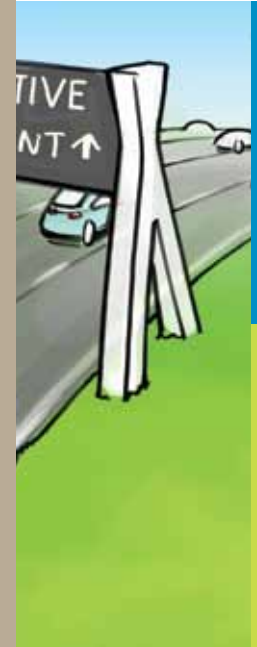




THE FUTURE OF TRAFFIC MANAGEMENT

State of the Art,
Current Trends and
Perspectives for the Future





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Current Trends and
Perspectives for the Future



TrafficQuest

CENTRE FOR EXPERTISE ON TRAFFIC MANAGEMENT



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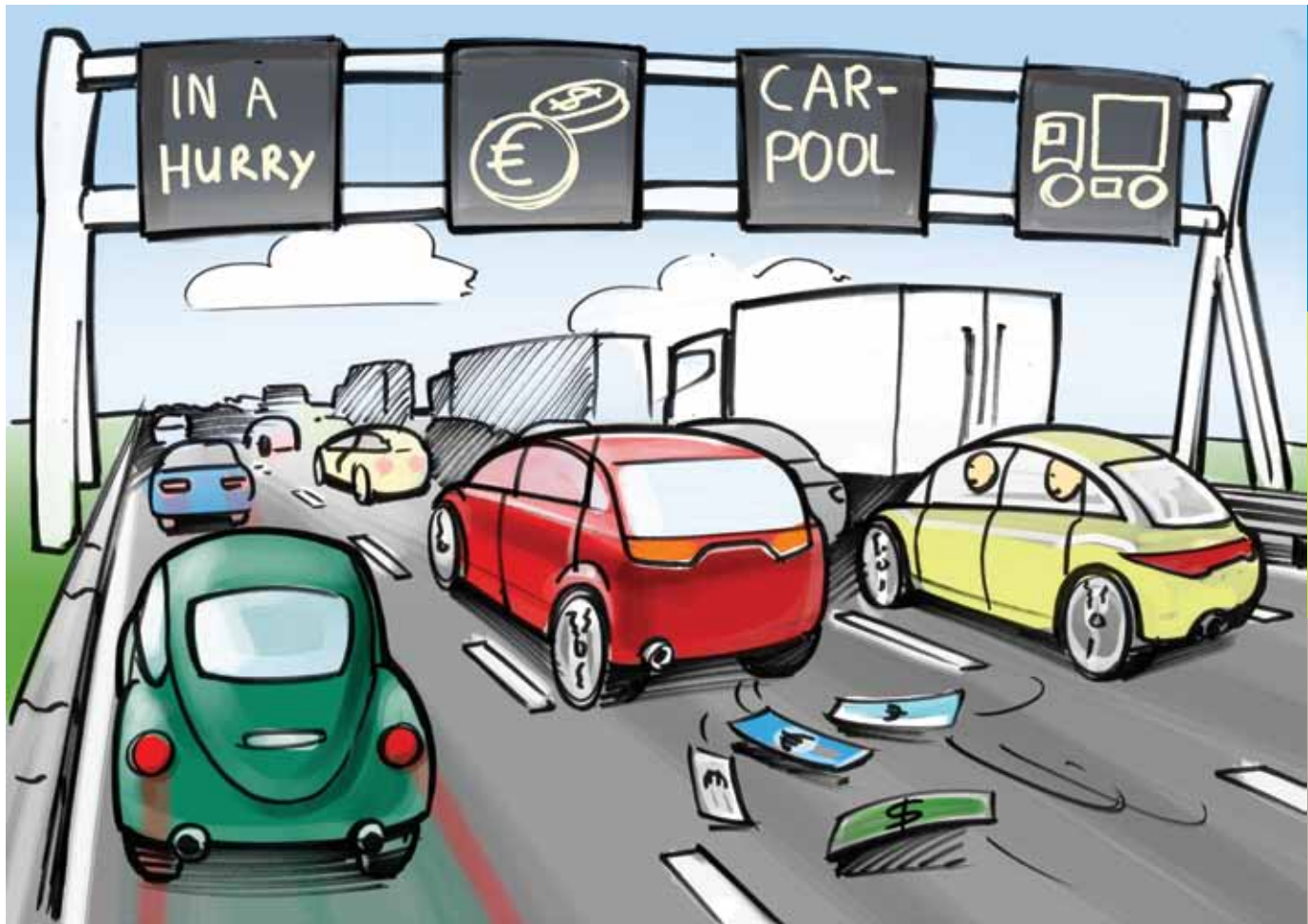
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BACKGROUND TRAFFIC MANAGEMENT IN THE NETHERLANDS

Traffic management applies measures to adjust the demand and capacity of the traffic network, in time and space, to better “match” the traffic demand and supply (capacity).

