally monitored and influenced every 500 metres, much more space is required than with an intricate, vehicle-based system. This means that even at lower penetration rates, vehicle systems have a clear added value. Since disruptions are detected quicker, they can be solved quicker while less space is required to achieve this.

However, to prevent is better than to cure. At sufficient penetration rates (achieved by providing vehicles with the relevant technology), the *occurrence* of shock waves can even be combated.

3.3. Cooperative systems

Based on the current communication technologies, it is possible to share more information and to share it more frequently. That provides opportunities for the traffic system: it allows the hitherto isolated systems in the vehicles and along the road to function in a more intelligent way and based on more and/or more up-to-date information. Within the field of traffic, such coupled systems are called *cooperative systems*. Within these systems communication can take place between vehicles (V2V), between vehicles and infrastructure (V2I), between infrastructure elements (I2I), between vehicle and device (V2D), etc. - also see Figure 23.

For the communication to be successful, the communicating parties should speak the same language and – in the case of cooperative systems also literally – be on the same wavelength. Especially in this area, there have been important advances, allowing the large-scale deployment of cooperative systems as soon as in 2015. Below we will briefly name the most important initiatives and results.

At the end of 2008, the European Commission adopted the *ITS Action Plan*. The purpose of this plan is to accelerate and coordinate the realisation of intelligent transportation systems (ITS). The standardisation organisations CEN and ETSI were asked in 2009 to jointly develop a minimum set of standards for interoperability, which they delivered early 2014. *Directive 2010/40/EU*, which was adopted at the end of 2010, is an important motor behind the coordinated im-

Figure 23: Illustration of a cooperative system (source: CVIS).

plementation of ITS in Europe. This Directive should ensure that ITS services are interoperable, while the Member States can make their own decision on the systems in which they wish to invest.

In the Netherlands, businesses, government and knowledge institutions decided to unite in DITCM, the *Dutch Integrated Testsite for Cooperative Mobility*. DITCM wants to be the point of contact in the Netherlands in the field of development, standardisation, testing and application of smart mobility. Additionally, DITCM strives to be a leading international partner in the field of cooperative mobility. The public-private organisation works along four programme lines which each have the main purpose of accelerating the deployment of cooperative systems: Human Factors (limitations and possibilities of the driver), Technology (standardisation), Effect Studies (tools to determine traffic-related benefits) and International Policy (matching international issues and ITS developments). Within Rijkswaterstaat, *Connecting Mobility* acts as a driving force for the developments.

Day one applications between vehicles (V2V)	Day one applications between vehicles and the roadside (V2I)
1 Hazardous location warning	1 Probe Vehicle Data (Floating Car Data)
2 Slow vehicle warning	2 Signal phase and time of traffic lights
3 Stationary vehicle warning	3 Road works warning
4 Emergency brake light	4 In-vehicle signage
5 Emergency vehicle warning	
6 Motorcycle approaching indication	

Table 7: Ten 'day one' applications for cooperative systems (source: Amsterdam Group).

In Europe, the parties that want to facilitate the joint deployment of cooperative ITS in Europe for 2015 are organised in the so-called *Amsterdam Group**. These are umbrella organisations CEDR (Conference of European Directors of Roads), ASECAP (European Association of Operators of Toll Road Infrastructures), C2C-CC (Car-to-Car Communication Consortium) and POLIS (network of European cities and regions working together on 'sustainable mobility'). The partners are working on a roadmap for the planned deployment of cooperative ITS. Seventeen items have been defined that require additional actions. Determining the so-called 'day one' applications is one of those items. These are applications that can be realised relatively quickly and have an immediate added value for the driver – even if only a relatively small part of the vehicles is equipped for the application. Table 7 summarises the selected 'day one' applications.

* See www.amsterdamgroup.eu.

The CEDR countries the Netherlands, Germany and Austria have taken the lead in realising two of the identified ‘day one’ applications over a motorway corridor that connects the three countries: the Cooperative ITS Corridor. These applications are ‘Road works warning’ and ‘Probe vehicle data’. Although on paper these do not seem very innovative applications, the main challenge is to get the applications working seamlessly along the entire corridor. Typical urban applications such as ‘Signal phase and time of traffic lights’ are taken up at the POLIS level and in European projects such as eCoMove and Compass4D.

Another item that requires attention according to the Amsterdam Group is the upgrading of vehicles that are not equipped with co-operative technology. This could be achieved by creating a link between the smartphone of the driver and the vehicle. The *Car Connectivity Consortium* is addressing these issues: it has developed an open industry standard for the integration of smartphones in the vehicle, called MirrorLink. This standard makes it possible to access the vehicle sensor data. In addition, guidelines are being prepared for the development of applications that the standard can use in the vehicle. The consortium has a set up a transparent certification process for connectivity and applications.

3.4. Data fusion

The subject data fusion has received a lot of attention in the past year. The expectation is that the combination of different data sources will lead to a significant improvement in both the quality and the completeness of the information we can get from our traffic data. By this we mean not only that the accuracy, reliability and timeliness of the information improve, but also that more traffic-related variables can be measured. For example: when we only use loop detectors, we will know the traffic volume, but by combining that data with Bluetooth observations, we can also determine the travel times and origin-destination data.

So data fusion seems to be a synonym for ‘more with less’. This may imply a qualitative leap, but also a reduction in costs while the quality level remains constant. A combination of just a few loop detectors and floating car data (FCD) could possibly deliver the same information quality as the current closed network of monitoring loops. In a time in which terms like economising of the monitoring network are often heard, data fusion seems an interesting option!

However, combining several data sources efficiently and effectively requires state-of-the-art data fusion techniques. Various methods have recently been developed, some of which are ‘ready to use’ and have already found their way into applications. This brings practical (traffic) applications a lot closer.

Level	Goal	Application (technique)
1	Processing of raw data	State estimation (digital filtering, Kalman filters, Adaptive Smoothing Method)
2	Determine characteristics and patterns	Classification methods (pattern recognition, neural networks, Fuzzy Set theory)
3	Taking decisions	Decision support and expert systems (Bayesian Belief Networks, Fuzzy AI)

Table 8: Examples of data fusion on different levels.

What is data fusion?

In the most general sense, data fusion comprises combining information (inferencing) from multiple data sources. This can be done at different levels: the processing of raw data, the derivation of the characteristics and patterns, and the making of decisions. Table 8 provides examples of data fusion at these three levels and the techniques employed.

The first level is the type of data fusion that gets a lot of attention lately and the first one we will discuss in more detail. It involves combining various raw data sources, such as loop detectors, floating car data, travel time data and video, to determine relevant traffic-related variables.

The importance of data fusion

Any source of traffic data contains errors. The causes and characteristics of these errors are diverse. Loop detector errors stem from missing or double counting vehicles, especially in locations where there are a lot of lane changes. The individual speed measurements are also averaged incorrectly, namely over time, thus structurally overestimating the average speeds per minute. Floating car data errors occur because data are available only from a (small) part of the vehicles. Another issue is that GPS does not always work everywhere.

The strength of data fusion is in the combining of data with different semantic properties. Loop data, for instance, provide an excellent picture of what happens on a cross-section, taking into account all passing vehicles. For part of the traffic, FCD traces provide an excellent picture in time and space. This way, the gaps from one source are filled by the other source. In addition, some variables simply cannot be determined by one single data source. For example, origin-destination matrices and data on the route choice of road users.

Opportunities

The expectations of data fusion are high, but is this fair? To illustrate this, we will discuss two cases here. In the first case, the data quality resulting from combining loop data and FCD traces was studied for different configurations. The main considerations thereby were the distances between the loop detectors (500 m, 1000 m and 2500 m) and the penetration of the FCD-equipped vehicles that emit an FCD-trace. The FOSIM simulation model was used to compare the results with the ‘ground truth’. The case used involved the A13 between The Hague and Rotterdam.

Figure 24 shows the result of the calculation for the estimation of the speed at a random location with the aid of the *Adaptive Smoothing Method* (Van Lint and Hoogendoorn, 2008). The chart clearly shows how a limited amount of floating car data significantly improves the estimation of the speeds: at 2% FCD, the error is only half the size of the error in the 0% FCD situation. At the same time, the figure shows that in the current situation (only loop detectors approximately every 500 m) the error is just over 6%. The same error can be achieved with far fewer loop detectors (for example, every 2500 m), as long as the data is combined with sufficient FCD (in this case, approximately 2%). In short, this theoretical exercise clearly shows the opportunities for data fusion.

For the secondary road network data fusion also offers opportunities to significantly improve the quality of the currently available traffic data. A recent study (Kuwahara et al., 2013) shows how estimations

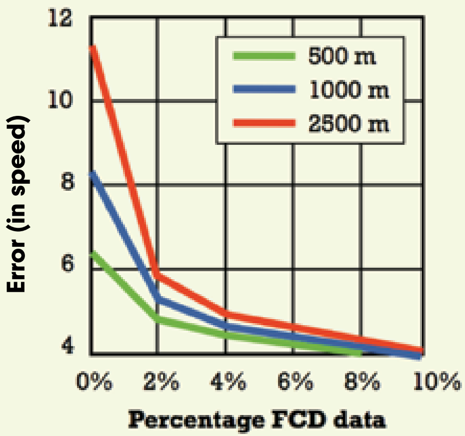


Figure 24: Relationship between the percentage of errors in estimating the speed and the share of vehicles that generates floating car data.

of the queue length, which are essential for the proper management of traffic on the urban road network, can be improved by combining the loop data with floating car data. In this concept, the routes of the floating cars, also called 'probes', are assumed to be (partly) known, while the counts at the beginnings and ends of the routes, in combination with a model, are used to reconstruct the dynamics of the queue. This provides excellent results with the queues being estimated very accurately.

Currently, the National Data Warehouse for Traffic Information (NDW) is conducting a pilot with data fusion. The results are expected later in 2014.

4

New developments in research.

Thorough research is the foundation of our field. This research is needed to first assess new policies, new systems and new methods, in order to safely, effectively and responsibly implement them. Therefore, this chapter focuses on the main research themes. What do we still want to know? What has been studied and published in recent years? And also: what are the research centres in the field of traffic and transport on an international level?

4.1. New research themes

For scientists the most important question is: what do we *not* know yet? We therefore begin this chapter by naming a number of knowledge gaps in the field of traffic management. For an important part, these research themes follow the 'hot topics' we discussed in the previous chapter, or they are preconditions for those topics. It successively involves behaviour, prediction with models, automated driving, the integration of roadside and in-car, the Network Fundamental Diagram, the management of mixed traffic (including bicycle flows) and open location referencing.

We link a clear research goal to each research theme. Based on a (short) elaboration of the theme we will indicate what the research will need to focus on.

Behaviour

Research goal: To increase knowledge and understanding of the behaviour of road users. Based on this, the effects of traffic management and traffic information measures can be predicted more accurately and the effectiveness of the traffic management can be increased.

Explanation: The purpose of a traffic management measure is normally to influence the behaviour of the road user on a strategic, tactical and/or operational level.
Currently, the emphasis of the influence is strongly aimed at informing, but it is expected that in the future the emphasis will shift to guiding and steering. This requires new knowledge about the choice behaviour of road users (such as route, speed and overtaking) under the influence of psychological, infrastructure and vehicle-related characteristics under different external conditions.
Moreover, modern influencing of behaviour does not just focus on one specific behavioural level. The challenge is to use the interactions between the levels: departure time, speed choice, route choice, mode choice and so on. These interactions then require a connection between the macro, meso, and microscopic models.
Another important thing is the change in

how traffic management is executed. Traffic management has evolved from the mission statement and tasks of the road authorities, but at the moment the trend is that more and more tasks are performed by private parties. At the same time, we have the growing influence of in-car systems and the possibilities offered by mobile communication. These developments change the tasks of the traffic manager irrevocably: coordination with the private sector and other service providers, for instance, is crucial. The question is how traffic management can be used in this new playing field in such a way that the behaviour of road users is effectively and consistently influenced.

Further reading*

- *The design road user – Characteristics of the road user and the relationship with traffic management. TrafficQuest, 2013 (in Dutch).*
- *Human factors in Traffic Management. TrafficQuest, 2012.*
- *Traffic control centres and network management. TrafficQuest, 2011 (in Dutch).*

*** For links and/or downloads, please go to www.traffic-quest.nl/en/traffic2014.**

Predicting traffic

Research goal: To determine how and with which methods models can generate reliable information about traffic management measures to be implemented, both for the long and the short term.

Explanation: Long-term estimations and short-term predictions each require their own approach and estimation methods. In doing so, a balance must be found between the accuracy (how accurate are the predictions in reality?) and the complexity of the method (what kind of investment does the method require?).

Long-term predictions

We will often use models for so-called offline applications. This may involve the prediction of a trend, for example, 'the traffic jams in 2030', or the prediction of the effects of measures, such as 'the situation next year after the construction of a rush-hour lane.' A static traffic model is normally sufficient for the assessment of general trends and predictions for the long term, however, for an accurate picture of congestion and the effects of measures, we need to rely on dynamic models.

Some questions we need to answer in this respect are:

- How can intersection delays correctly be included in the model calculations, including in congested situations?
- How can a reliable dynamic origin/destination table be estimated?
- What is the influence of different road users and modes of transport on the capacity and quality of the traffic performance?
- What is the effect of measures aimed at influencing the driver's behaviour?
- How can we model the traffic flow at a congested acceleration lane?

Short-term predictions
Estimations of the traffic performance can be very useful in coordinated network-wide traffic management: these estimations make proactive management possible. This does, however, require that the effects of various measures are calculated in real-time and *parallel to the operational process*, based on the current traffic situation and predicting no more than two hours ahead.
The results of these calculations can be communicated directly to users, for example through variable message signs or via an in-car application, or they can serve as input for traffic management.

The use of short-term predictions in proactive traffic management requires further research and improvement in the following aspects:

- How can we accelerate the calculation time sufficiently? We need to be able to run a (number of) traffic simulation(s) faster than real-time.
- What is the effect of external influences – inflow, incidents, weather – on the traffic performance?
- For short-term estimations, it is essential to gain more insight into how road users react to traffic management measures and to what extent they comply with them.

Further reading*

- *Dynamic Origin-destination Matrix Estimation in Large-scale Congested Networks. Rodric Frederix, 2012. Doctoral thesis at the Faculty of Engineering of the KU Leuven, Group Science & Technology. ISBN 978-94-6018-505-2.*
- *Intersection Modelling and Marginal Simulation in Macroscopic Dynamic Network Loading. Ruben Corthout, 2012. Doctoral thesis at the Faculty of Engineering of the KU Leuven, Group Science & Technology. ISBN 978-94-6018-506-9.*
- *Bayesian Data Assimilation for Improved Modeling of Road Traffic. Chris van Hinsbergen, CPIJ, 2010. TRAIL thesis no. T2010/9, TU Delft. ISBN 978-90-5584-132-5.*
- *Multi-Class Continuum Traffic Flow Models: Analysis and Simulation Methods. Femke van Wageningen-Kessels, March 2013. TRAIL thesis no. T2013/7, TU Delft. ISBN 978-90-5584-163-9.*
- *Lagrangian Multi-Class Traffic State Estimation. Yufei Yuan, March 2013. TRAILthesis no. T2013/5, TU Delft. ISBN 978-90-5584-162-2.*

*** For links and/or downloads, please go to www.traffic-quest.nl/en/traffic2014.**

Automated driving

Research goal: To determine how the concept of automated driving can be applied in the future. On which sections of the network would it be possible? Which problems should be solved first?