Examples of traffic management measures in the Netherlands are:

- Ramp metering
- Dynamic route information
- Dynamic lane management
- Queue storage
- National data warehouse
- Incident management
- Tapering
- Variable speed limits
- Peak-hour lanes (hard shoulder running during peak hours)
- Plus lanes (dynamic left lane)
- Section control (variable speed limit and enforcement)
- Queue tail warning

At least eight entities are used for traffic management, which determine the total traffic system, and which are constantly interacting:

- Traffic management center / emergency management center
- Measures
- Control principles / scenarios
- Vehicles
- Road / infrastructure
- Road user
- Organization
- Data and Information
- Road inspectors
- Service providers / police / emergency services

1. THE SOCIAL AND ECONOMIC URGENCY OF TRAFFIC MANAGEMENT

In just a few years, traffic management has been transformed from an everyday, passive task for the highway authority to an important policy instrument. This transformation is not without reason. Traffic management has improved the safety and operations on our roadways, while it is relatively inexpensive, flexible and rapidly deployable. Transportation professionals are also convinced that the potential of traffic management is far greater than previously imagined.

We know that there are critical problems that call for traffic management solutions. Despite the fact that the Netherlands boasts the highest motorway density in the European Union, we still spend about 65 million hours per year in congestion. The economic cost of this congestion is estimated at an amount between 2.5 and 3.4 billion euros each year.

Because our road network along key routes is already heavily loaded, each percent increase in traffic flow compounds the problem.

Promising Solutions

Solutions to improve mobility, accessibility and reliability are therefore necessary and very much desired. Traffic management is obviously not the only approach toward solving congestion and mobility problems (see also the page 9), but it is certainly one of the most important, cost-effective and promising tools in our toolbox.

What do we mean by traffic management? Definitions vary slightly, but simply put, we try to influence supply and demand with traffic management, such that the traf-

fic demand and the supply (capacity) of the network better match, along both the dimensions of time and space. The problems that occur on the road primarily concern specific bottlenecks (points in space) and specific moments in time (peak periods, incidents and special events). The aim is to spread both the traffic demand and the supply of infrastructure (capacity) in order to adapt dynamically and thus make better use of the existing road network. The field of traffic management includes both traffic control and traveler information.

Typical traffic management measures include ramp metering, dynamic speed limits, peak hour lanes (hard shoulder running), and traveler information displayed on variable message signs above the roadway or via other channels. The measures have been primarily intended to improve mobility, accessibility, and reliability, but they are also increasingly deployed to improve road safety (for example, congestion or queue warnings via the variable speed limit signs) or to improve livability (for example by speed restrictions).



Benefits of Traffic Management

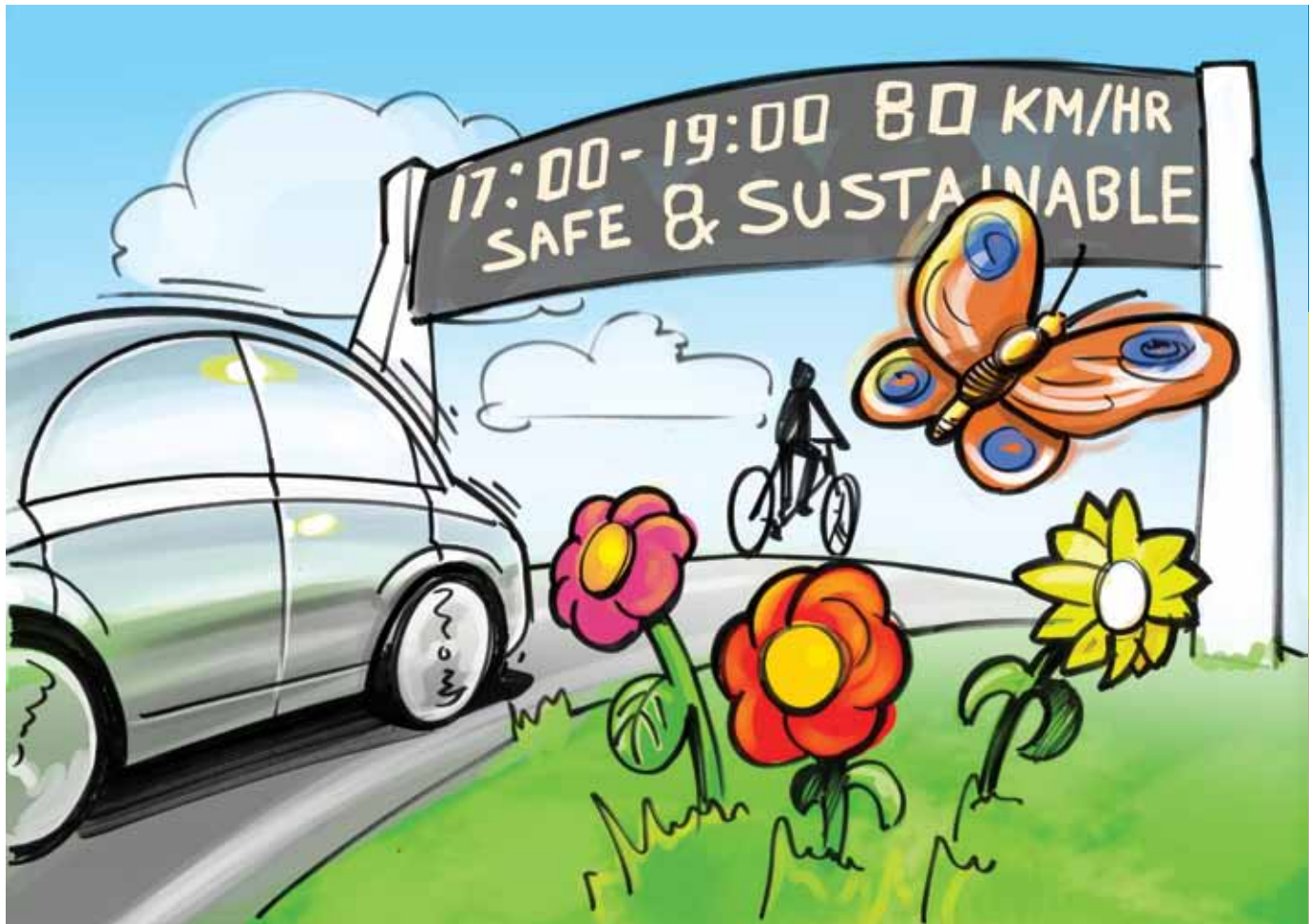
We are still working on the question of exactly how effective traffic management measures are in practice, and this is an important discussion. We particularly need to understand the cumulative benefits of the joint deployment of multiple measures, which is difficult to determine. But we are certain that traffic management measures lead to real benefits to safety, mobility and sustainability. For example, the Netherlands Institute for Transport Policy Analysis (KiM) has estimated that during the period

2000 to 2010 traffic management in the Netherlands succeeded in reducing delays by 14%, with a fraction of the cost of the construction of new roadways.

It is expected that traffic management can result in added benefits by encouraging and facilitating closer cooperation between road authorities, other transport entities, emergency responders, and the private sector, partly thanks to the availability of new technology. Given the mobility problems for both passenger and freight travel in

the Netherlands, we consider traffic management to be socially relevant and even urgent.

There appear to be sufficient reasons to consider this policy instrument more deeply. Why does it work? How is it currently deployed? What kinds of near term deployments do we envision? And how can we ensure that the potential benefits of traffic management are fully realized? In this document we will discuss each of these topics.



SOLUTIONS BEYOND TRAFFIC MANAGEMENT

Traffic management is not the only tool for maintaining mobility, accessibility and reliability. What other solutions are there?

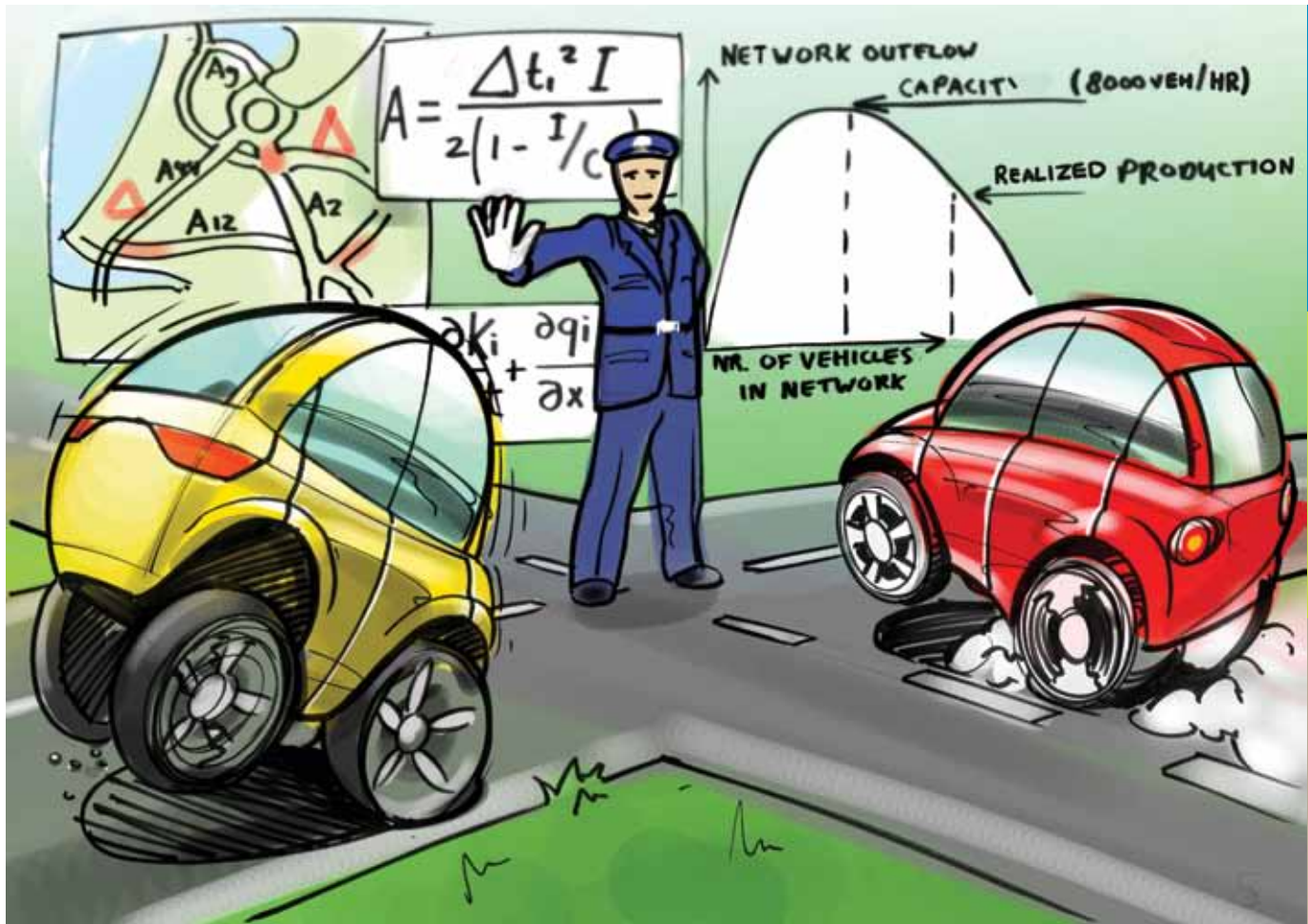
Constructing new roads, improving bottlenecks or widening existing roads are obvious approaches for solving mobility problems. These are usually effective and sometimes even necessary. However, there are drawbacks. Sometimes addressing one bottleneck simply shifts the bottleneck to another location. Also, construction in a highly developed environment is expensive and time consuming, and itself has traffic impacts. Given its spatial, social and environmental consequences new capacity should only be considered with caution.