Explanation: Thanks to *Adaptive Cruise Control* (ACC) and *Cooperative Adaptive Cruise Control* (C-ACC) the vehicle can already take over many driver tasks. However, this does not mean that the developments end here: in various parts of the world, experiments are carried out with partially or fully automated vehicles, cars that can participate in traffic without the intervention of the driver. The introduction of such an automatic vehicle can have major implications on traffic flows (Van Arem, 2013). A few expectations:

- Automated driving with vehicles that communicate with each other can significantly reduce congestion, among other things by anticipating the downstream traffic situation and by increasing the outflow of the queue.
- An important purpose of automated driving is to reduce the number of accidents involving vehicles to zero. Using advanced technology, the vehicle can detect and neutralise risks of accidents more adequately than the driver. This also reduces the accident-related congestion.
- Automated driving can improve the energy consumption of a vehicle by 20% (Van Arem, 2013).
- Thanks to automated driving, the travel experience will also become more enjoyable. Drivers can enjoy their personal space in the car, while having the freedom to concentrate on other (useful, fun) activities.

Pilot projects to study the possibilities of automated driving have been organised in several countries – also see Chapter 5.3. However, there are still uncertainties about the introduction of automated driving. There are still many technical challenges, such as the robustness of the technologies and their integration. The following points also need to be solved before it can become a reality (EU, 2011; KPMG and CARgroup, 2012):

- **Legislation and regulations.** Who manages the traffic flows? Who is responsible in case of accidents? According to the Vienna Convention “every driver shall at all times be able to control his vehicle”. How will this be dealt with?

- **Acceptance by road users.** What are the effects of the introduction of automated driving on the behaviour of the ‘driver’?
How will the transfer of information to the driver take place and how can information overload be prevented?

- **Training.** How should users be trained? Should road users who do not drive automated vehicles also be trained so they are prepared for the new road users?

- **Financial aspects.** Who will make the necessary investments? Does the consumer alone need to pay for the in-car systems?

- **Technology.** What about the standardisation of technologies used, such as for

automated vehicle control and the interface? How can the computers and communications systems in the vehicles be protected against hackers?

- **Transition.** How should the automated vehicle operate in mixed traffic?

Further reading*

- *Self-driving cars: The Next Revolution. KPMG and Center for Automotive Research, 2012.*
- *Four Reasons Why the Car Should Do the Driving. Bart van Arem, 2013. Short note, TU Delft.*

* **For links and/or downloads, please go to www.traffic-quest.nl/en/traffic2014.**

Integration of roadside and in-car

Research goal: To achieve optimal cooperation between roadside and in-car systems in order to maintain an acceptable level of traffic performance.

Explanation: In the coming years, cars are expected to become more 'connected': it will be possible to send more information to and from cars. This means that not all information will have to be provided by the roadside systems. In Chapter 3 we already described what impact the transition to a fully in-car system will have and how these systems could coexist during the transition period. But roadside and in-car systems can also reinforce each other. A simple example: (connected) vehicles collect data about the tail of a queue and communicate this information via in-car systems as well as via roadside systems. This ensures reaching both connected and non-connected vehicles.

However, while the transition from roadside to in-car is a hot topic, the integration of both systems is not getting much attention in the current research. Especially this integration can help solve a number of practical issues. The transition from roadside to in-car may even be easier by making use of these integration possibilities.

Network Fundamental Diagram

Research goal: To describe traffic in a large metropolitan area in a simple and accurate way.

Explanation: Since 2007, the Network Fundamental Diagram or the Macroscopic Fundamental Diagram has been back in the spotlight. Traditionally, traffic is described at the level of a vehicle (microscopically), or at the level of a road (macroscopically). In 2007, an older idea was reintroduced, namely the fact that the traffic conditions in

an area depends on the number of vehicles in the area. This introduces a third level of description, that of areas. In this case, an area comprises a (preferably homogeneous) piece of one to a few kilometres in diameter, such as, for example, a city centre. After the empirical establishment of a Network Fundamental Diagram in Yokohama (Geroliminis and Daganzo, 2008), a very active field of research has emerged. At the moment, the subjects of study are mainly the (in)homogeneity in the area and the dynamics of the system. In other words: what happens when traffic flows into or out of the area? Once this is known, the traffic flow can quickly be calculated with a suitable traffic model for a large area. Such a simulation can be used to calculate traffic management measures in advance, and to optimise the traffic flow.

Further reading*

- *Urban Gridlock: Macroscopic Modeling and Mitigation Approaches. Carlos F. Daganzo, 2007. Transportation Research, Part B: Methodological 41.1 (2007): 49-62.*
- *Existence of Urban-scale Macroscopic Fundamental Diagrams: Some Experimental Findings. Nikolas Geroliminis and Carlos F. Daganzo, 2008. Transportation Research, Part B: Methodological 42.9 (2008): 759-770.*
- *Impact of Traffic Dynamics on Macroscopic Fundamental Diagram. Victor L. Knoop, Serge Hoogendoorn and Hans van Lint, 2013. Transportation Research Board 92nd Annual Meeting. No. 13-0595.*
- *Urban Network Gridlock: Theory, Characteristics, and Dynamics. Hani S. Mahmassani and Meead Saberi, 2013. Procedia-Social and Behavioral Sciences 80 (2013): 79-98.*
- *A new look at the handling of traffic in networks. Serge Hoogendoorn and Victor L. Knoop, 2013. NM Magazine, volume 2013, edition 2, p. 34-36 (in Dutch).*
- *Network Transmission Model: a dynamic traffic model at network level. Serge Hoogendoorn and Victor L. Knoop, 2014. Transportation Research Board 92nd Annual Meeting. No. 14-1104.*

*** For links and/or downloads, please go to www.traffic-quest.nl/en/traffic2014.**

Management of mixed traffic (bicycle flows)

Research goal: How can bicycle traffic be adequately included in the traffic signal control?

Explanation: Bicycle traffic is steadily growing in the cities (Municipality of Am-

sterdam, 2012). This traffic flow has become so voluminous that it is of importance to urban traffic management. In practical terms, this means that traffic signal control should be adjusted to the bicycle flows, which will result in delay for other road users. In addition, there are already ‘bicycle traffic jams’ in the centre of the large cities.
There are two major (scientific) challenges for this mode of transport.
First, it is unclear how to model bicycle traffic as a flow. This makes it difficult to calculate the effect of traffic management measures. Second, the growth of the bicycle traffic provides a safety issue: cyclists are a vulnerable group. Both research topics are especially interesting for traffic in mixed flows (cars and slow modes together).

Further reading*

- *A Porous Flow Approach to Modeling Heterogeneous Traffic in Disordered Systems. Rahul Nair, Hani S. Mahmassani and Elise Miller-Hooks, 2011. Procedia-Social and Behavioral Sciences 17 (2011): 611-627.*
- *Long-term Bicycle Plan 2012-2016. Municipality of Amsterdam, Department of Infrastructure, Traffic and Transportation, 2012 (in Dutch).*

Also see **www.vruits.eu**, the website of the EU project VRUITS, short for *Improving Safety and Mobility of Vulnerable Road Users through ITS Applications*.

* **For links and/or downloads, please go to www.traffic-quest.nl/en/traffic2014.**

Open location referencing

Research goal: Introducing an open standard which allows each data provider to unambiguously encode its traffic data.

Explanation: Due to the rapid advance of technologies to send data, there are more and more options to collect traffic data from road users. For these data to be useful for traffic information and ITS services, the positions, and, even more importantly, the roads, should be encoded unambiguously. With this purpose, TomTom developed the standard OpenLR, meaning ‘open location reference’ in 2009. The goal is to classify all roads in a functional manner. OpenLR can be used freely without charge.

Although the standard is far from being fully developed, it is without a doubt helpful to have a uniform standard. It can also be used for the further development of (open source) maps, such as OpenStreetMap and for other information purposes, like travel time information through the Waze network.

For more information on OpenLR, visit **www.openlr.org**.

4.2. Relevant PhD research

To stimulate the required knowledge development, TrafficQuest actively supports a number of PhD projects. Currently, TrafficQuest funds partially two PhD studies: the research of Gerdien Klunder into the relationship between the quality of traffic data and the effectiveness of traffic management, and the research of Simeon Calvert into the modelling of the variations in traffic. Both are doing their PhD at Delft University of Technology.

Relationship between data quality and the effectiveness of traffic management

An increasing amount of traffic data is becoming available from an also increasing number of sources: loop detectors, floating car data, Bluetooth data, etc. The quality of these data varies per source on aspects such as timeliness, accuracy and reliability. Even within one type of source the quality can vary greatly, depending, for instance, on the density of the measurement network at the location. An important question in this context is: when is the quality good enough? It is evident that the quality requirements may not be the same for every traffic management measure, traffic information service or for every situation. A time critical measure, such as the automatic incident detection system, for example, needs more accurate and higher resolution data than a system providing route information or a network-wide traffic management system. However, in most cases, the exact relationship between the various applications and the quality requirements of the data is unknown. This is an important point. After all, if you can manage with lower quality data, this saves money, for instance, because it requires fewer detection loops.

By clearly mapping the relationship between data quality and effectiveness, traffic management can perform better with the same data. In more advanced applications, it would even be possible to switch between different quality levels, depending on the time. The central research question in the

PhD research of Gertie Klunder is therefore: what is the relationship between the quality of different types of traffic data and the effectiveness of traffic management?

Since no standard approach was available, a general framework based on the utility theory and sensitivity analysis was developed to deal with this problem. To quantify the effect of uncertainty of a given input parameter on the ultimate performance of the system it should first be determined what the purpose of the measure is and how this can be measured and quantified with a so-called *measure of effectiveness* (MOE). Finally, a quantitative relationship can be found between the accuracy of the input variables and the MOE. This framework was tested on the basis of several cases.

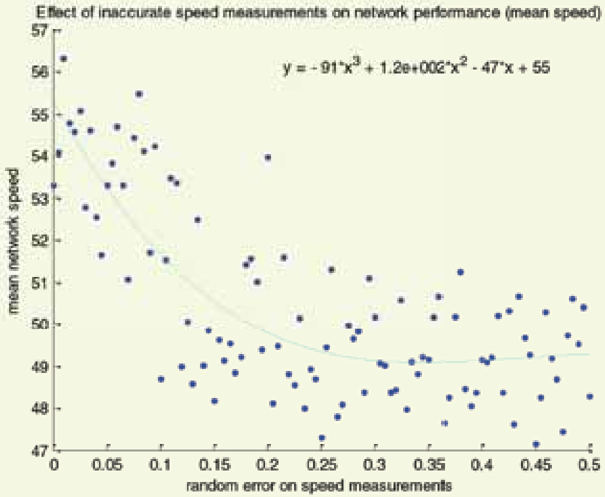


Figure 25: The effect of inaccurate measurements on the network performance of on-ramp metering (Klunder et al., 2014).

A case study on the impact of loop detector distance and penetration of floating car data on the queue tail warning application of the motorway traffic management system shows that at a detector distance of more than 300 metres, performance deteriorates rapidly and that the addition of floating car data with a penetration rate of only 1% greatly improves performance. A second case study examined a network with an ramp metering system. This study showed that the accuracy of the input data has a large impact on the traffic performance of the network. In the example, the researchers used simulations to determine the effect of the accuracy of the collected data for an ramp metering system (RMS) on the performance of the network, assuming a common configuration of loop detectors. It was then assumed that the same

measurements could also be performed with cameras, which yield less accurate measurements but are cheaper to purchase and maintain. This way, a design/time optimisation was performed, which allows for taking an investment decision based on a cost-benefit analysis. Both the speed and the traffic volume measurements were manually adjusted in the simulation to simulate inaccurate measurements. The study examined the effect of these inaccuracies on the functioning of the RMS – see Figure 25 for an example. The results show, among other things, that an error in the volumes has less impact than an error in the speed measurements. A utility function was derived for each type of error. This was used to determine the relationship between the accuracy of the collected data and the resulting effect on the traffic system. Then the cost-effectiveness of the different measuring systems was determined based on assumptions about the investment and maintenance costs and accuracies of different measuring systems.

In the remainder of the study, Klunder will further elaborate this approach for real-time optimisation. The case selected was queue length estimation at an RMS, using a combination of loop detector data and floating car data. The approach will be developed theoretically and will then be generalised. She will also further examine which measurement errors occur in practice, including their statistical correlations, and their impact on the quality of various traffic management applications with different time scales: Adaptive Cruise Control (very time critical), queue estimator (less time critical) and a dynamic routing system (hardly time critical).

Further reading*

- *Data fusion – what does it mean and what does it do? Gerdien Klunder, Serge Hoogendoorn, Leon Kester and Henk Taale, 2013. NM Magazine, volume 2013, edition 4 (in Dutch).*
- *The Impact of Loop Detector Distance and Floating Car Data Penetration Rate on Queue Tail Warning. Gerdien Klunder, Henk Taale and Serge Hoogendoorn, 2013. MT-ITS Dresden.*
- *The Effect of Inaccurate Traffic Data for Ramp Metering: Comparing Loop Detectors and Cameras Using Information Utility. Gerdien Klunder, Henk Taale, Leon Kester and Serge Hoogendoorn, 2014. 19th IFAC World Congress, Cape Town.*

*** For links and/or downloads, please go to www.traffic-quest.nl/en/traffic2014.**

Modelling of stochastics in traffic

In macroscopic traffic models, we always allocate a certain average value to the different input variables. In reality, however, the values of these input variables may show a large spread, caused, for instance, by changes in human behaviour and all sorts of external influences. The goal of the PhD research of Simeon Calvert is to develop a method to model variations in traffic. This will give us a better insight into the variation and reliability of the model results, and, in consequence, into the uncertainties of the traffic system. Another goal of the research is to shorten the required calculation time, thus increasing the applicability.

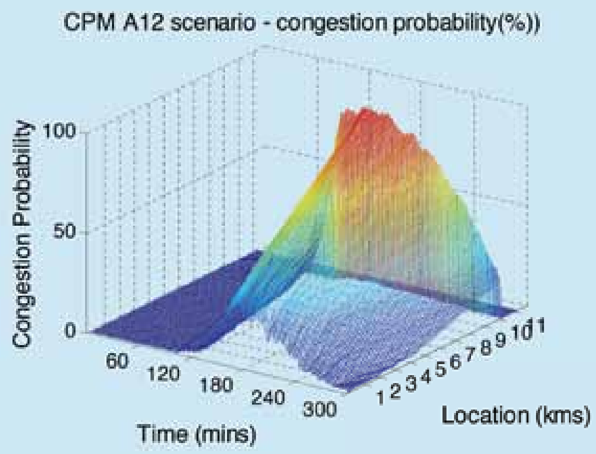


Figure 26: Modelled congestion scenario for a test case on the A12 (Calvert, 2014).

In his research, Calvert will, among other things, further elaborate the quantification of disruptions in traffic. Understanding the extent of these disruptions is needed to produce reliable input for the traffic model. He also develops a framework that allows communicating the reliability of the results (the uncertainties) of traffic models to the users, such as policy makers, in a clear manner. A correct interpretation of the results of traffic models demands a clarification on both the input data used and the model calculations performed.

Some interesting results have been achieved over the past period. Through an extensive data analysis, for example, Calvert has identified key variables that affect the traffic flow, particularly on the motorway network. Especially the day-specific variation (e.g.,

day of the week or holidays) and weather conditions (such as rainfall, frost and other extreme weather conditions) turn out to play a major role. In determining the impact on the traffic flow, variations in demand (traffic demand under varying conditions), variations in the supply (the capacity of the road) and the interaction between supply and demand have been taken into account. This made it possible to derive uncertainties regarding the capacity drop – the additional loss of capacity in the transition from free-flowing to congested traffic – in different situations. The result of this analysis is documented in a series of probability distributions that can serve as input for a probabilistic traffic model.

A conceptual theoretical description of the probabilistic traffic model or *Core Probability Framework* (CPF) was also drawn up. Step by step, a method has been developed, that makes it possible to describe the probability and reliability in a model calculation. The description of the core of the methodology has been completed, but the further development of the model is ongoing.