The rational pricing of the infrastructure, such as road pricing and distance

based charging, is another possible solution. One approach is to develop a charging system that is constant in time and space. It is also possible to vary the pricing rates in time and space which will make peak period travel and congested routes less attractive and thereby reduce congestion. Road pricing is seen as offering interesting possibilities, but so far the major political hurdles have proven too difficult. One possible explanation is that complex decision-making must be handled by one government, while the implementation and management depends on the policies of the next government ad-

ministration. In any case, such a solution will likely not be introduced in the Netherlands in the short term.

Transportation demand management includes efforts by government agencies and employers to reduce travel by using measures such as teleworking or telecommuting, measures to shift the travel mode to walking, cycling and public transportation, and measures to shift travel to off-peak periods. Transportation demand management is often used as a measure to support large-scale infrastructure construction or maintenance projects, but does offer more possibilities.



2. TRAFFIC MANAGEMENT: HOW DOES IT WORK?

Most of the time, traffic can organize itself. But as traffic gets busier, the system is confronted with phenomena such as spillback and capacity drop. Through careful intervention aimed at optimizing traffic flow – traffic management – we aim to prevent or at least mitigate problems.

Drivers typically choose their preferred or optimal routes from their origins to their destinations. As long as traffic is light, transportation system users do not cause any significant disruptions to one another. On the motorway, drivers will spread themselves effectively across the lanes, leading to a synchronized situation. The great thing is that individual choices of system users also result in a balanced situation at the network level, in which the available space is used efficiently.

But this self-organization has its limits. As traffic becomes heavier or there are unforeseen incidents (such as a crash, a breakdown, or other random events), the traffic system can become unstable. In just a few minutes, traffic conditions can transition from “running smoothly” to “severe delays.”

What Can Go Wrong

For traffic management measures to postpone or prevent the onset of congestion, it

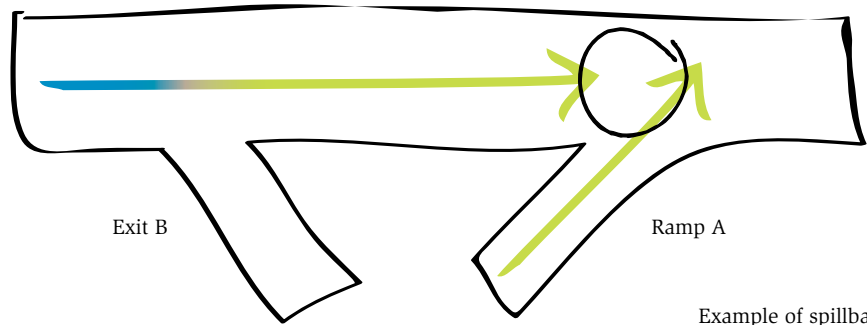
is important to understand the underlying processes. In other words: what exactly happens when congestion arises?

One phenomenon that arises is the *capacity drop*. Capacity is measured as the maximum number of vehicles that can pass a given point over time (usually in vehicles per hour). When congestion occurs, the capacity typically drops an average of 14%, sometimes as much as 30%. This happens at fixed bottlenecks but also frequently in moving shockwaves. Shock-

waves occur when, for example, a driver brakes sharply, resulting in a queue forming behind with higher density and lower speed. The shockwave acts like a wave of brake lights moving against the direction that traffic is moving, with a speed of approximately 18 km/h. The shockwave can sometimes persist longer than one hour.

Once we observe the capacity drop, it is too late – congestion has formed and it will take time to dissipate. The challenge here is to actually anticipate the formation of congestion and thereby prevent or postpone the lost capacity.

The *sub-optimal route choices* of individual travelers can also cause problems for other users. Obviously not when traffic is light. If you then choose a less optimal route, at most it leads to a longer travel time (plus added fuel consumption and emissions) for yourself. But if traffic is heavy, one person's choice will impact the others' – traveler B spends more time in the queue because traveler A spends more time on the network. Since most road users receive no information about the consequences of their route choice, they



continue to make inefficient choices.