The intention is to focus on the presentation of the results of a probabilistic model in the follow-up. Figure 26 shows an example of the results of a calculation of the probability of traffic jams on the A12. The example makes it clear that visualising the results in a consistent way is no trivial matter. Therefore, cognitive scientists were involved in the project in order to jointly work out a visualisation system that makes it possible to communicate the uncertainties in the model results in an understandable manner.

Further reading*

- *The Need for Probabilistic Modelling for Tactical and Operational Analyses. Simeon Calvert and Henk Taale, 2014. Transportation Science Magazine, Volume 51, No. 2, May 2014.*
- *Quantification of the influence of rain on the traffic flow. Simeon Calvert, Wouter van Stralen and Eric Molin, 2013. Colloquium Transport Planning Research 21-22 November 2013, Rotterdam (in Dutch).*

*** For links and/or downloads, please go to www.traffic-quest.nl/en/traffic2014.**

4.3. Interesting conference papers

Every year, researchers in the field present their research results at various national and international conferences. A number of these papers stood out due to their particular focus or practical applicability. Without denying the value of the other papers, we will provide a summary of the most important contributions.

ISTTT20

The twentieth edition of the *International Symposium on Traffic and Transportation Theory*, from 17 to 19 July 2013 in Noordwijk, mainly saw the presentation of theoretically oriented contributions. However, the two papers below quickly make the link to practical traffic management applications.

- *Freeway On-ramp Bottleneck Activation, Capacity and the Fundamental Relationship. Seoungbum Kim and Benjamin Coifman, 2013.*
  This publication discusses how the concept of capacity drop may be explained by interpreting the measurements differently.
- *Modelling Supported Driving as an Optimal Control Cycle: Framework and Model Characteristics. Meng Wang, Martin Treiber, Winnie Daamen, Serge Hoogendoorn and Bart van Arem, 2013.*
  This paper shows how traffic flow can change when vehicles drive automatically and thereby optimise both the flow and energy consumption.

*** For links and/or downloads, please go to www.traffic-quest.nl/en/traffic2014**

Also see www.isttt.net.

IEEE-ITSC

IEEE annually organises the *Intelligent Transport Solutions Congress* (ITSC), a congress on ITS and its technical aspects. In 2013, the ITSC was held in The Hague from 6 to 9 October. In this edition, IEEE again granted several Best Paper Awards. For road traffic, the following contributions were especially interesting.

- *Analysis of Traffic Performance of a Ramp Metering Strategy Using Cooperative Vehicles. Riccardo Scarinci, Benjamin Heydecker and Andreas Hegyi, 2013.*
  This paper describes how you can improve the effect of ramp metering with the help of in-car technology.
- *A Cooperative System Based Variable Speed Limit Control Algorithm against Jam Waves – an Extension of the SPECIALIST Algorithm. Andreas Hegyi, Bart Netten, Meng Wang, Wouter Schakel, Thomas Schreiter, Yufei Yuan, Bart van Arem and Tom Alkim, 2013.*
  The key question in this contribution is how in-car speed advice can help dissolve shock waves.

*** For links and/or downloads, please go to www.traffic-quest.nl/en/traffic2014**

Also see **www.ieee-itsc13.org**.

ITS World Congress

The *ITS World Congress* brings together new ideas and best practices of ITS worldwide. At the ITS World Congress 2013, held from 14 to 18 October in Tokyo, three Best Paper Awards were granted by the European, Japanese and American ITS Committees respectively. These Best Papers were:

- *Improving Moving Jam Detection Performance with V2I Communication. Bart Netten, Andreas Hegyi, Meng Wang, Wouter Schakel, Yufei Yuan, Thomas Schreiter, Bart van Arem, Coen van Leeuwen and Tom Alkim, 2013.*
  This paper is similar to the SPECIALIST-paper on IEEE-ITSC – see above.
- *Development of a Car-Following Tendency Prediction Method and Its Application to a Forward Collision Warning System. Hirofumi Aoki and Osamu Ozaki, 2013.*
  In this contribution, the authors describe how a driver assistance system can 'learn' the driving behaviour of a driver, so it only alerts in case of abnormal manoeuvres.
- *Dynamic Travel Time Prediction using Pattern Recognition. Hao Chen, Hesham Rakha and Catherine McGhee, 2013.*
  This paper explains how travel times can be predicted with the aid of pattern recognition, making use of the traffic characteristics.

*** For links and/or downloads, please go to www.traffic-quest.nl/en/traffic2014**

Also see **www.itsworldcongress.jp**.

National Traffic Management Congress 2013

During the *National Traffic Management Congress*, which was held on 6 November 2013 in Den Bosch, the best graduation thesis was chosen:

- *Organise smarter, travel smarter. Martijn Hoogenraad and Gijs van der Kolk (Windesheim Technical High School), 2013.*
  This basically concerns a project for the design of a toolbox for mobility management measures: what is the appropriate measure for a certain type of problem? Ninety measures were analysed, classified and processed in an Excel application for the toolbox. The toolbox provides an almost complete overview of promising means to achieve behavioural change.

*** For links and/or downloads, please go to www.traffic-quest.nl/en/traffic2014.**

Also see www.nationaalverkeerskundecongres.nl.

4.4. Research groups

Figure 27: Main research centres in the field of traffic: a geographical overview.

To conclude the 'research chapter' in this Annual Report, we will briefly describe where in the world – at which universities and which institutions – relevant research is being done. We take this information from the list of winners of the *IEEE ITS Institutional Award*, which is awarded annually to the most influential institution in the field of ITS, and other sources. We will, however, also name other relevant institutions, especially in the field of traffic management.

PATH, University of California, Berkeley (US). Berkeley is one of the campuses of the University of California. PATH is a research and development program of the University of California (also located in Berkeley). The university excels in reducing problems to the

essence, making it the more theoretically oriented institute, while PATH, Partners for Advanced Transportation Technology, focuses more on examining practical problems. This research group won the IEEE ITS Institutional Award in 2007.

VisLab, Universit degli Studi di Parma (Italy) and NavLab, CMU (US). These institutes, winners of the Institutional Award in 2008 and 2009 respectively, mainly work on the facilitation of assisted automated driving.

CAST Lab, Institute of Automation, Chinese Academy of Sciences (China). The researchers of the CAST Lab, winners of the Institutional Award in 2010, are concerned with the automation side of traffic: parallel computing and artificial intelligence. The group mainly focuses on the development of software and hardware.

Technical University of Crete (Greece). The Technical University of Crete, in the traffic management world known as the university of Professor Markos Papageorgiou, has an extensive history in the field of traffic control. It is the cradle of the traffic model METANET and the HERO algorithm for the coordination of ramp metering. The TU of Crete won the IEEE ITS Institutional Award in 2011.

Northwestern University in Chicago (US). Hani Mahmassani has been with the Northwestern University in Chicago since 2007. His work is characterised by an approach which describes the traffic dynamics based on data. The group won the IEEE ITS Institutional Award in 2012.

Google Self-Driving Car Team, Google (US). In 2013, the IEEE ITSC Institutional Award was won by the Self-Driving Car Team of Google. Also see Chapter 5.4.

Siemens, TomTom, DLR in Berlijn (Germany). For Siemens, the German capital is an important test site for traffic management applications. TomTom has its German head office there and performs much of its traffic research there. DLR, the German Aerospace Centre, is also based in Berlin. The Institut für Verkehrssystemtechnik, led by Peter Wagner, is part of DLR and concentrates its efforts on traffic flows and control.

Transport & Planning, TU Delft (The Netherlands). This research group is one of the largest in the world in the area of transportation. The research covers the entire spectrum from planning and strategic models (Bart van Arem) to the traffic management of vehicles and pedestrians (Serge Hoogendoorn). Traffic management plays an important role in the research work. Other groups and faculties of the TU Delft also perform traffic research. All these research activities are bundled in the Transport Institute Delft, led by Bart van Arem.

EPFL in Lausanne (Switzerland). EPFL, the École Polytechnique Fédérale de Lausanne, has two groups that engage in traffic management. Michel Bierlaire mainly focuses on behavioural models, while Nikolas Geroliminis and his group focus on the modelling and controlling of Urban Transport.

Imperial College London, University College London, City University London (Great Britain). The metropolis of London has plenty of traffic problems, and they have made a large research budget available to solve them. Imperial College London is the technical university, with John Polak as the head of the Transport Department. They have a large group of researchers who focus on all traffic-related issues, including traffic management. The most relevant non-technical university is University College London. The group of Benjamin Heydecker has a general interest in traffic management. Ioannis Kaparias recently launched a traffic engineering department at City University London.

Institute for Transport Studies in Leeds (Great Britain). This institute has a broad focus on traffic flows, but has a particularly good name in the field of Human Factors (Oliver Carsten).

IFSTTAR in Lyon (France). A small group that is highly specialised in traffic flow and is led by Ludovic Leclercq and Christine Buisson are based in Lyon as a part of IFSTTAR. In this particular area, the researchers are certainly among the world leaders. The scope is quite narrow, which means that network management and optimisation of traffic control are not researched.

Siemens, BMW, TU München in München (Germany). A large part of German industry that is active in the field of traffic management is based in Munich. The traffic department of Siemens, for instance, is based in Munich. BMW is also from Munich, and this company has been investing heavily in research & development for connected vehicles and automated driving in recent years. Additionally, there is a group at the Technische Universität München who focus on traffic and traffic engineering (Fritz Busch).

University of Newcastle (Great Britain). The researchers at this university are working on a variety of subjects that touch the so-called multi-criteria optimisation of traffic management. Margaret Bell, for one, engages in environmentally friendly traffic management and monitoring in the urban environment (including with sensor networks). The group also focuses on intelligent transportation systems.

Kyoto University (Japan). In Kyoto, Nobuhiro Uno of Kyoto University focuses on ITS. In particular, his group investigates how IT systems assist in the improvement of the traffic processes. Recently, a new, moving base driving simulator was installed, which should provide new insights.

Tohoku University (Japan). Masao Kuwahara has been active in the research field of traffic engineering and the application of ITS systems for several decades. He was with the University of Tokyo for a long time, but now he has joined Tohoku University, also in the greater Tokyo area.

5

Traffic management pilots.

In this final chapter we focus on research as well as practice, which in this case means the field operational tests and pilots. Since the tested technologies and services are already very close to being deployed, the tests in the 'real world' offer a nice glimpse into the traffic systems and services of tomorrow. We will provide a thematic overview of the main pilots in which traffic management measures and intelligent transportation systems are tested. We will also name some platforms that facilitate and stimulate operational tests.

5.1. Coordinated Network-wide Traffic Management

Connecting Mobility (The Netherlands)

The challenge the Minister of Infrastructure and the Environment has set with the action programme *Connecting Mobility*, is a solid cooperation between governments, service providers and industry in order to achieve a smart and consistent mix of information via smart phones, navigation systems and collective information channels. This way, the Minister wishes to work on various social goals: 1) contribute to the objectives of accessibility, quality of life and safety set by the Ministry, 2) improve the service provision to travellers, 3) improve the (cost) effectiveness and efficiency of public traffic management and 4) strengthen the competitive position of Dutch companies.

The programme for 2014 includes the following key projects (also see later in this chapter):

- Theme Coordinated Network-wide Traffic Management: Practical Trial Amsterdam.
- Theme Logistics and International: Co-operative ITS corridor The Netherlands-Germany-Austria.
- Theme Multimodal Urban Accessibility: The Digital Road Authority.
- Theme Automotive and In-car (cooperative systems): Driving with in-car systems.

Phantom traffic jams on the A58 (The Netherlands)

Within this project, the Brabant region wishes to address the so-called phantom traffic jams (shock waves seemingly coming out of nowhere) using ITS applications. The idea is to use in-car speed advice to prevent congestion waves from originating and to reduce or even prevent the growth of traffic jams due to shockwaves.

More information:
www.sre.nl/projecten/spookfiles.

USDOT Integrated Corridor Management Pioneer Sites (US)

The US Department of Transportation (USDOT) has selected eight 'pioneer sites' that will act as a critical partner in the development, implementation and evaluation of

Integrated Corridor Management (ICM) strategies. These strategies have been developed to combat the congestion in the busiest urban corridors. Table 9 summarises the pioneer sites thereby indicating which applications will be used at each site.

The tests at the pioneer sites always go through three phases:

- Ph*ase 1:* Development of the management concept, data collection and preparation of the specifications.
- *Phase 2:* Analysis, modelling and simulation.
- *Phase 3:* Demonstration and evaluation.

More information:
www.its.dot.gov/icms/pioneer.htm.

DMA-ATDM Analysis-Modeling-Simulation Test Bed (US)

The *Analysis Modeling Simulation Test Bed*, known as AMS Test Bed, is also an initiative of the US Department of Transportation. The Test Bed provides a virtual computer-assisted simulation environment for targeted, integrated tests prior to deployment in the field. The AMS Test Bed is used to determine the effects of *Dynamic Mobility Applications* (DMA): innovative applications that are possible thanks to the data of wirelessly connected vehicles, travellers and the infrastructure. The possibilities of *Active Transportation and Demand Management* (ATDM) are also being studied.

For links and/or downloads, please visit:
www.traffic-quest.nl/en/traffic2014.

ITS Spot Services (Japan)

ITS Spot Services is a partnership of ten car manufacturers (Audi, Citroën, Mazda, Mercedes-Benz, Mitsubishi Motors, Nissan, Peugeot, Suzuki, Toyota and Volkswagen) and six developers of navigation systems and on-board units (Alpine, Clarion, Mitsubishi Electric, Mitsubishi Heavy Industries, Panasonic, Pioneer). Three services are offered on the test site: dynamic route advice, advice for safe driving and electronic toll collection.
The test site consists of 1670 ‘ITS spots’ on the expressways in Japan.

For links and/or downloads, please visit:
www.traffic-quest.nl/en/traffic2014.

	Corridor Assets to Be Integrated with ICM									
	Freeway			Arterial	Bus			Rail		
Pioneer Site Location	HOV	Tolling	Value Pricing	Real-Time Control	Fixed Route	Express Buses	Bus Rapid Transit	Commuter Rail	Light Rail	Subway, Heavy Rail
Dallas, Texas	●	●		●	●	●			●	
Houston, Texas	●	●	●	●	●	●	●			
Minneapolis, Minnesota	●	●	●	●	●	●	●			
Montgomery County, Maryland	●			●	●	●		●		●
Oakland, California	●	●		●	●	●	●	●		●
San Antonia, Texas				●	●	●				
San Diego, California	●	●	●	●	●	●	●			
Seattle, Washington	●			●	●	●		●	●	

Table 9: Integration of applications per 'Integrated Corridor Management Pioneer Site' (source: USDOT, 2014).

5.2. Integration of roadside and in-car, Cooperative systems

Practical Trial Amsterdam
(The Netherlands)

The *Practical Trial Amsterdam* is a large-scale and innovative field test in which government, industry and research institutes work together to reduce congestion in the Amsterdam region. Road users receive personalised travel information in their cars, so they can select the best route. Traffic lights and ramp metering systems respond to predictions of traffic jams in a coordinated manner. This enables road users to reach their destination faster while they can also count on a reliable travel time. If cost-effectiveness is demonstrated, the Practical Trial Amsterdam applications can be deployed nationally as well as internationally.

The project comprises three phases. In the first phase, the possibilities of roadside systems and in-car systems are tested separately. In phases 2 and 3, tests will be conducted that aim to achieve an optimal capacity utilisation of roads with full integration of both systems at the network level.