A final process that we want to highlight is *spillback*. This occurs when a queue emanating from a bottleneck at one location obstructs traffic flow at another (upstream) location. The above figure shows an example of spillback on a motorway. There is so much traffic entering the motorway at ramp A that this leads to the formation of a queue on the motorway. The queue grows and grows, propagating upstream until exit B is blocked. The result is that motorists who want to use exit B (and so have nothing to do with ramp A), are blocked. This just

causes the traffic jam to continue growing as it spreads like an oil slick across the network. Just remember: we should never block an exit where people actually want to leave the system!

Fundamental Diagram

The phenomena described above are good examples of why traffic can become unstable. There are more processes working together, but the end result is always the same: at a particular moment the system will collapse and it will take hours to recover.

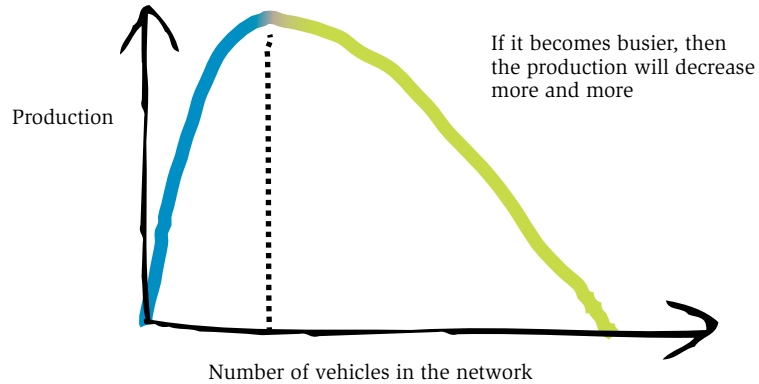
At the network level this can be de-

scribed by a very simple relationship, known as the *fundamental diagram*. This diagram, as shown in the figure on this page, shows the relationship between the number of vehicles in the network and the “production” (the number of vehicles leaving the network per unit time). If traffic is light, an increase in the number of vehicles in the network leads to a proportional increase in the production. But beyond a certain point when traffic becomes heavier, productivity increases less rapidly and at a specific point it even starts to decrease. In that region, an increase in the number of vehicles leads to fewer vehicles leaving the network. We call this stagnation!

Traffic Management Solutions

This fundamental diagram is in fact a basic building block for all traffic management strategies. If the number of vehicles in any traffic network approaches the critical point and you fail to intervene, the problems quickly begin to multiply.

Of course it is important to intervene correctly. The good news is that the previously discussed causes and phenomena provide



useful guidance for the development of intelligent ways of managing traffic in a network. We can identify four basic types of solutions in the field of traffic management:

1. Increase Throughput

One way to combat congestion is to increase traffic flow at critical locations. For example, you can adjust capacity temporarily by using an additional lane during the peak period. Combating the creation of shockwaves is another way of increasing traffic flow. Congestion leads to a capacity drop. If you effectively combat shockwaves

(by slowing the traffic that is driving towards a shockwave) this increases the capacity and thus the throughput.

2. Effectively Distribute Traffic Across the Network

The second key approach is the better distribution of traffic over the network. This is important because the sub-optimal choices of travelers lead to an unbalanced and inefficient use of the infrastructure. This means that one route may become significantly overloaded while other routes remain freely flowing. By providing helpful information

2. **TRAFFIC MANAGEMENT: HOW DOES IT WORK?**

to users so that they can make better decisions, the entire network is more efficiently utilized.

3. *Regulate the Inflow of Traffic*

The third solution involves regulating the inflow of traffic so that the number of road users traveling into an area remains below the critical number – below the tipping point. Consider a motorway ring around a city – keeping the ring moving can be crucial for maintaining access. One possibility is to regulate the inflow on the ring with measures such as speed limits on access roads, traffic signals, or ramp metering (“one vehicle per green”) at on-ramps.

4. *Prevent Spillbacks*

The fourth and final approach is preventing spillback. This can be accomplished in several ways. In the situation outlined on page 12 you can regulate the inflow to the bottleneck using ramp metering. This would prevent the queue from forming at that point

and from propagating upstream to exit B. We should bear in mind that this may cause a queue to back up onto the underlying network. But that traffic can be temporarily stored in a buffer area in a location where a queue will not disrupt local roadways. Traffic in the buffer must wait for a short while, but the system as a whole, and ultimately all travelers, are better off.

In addition, we note that the above four solutions focus on improving the performance (the efficiency) of the traffic flow. In the Dutch framework of Sustainable Traffic Management (GGB), other key objectives are relevant such as improving road safety and reducing the emissions and fuel consumption. To realize these objectives other solutions emerge such as:

- Managing or controlling the speed of traffic.
- Improving the safety of vehicles (such measures fall under the concepts of eSafety).
- Improving the safety of the roadway infra-

structure (such as high risk site management).

Is More Possible?

The above solutions are fairly common in the transportation and traffic engineering communities. Most road authorities are developing their traffic management programs along these lines. As we have pointed out, these techniques have been relatively successful (in the Netherlands an 14% decrease in delay has been reported due to traffic management improvements between 2000 and 2010). But traffic experts suggest that there is still more possible with traffic management, for example with a regional, coordinated deployment of mutually complementary and reinforcing measures. An important issue is also that the field of traffic management is constantly changing along technological and societal dimensions. To ensure that traffic management is effective in the future, it is important to respond or better yet, anticipate.

MEASURES IN RELATION TO THE MAIN SOLUTIONS

MAIN SOLUTIONS	RAMP METER	TRAVELER INFORMATION	PEAK HOUR SHOULDER LANES	DYNAMIC SEPARATION OF THROUGH AND LOCAL TRAFFIC
INCREASE THROUGHPUT	Effective capacity increase by postponing queue formation	-	Increase capacity by opening an extra lane during peak periods (shoulder and/or re-striping)	Increase in capacity by decreasing weaving movements
EFFECTIVELY DISTRIBUTE TRAFFIC	Reduce cut-through traffic (rat running)	Inform drivers about routes with residual capacity	-	-
REGULATE INFLOW	Regulate entering traffic to main roadway	Inform drivers which on-ramp to use if options are available	-	-
PREVENT SPILLBACKS	Prevent queue spillback on the main roadway to an upstream exit	Inform drivers to choose exit if options are available	Prevent spillback by buffering traffic	Prevent spillback by channeling exiting traffic to dedicated lanes

The traffic management measures that we are familiar with and apply in the Netherlands can be linked to the four types of main solutions described above. In the table on this page we illustrate this for a range of specific traffic management applications. Note that the measures shown can generally be used to address more than one problem and so in that respect are multifunctional and complementary.







3. STATE OF THE ART AND CURRENT TRENDS

It is clear that traffic management works and will continue to be effective in the future. But what does that future look like? To provide such a vision, it is important to describe the current state of the art first. In other words, where do we stand with traffic management? A look at the trends will then provide insights into the direction we're heading.

STATE OF THE ART

We have applied traffic management in the Netherlands for several decades. What began in the 1980s as a single initiative of Rijkswaterstaat (executive agency of the Ministry of Infrastructure and the Environment) has now become a broad field with multiple different players and a wide range of solutions, measures and technologies.

Measures

For controlling and managing traffic flows, road authorities have a range of instruments: ramp metering, adaptive traffic signal control systems, green waves, roadside panels for dynamic route information, and

dynamic dedicated lanes. Most of these systems are primarily focused on improving traffic flow, but some have been developed with the benefits of improving safety, livability and sustainability (including reducing fuel consumption and emissions). Examples of this include the motorway traffic management system, and the queue tail warning system and variable speed limits (to improve air quality) which are part of that.

Traveler and traffic information is available via radio, television, computer, smartphone and in-vehicle navigation system. The information itself is changing from pre-trip expectations to real-time pre-trip and

en-route information (in some cases even multimodal). We now are aiming toward meeting user expectations by providing information that accurately describes the current and future traffic conditions, and is accessible safely, anytime, and anywhere. This transition is not yet complete – in particular we need to improve the accuracy and personalization of traveler information.

Collecting Traffic Data

Currently it is primarily the road authorities that collect traffic data, typically through infrastructure-based sensors of different kinds, including inductive loops, radar, video and Bluetooth. In the Netherlands,

3. STATE OF THE ART AND CURRENT TRENDS

the data are archived in the National Data Warehouse for road data (NDW) and made available for a fee to service providers.

However, more and more the private sector is actively collecting additional data from multiple sources including vehicles and smartphones. These data most often include position, speed and travel time. The challenge is how to bring these complementary data sources together.

Players

Government agencies – in the Netherlands including Rijkswaterstaat, the provinces, and municipalities – have the responsibility for controlling and managing traffic. This is done from the different traffic management centers. The private sector plays a leading role in informing road users. That subdivision of responsibilities is not entirely accidental. By controlling and managing traffic, government agencies are involved in primarily “community interests” such as accessibility, quality of the environment and safety, and those interests are traditionally

provided by the government. The private sector is driven by the profit motive and therefore focuses more on the individual interests of road users: traffic information services to help customers avoid traffic jams, providing alternate routes and real time information.

Cooperation

The cooperation and collaboration between government agencies for controlling and managing traffic is reasonable to good. The traffic management approach was until recently “location based,” where the various road authorities focused mainly on isolated bottlenecks and on the roads within their particular jurisdictions. With the increase in the number and complexity of mobility problems, it has become clear that a more regional approach is required, including in the traffic management centers. Thanks to methodologies such as Sustainable Traffic Management (GGB), the focus has shifted to a more network-oriented approach. True operational traffic management at the re-

gional level is still rare, but in many regions there is good cooperation on the strategic and tactical levels. Also during major road construction, cooperation is fine (e.g., coordinating work and detours on different jurisdictions’ roads).

However, when we look at the cooperation between government agencies and the private sector, in other words between controlling and managing on one hand, and informing on the other, the picture is less clear. The domains do not always reinforce one another – and sometimes they even work against each other. Take for example, the growing group of road users who, thanks to the traffic information on their in-vehicle navigation systems, avoids problems on the main network by choosing an alternative route via local roads, sometimes through village centers. In that case there is a conflict between the individual interest of road users and the collective public interest (quality of life and safety) where government agencies and road authorities are responsible.