Cooperative ITS Corridor The Netherlands-Germany-Austria
(The Netherlands)

In the *Cooperative ITS Corridor*, cooperative services are realised on an international level. No longer as an experiment or a test, but as a real, practical application. With this project, the Netherlands, Germany and Austria focus on the corridor Rotterdam-Frankfurt-Vienna. Initially, the project will provide two services: roadworks warning and probe vehicle data collection for the purpose of traffic management and traffic information.

Once the services have been fully implemented, other services will be added in cooperation with the market, based on the technology applied and data available. These services may include bringing traffic signs in-car (in-vehicle signage), or providing advanced information for freight traffic to and from the port of Rotterdam, taking account of roadworks, available parking spaces along the route, driving and resting times and loading and unloading options at the port.

DRIVE C2X (EU)

In the EU project *DRIVE C2X*, Field Operational Tests were conducted at various locations in Europe to test and evaluate cooperative systems. At these test locations, participating parties could verify the advantages of cooperative systems and pave the road for their introduction by the market. The project has just been finished.
There were seven test locations in Germany, Italy, the Netherlands, Sweden, Spain, France and Finland. The functions that were tested include: in-vehicle signage, warnings for obstacles, roadworks, traffic jams, emergency vehicles and bad weather, speed advice at controlled intersections and various information services.
The aim was to study the impact of cooperative driving on users, the environment and society. The technical functionality and robustness of the systems – under favourable and unfavourable conditions – were also included in the operational test.

More information: **www.drive-c2x.eu**.

Compass4D (EU)

Seven European cities – Bordeaux, Copenhagen, Helmond, Newcastle, Thessaloniki, Verona and Vigo – have joined forces in *Compass4D* with the common goal to improve road safety, increase energy efficiency and reduce congestion levels for road transport. To tackle these challenges, the cities and industrial partners will jointly implement three cooperative services:

- *Forward Collision Warning: reducing traffic accidents by warning drivers about queues or vehicles that suddenly stop or slow down (upstream).*
- *Red Light Violation Warning: aimed at reducing the number of times the red light is ignored and minimising the effects of such violations, for example in case of crossing emergency vehicles.*
- *Energy Efficiency Intersection Service: this service allows the driver to select a fuel-efficient and comfortable speed profile when crossing an intersection.*

More information: **www.compass4d.eu**.

Connected Vehicle Research - V2V and V2I Technology Test Bed (US)

The *V2V and V2I Test Beds* are designed to test safety, mobility and environmental applications in a cooperative environment with the latest technology from the Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) research programme of the US Department of Transportation. The Test Bed provides roadside equipment in a number of cities in Oakland County, Michigan. A total of 32 miles of interstate highways and divided highways and 43 miles of arterial roads have been with equipped with roadside equipment.

For links and/or downloads, please visit: www.traffic-quest.nl/en/traffic2014.

ITS Green Safety (Japan)

The objective of *ITS Green Safety* is to use ITS for a greener and safer society. The operational tests take place in 'Greater Tokyo'. The applied technologies are:

- *Next Generation Driver Safety Support Systems (I2V)*
- *Cooperative Advanced Safety Vehicles (V2V, V2P)*
- *Smartway with ACC/CACC (I2V, V2V)*
- *ITS Spot Services (I2V)*
- *Mobile and ITS Spot Cooperative Services (I2V)*

More information: www.its-jp.org/english/its-green-safety-showcase.

5.3. Automated driving

Driving with in-car systems (The Netherlands)

The project *Driving with in-car systems* is the user-oriented cross-link between a number of ongoing projects within the theme automotive and in-car, namely Compass4D, Phantom Traffic Jams on the A58, Cooperative ITS Corridor, SPITSlive, Practical Trial Amsterdam (in-car track) and Brabant In-Car III. Within the programme line 'The human factor' of DITCM – see 5.6. – the market, government and knowledge institutions jointly share experiences regarding the use, perception and satisfaction of road users of in-car services. This includes the different ways in-car advice, for example, on speed is provided: what works well and what does not? This project will generate advice on the required (legal) conditions for the deployment and implementation of user-oriented in-car communication. It also provides input for a knowledge agenda within the so-called Implementation Agenda of the action programme Connecting Mobility.

Brabant in-car II (The Netherlands)

Four traffic tests were carried out in Brabant in 2012, which studied the effects of real-time information in the car on the driving behaviour of road users. The main focus of the *Brabant in-car II* projects was the relationship between humans and technology: how do the road users react to new technology in their cars or lorries? And what are the social effects? The information was provided pre-trip and on-trip via smartphone, tablet or navigation system. A total of more than 600 test drivers participated in the tests.
The follow-up project Brabant In-Car III is part of the project Driving with in-car systems.

More information:
www.sre.nl/projecten/brabant-in-car-ii.

Self-driving car on the A270 (The Netherlands)

The province of Noord-Brabant is becoming a test site for the self-driving car. This car will drive on the A270, the road between Eindhoven and Helmond. The vehicle will initially be tested responsibly in a so-called closed environment on the A270, before it takes part in the daily traffic. This phase will take at least seven years.

DAVI (The Netherlands)

TU Delft, TNO, RDW and Connekt initiated DAVI: the *Dutch Automated Vehicle Initiative*. DAVI will develop automated vehicles with robot vision, vehicle-to-infrastructure (V2I) communication and vehicle-to-vehicle (V2V) communication. The automated vehicles will share the road with manually driven vehicles. A first public demonstration of automated driving took place on 12 November 2013 during the Innovation Relay in Amsterdam.

More information: **www.davi.connekt.nl**.

Automated driving (EU)

In Europe, it is mainly the automotive industry which is committed to the introduction of automated driving. Volvo, for instance, intends to market an accident-free car by 2020. To this end, the company develops systems for automated driving in traffic jams, systems for automatic braking at intersections and systems aimed at detecting stray animals. Mercedes hopes to have a Mercedes S-class vehicle ready in 2020 which is able to participate in traffic completely automatically. Mercedes already has a fully automated prototype, the S500 Intelligent Drive, which completed a 90 km long route without the intervention of the driver. Audi, Bosch and BMW are also involved in the development of an automated vehicle.

Characteristic of the European approach is that in all cases, the driver remains in control of the vehicle. This is in accordance to the Vienna Convention (1968), which states: ‘Every driver shall at all times, be able to control his vehicle or to guide his animals.’

More information: **www.imobilitysupport.eu**, **www.citymobil-project.eu**, **www.haveit-eu.org** and **www.sartre-project.org**.

Source: Dutch Automated Vehicle Initiative

Automated driving (US)

Google has been involved in the development of an automated vehicle since 2005, the Google Driverless Car. In the meantime, this vehicle has driven approximately one million kilometres without accidents or the intervention of a driver. Interestingly, the state of Nevada adopted a law in June 2011 that regulates the use of automatically guided vehicles. Florida and California have also passed legislation allowing the use of automated vehicles. The US National Highway Traffic Safety Administration, however, has expressed concerns about the legislation of the states. The organisation 'does not recommend at this time that states permit operation of self-driving vehicles for purposes other than testing'.

Together with Segway, General Motors is developing the General Motors EN-V vehicle (Electric Networked-Vehicle). This is a two-seat, electric-powered concept car suitable for use in an urban environment. Tesla is also developing a driverless car.

For links and/or downloads, please visit: www.traffic-quest.nl/en/traffic2014.

Autopilot System (Japan)

A programme aimed at testing the technology of automated vehicles has also been established in Japan – see Figure 29. The following steps are followed in the development process:

- Introduction of systems that support the autonomous driving task, such as Adaptive Cruise Control (ACC), Pre-Crash Brake and Lane Keeping Assist.
- Introduction of cooperative driver assistance, such as an experiment on congested locations on the expressway with the aid of ACC and roadside-to-vehicle communication.
- Realisation of an autopilot: cooperative driver assistance systems for the control of the vehicle on motorways (ACC, longitudinal and lateral).