CURRENT TRENDS

In coming years we will see many changes in the field of traffic and transportation. Societal and demographic trends, technological and economic developments – they will all, to a certain extent, impact the development and application of traffic management solutions. In the following we will highlight the most relevant influencing factors for the next 10 to 25 years.

Societal Trends

Society will further personalize, with increasing emphasis on individual citizens and their freedom of choice. At the same time, however, citizens will expect government agencies to pursue the social goals of safety, accessibility, livability, and sustainability.

Road users have access to accurate and intelligent traffic information, and will therefore be able to manage their individual objectives (including comfort and optimal travel time). Future trip purposes and travel patterns will continue to change, partly as a result of demographic shifts, the aging population and social me-



dia (“Generation Y”). These changes may lead to less traditional commuting, but to more leisure and recreational traffic and more public transport use. The interest for flexible work environments (teleworking, teleconferencing and hoteling) will grow accordingly. This has implications for residential locations, departure times, and commuting distances. As traffic volumes continue to increase, discussions about

road pricing (paying for the use of infrastructure) will likely return.

Organizational Trends

From the traffic engineering and administrative perspective we see an increasing integration of major roads, provincial roads and urban networks. This includes data collection, traffic management planning activities and implementation.

3. STATE OF THE ART AND CURRENT TRENDS

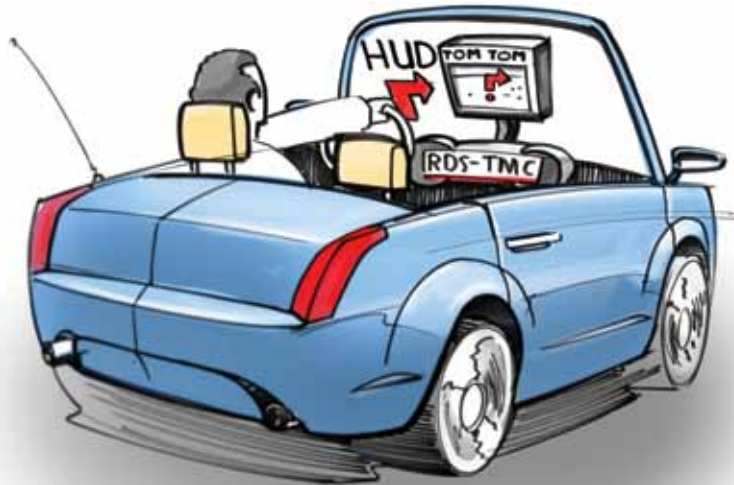
Public-private relationships will also change in the coming years. With Design, Build, Finance, Maintain and Operate (DBFMO) contracts, for example, new government and private sector roles will emerge. The responsibility for maintenance, administration and management

will fall increasingly on the private sector. Also with the growth in the use of in-vehicle technologies (such as navigation systems and more advanced cooperative systems) the private sector could ultimately take on more traffic management tasks than just providing information.

Finally, for the Netherlands there is the further internationalization of transportation policies. Europe's transportation policies are developing, and this also has implications for traffic management. The Netherlands will have to take into account the European Commission's Action Plan for the Introduction of Intelligent Transport Systems in Europe (ITS Action Plan, 2008) and the ITS Directive (2010). For example, with this Directive the EC may issue binding specifications for intelligent transportation systems in the future.

Technological Developments

Technological innovations in the field of traffic information, driver assistance systems and intervention in hazardous situations will make it possible to develop further traffic management innovations. For example, imagine the enormous opportunities offered by the communication between in-vehicle and roadside systems. New cooperative systems will be platforms for services beyond traveler information



alone – such as individual guidance, routing, hazard warnings and crash avoidance. Given sufficient penetration into the vehicle fleet, new traffic management systems will be possible due to the presence of increasing proportions of probe vehicles with more accurate positioning data leading to preventative intervention. Secure and convenient financial transactions will also be possible through such a platform, useful for any kind of pricing mechanism desired in the future.

For intelligent transportation systems (ITS) to be effectively used as a traffic management measure, a sufficiently high penetration rate of 30 to 70% is necessary. The auto industry assumes that in-vehicle systems will be standard for all new vehicles. Government agencies can actively support this development. Standardization is a requirement – this will facilitate the development of new functionalities and services and thus accelerate the implementation, reduce unit costs and increase confidence in investments. Standardization can be organized from the EU, but also from the



automotive and supplier industries. The developments in other major markets (Japan, U.S.) will certainly play a role.

It is not yet clear to what extent in-vehicle systems complimentary to roadside systems can and will be used for regulation and enforcement.