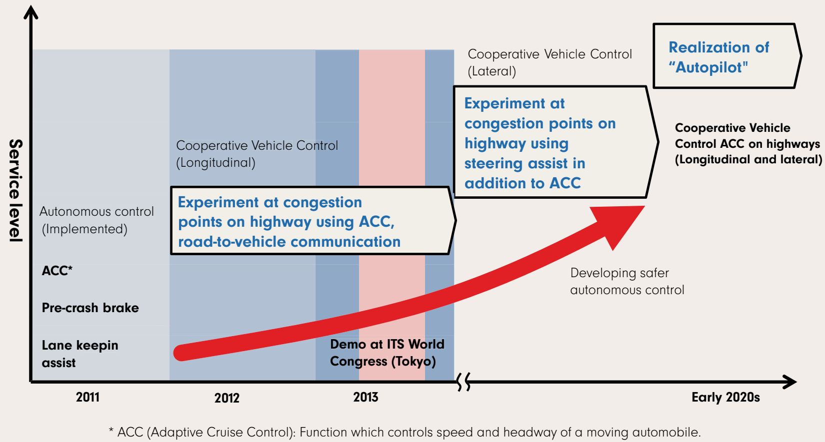


Figure 29: Development process of the autopilot system in Japan.

Around 2020, automated driving should be possible on the Japanese motorway network. As is customary in Japan, government, industry (including car manufacturers like Nissan, Toyota, Mazda and Honda) and research institutes (Tokyo Institute of Technology) worked closely together in the development of the AutoPilot. Car manufacturers have also set up their own test sites to test certain proprietary technologies. For example, Nissan and NTT DoCoMo are jointly exploring ways to improve the safety of pedestrians via communication (avoiding conflicts with vehicles). On 12 November 2012, Toyota inaugurated the Higashi-Fuji Technical Center in Susono City, Shizuoka. Intelligent transport systems can be tested at this site. The main goal is to reduce the number of traffic accidents by using roadside-to-vehicle communication.

For links and/or downloads, please visit: www.traffic-quest.nl/en/traffic2014.

5.4. Safety

SAFER (Sweden)

SAFER is a multidisciplinary research unit of 25 partners from the Swedish automotive industry, the academic world and the government who work together in the field of vehicle and road safety. Road safety is a high priority in Sweden, which is evident from the ambitions laid down in the policy vision *Vision Zero*. The project SemiFOT, *Sweden Michigan Naturalistic Field Operational Test*, was recently completed under the banner of SAFER. During this test, data on the interaction between human, vehicle and road (environment) of regular drivers during their daily movements were collected on a large scale. Additionally, a number of tests with *Intelligent Speed Adaptation* (ISA) were carried out in Sweden. As a result, Sweden is leading in the implementation of ISA: various governments have already equipped their vehicle fleets with ISA. Many other European countries, including the UK, France, Denmark, Spain, Belgium, the Netherlands (Tilburg) and Hungary, have also carried out ISA tests.

For links and/or downloads, please visit:
www.traffic-quest.nl/en/traffic2014.

Connected Vehicle Safety Pilot Program (US)

The *Connected Vehicle Safety Pilot Program* is a scientific research initiative that focuses on the real-world implementation of interconnected (V2V) technologies, applications and systems for road safety. The objectives of the Safety Pilot include the testing of the effectiveness and usefulness of the wireless vehicle communication in multimodal driving conditions. The behavioural component also gets a lot of attention: how do ordinary drivers adapt to wireless vehicle communication technology and how do they use it?

More information:
www.its.dot.gov/safety_pilot.

5.5. Data

Digital Road Authority (The Netherlands)

The *Digital Road Authority* tests a concept in which a virtual platform electronically connects market parties, public authorities and road users (consumers). It is an open platform on which information and services can be offered and purchased. This allows the parties connected to the Digital Road Authority to seek each other's assistance in order to make their own measures and advice even more effective. This could include navigation providers who provide origin-destination information and retrieve the current control strategies from the authorities. The basis for the communication and cooperation is a uniform and open technical and organisational concept. The project is aimed at actually realising and testing the concept based on three pilots in Amsterdam. This is not only about the functional operation, but also about the level of commitment and support from all stakeholders. The three pilots in the project focus on urban scale application and have a multimodal character.

Sensor City (The Netherlands)

The province of Drenthe and the municipality of Assen have jointly set up the *Sensor City* project. In the experiment *Sensor City Mobility*, government and industry study the extent to which people travelling by road and rail benefit from travel information and traffic management services, and how this can assist traffic managers in achieving their collective goals (improved traffic flow, reduced environmental impact and increased road safety).

The following parties were involved in Sensor City: DySI, Elevation Concepts, Municipality of Assen, Goudappel Coffeng, MagicView, Mobuy, NXP, 9292, Parkingware, Imtech, Quest Traffic Consultancy, the Sensor City Foundation, TNO and TomTom.

More information:
www.sensorcitymobility.nl
www.sensorcity.nl.

Information Integration (Japan)

The objective of the Japanese pilot *Information Integration* is the establishment of an information platform for ITS services. To this end, large amounts of data are collected and shared on a common platform. The purpose of this is to use public and private data sources as effectively as possible by value creation and to enable the development of ITS services.

For links and/or downloads, please visit:
www.traffic-quest.nl/en/traffic2014.

5.6. Platforms and partnerships

DITCM (The Netherlands)

DITCM is an open innovation organisation in which government, industry and knowledge institutions collaborate to accelerate the introduction of cooperative systems. Currently, DITCM has nearly thirty partners who jointly form a development and testing environment for intelligent vehicles and who operate the corresponding intelligent roadside systems.

The following partners work together in DITCM: TNO, TU Delft, TU Eindhoven, Twente University, NHTV, Fontys, Arcadis, Gold Apple, TomTom, DAF, Imtech, ARS T&TT, Vialis, Grontmij, TASS, Siemens, NXP, Technolution, HERE, AutomotiveNL, ANWB, NDW, RDW, Rijkswaterstaat, the Province of Noord-Brabant, the municipality of Eindhoven, the municipality of Helmond, SRE, Beter Bereikbaar Zuidoost-Brabant and Brainport Development.

More information: **www.ditcm.eu**

iMobility Forum (EU)

In the period 2011-2020, the *iMobility Forum* wants to realise the following improvements in the European transport system through the implementation of ITS:

- *30% reduction in the number of traffic fatalities.*
- *30% reduction in the number of serious injuries.*
- *15% reduction in road traffic-related congestion.*
- *20% improvement in energy efficiency of road traffic.*
- *50% increase in the availability of real-time traffic and travel information.*

To achieve this, the Forum provides a platform for all stakeholders in Europe for the development, implementation and monitoring of work programmes linked to roadmaps for the promotion of international cooperation necessary for the successful development and deployment of ITS.

On 11 September 2013, the ANWB organised an international demonstration day *Intelligent Mobility for Smart Cities*. The aim was to show how European cities can implement smart, energy-efficient, environmentally friendly and safe transport systems.

More information: **www.imobilitysupport.eu**

CHARM (EU)

CHARM is an English-Flemish-Dutch partnership between the Highways Agency, Rijkswaterstaat, Mobility and Public Works, Technology Strategy Board and NL Agency. The goal of this collaboration is to define a new generation of traffic management systems that can be purchased together for both organisations. The market is challenged to develop new solutions for the next generation of traffic control centres. A number of challenges was formulated for this purpose: 1) innovative, network-wide traffic management, 2) innovative traffic estimation methods and 3) the support of cooperative ITS functions.

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About TrafficQuest.

TrafficQuest

CENTRE FOR EXPERTISE ON TRAFFIC MANAGEMENT

TrafficQuest, the centre for expertise on traffic management, is a cooperation between Rijkswaterstaat, TNO and Delft University of Technology. A lot is going on in the field of traffic management; the three organisations work together in TrafficQuest to ensure that the existing knowledge does not get lost and is made accessible to practitioners. This is done by collection, developing and disseminating knowledge. The partners in TrafficQuest together cover knowledge on traffic management from science, applied science and operations. The activities consist of answering questions, giving advice in projects, conducting research and recording and disseminating knowledge.

www.traffic-quest.nl

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