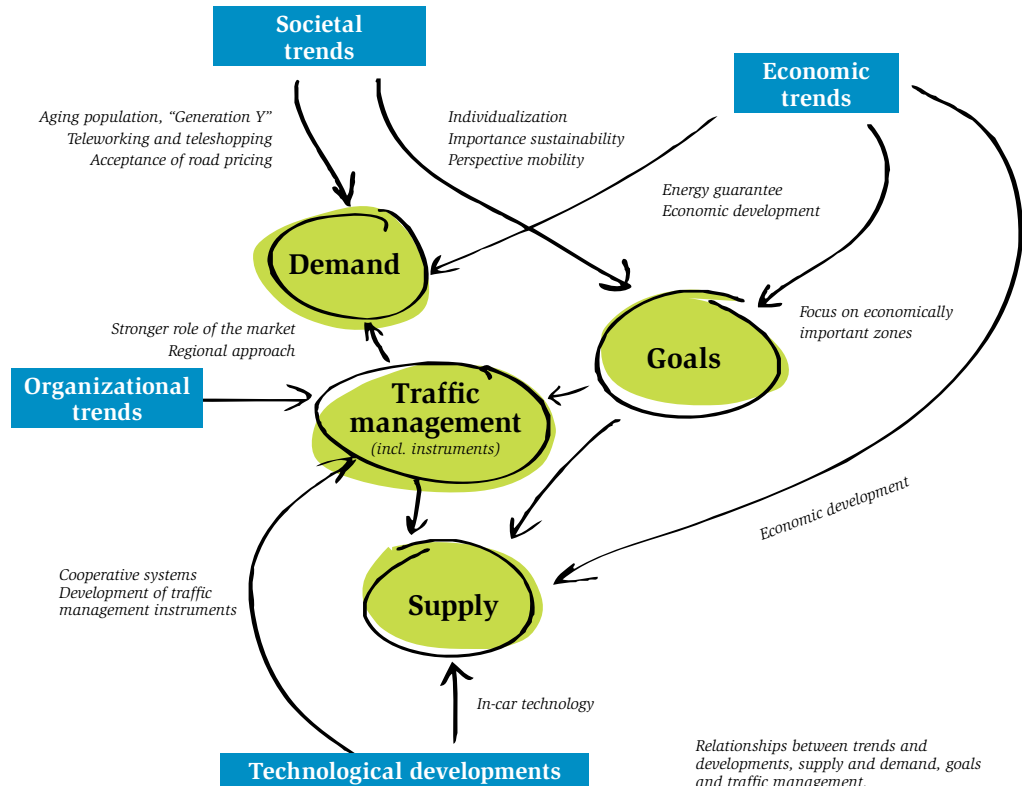
Economic Trends

There is a strong relationship between

traffic demand and economic development. Economic fluctuations can therefore lead to substantial changes in the deployment of traffic management strategies. Particularly in a growing economy it will be necessary to use the existing capacity of the road network as effectively as possible. The economic situation also affects the investment climate and business opportunities for mobility services.

TREND ANALYSIS CONCLUSIONS

The above discussion provides a glimpse into the current and foreseeable problems around traffic and mobility, along with various trends and possible future developments. The adjacent figure outlines these developments and shows the relationships between the trends, goals, demand, supply and traffic management.



3. STATE OF THE ART AND CURRENT TRENDS

It is clear that we expect significant shifts in traffic demand as a result of social and economic trends, but also in the mobility objectives. For example, we foresee more focus on sustainability. At the same time, we have substantial opportunities for increasing the effectiveness of traffic management. Cooperative systems, further development of the tools for dynamic traffic management, and new performance measures and methods are all possible. Also at the organizational level, we will be able to gain benefits from better regional cooperation, further developments in the private sector and future public-private partnerships.

A side effect of personal traffic information and the role that the private sector plays, is that road users are becoming less easy to influence, for example, with quality of life, livability, or safety as objectives. This means that in the future it is even more important that the government and the private sector work

together in informing, managing and controlling traffic streams. Individual interests represented by the private sector and social interests (government) must be reconciled. If not, the government will need to become more strict in preventing unwanted behavior of knowledgeable users – for example: travel through a town center because it is just a little faster.

Finally, in the future changes in mobility objectives may be required in order to allow a more flexible deployment of the infrastructure and a proactive influence on the traffic demand. This leads almost automatically to an extension of the role of traffic management. If we add the economic development and social restraints on the construction of new infrastructure, then it becomes clear that the opportunities and possibilities for the effective deployment of traffic management will only increase in the coming years.

4. PERSPECTIVES FOR THE FUTURE

Traffic management of the future needs to be especially flexible, cooperative and proactive. We should be able to quickly respond to changes in supply and demand, to deploy coordinated measures and manage the different networks as a whole. What is required? One requirement is that road authorities, private sector partners and research/education institutes should work together and cooperate more closely.

The primary task of traffic management is the appropriate optimization and matching of traffic supply and demand according to infrastructure constraints. Even now this is the primary task, but the importance of the supply/demand alignment will only grow in the coming years.

The first level of optimizing or matching transportation supply and demand occurs at the network planning level. The regular pattern of demand, insofar as it exists, will establish a “base load” for the network, defining the quantity of traffic

that needs to be accommodated. A certain degree of congestion is allowed due to the peaking phenomenon. What exactly is allowed, determines the necessity of road capacity.

Once the network capacity has been established, then the balance between supply and demand is an operational issue, with traffic management as an important initial instrument. Traffic management makes it possible to dynamically respond to the ever-changing traffic supply and demand. Traffic management is also

particularly critical during nonrecurrent and unexpected situations, such as road construction, special events or incidents. This will lead to a better balance between individual interests and the interests of the road authority and society. Individual choices must be adjusted so that the entire network will benefit.

High Demands

If we want traffic management in high demand situations to be sufficiently effective, the measures must be powerful and

impactful. With more flexible management of supply and demand, there will be greater opportunities for coordination and thus for combating congestion. This requires a high degree of instrumentation on routes where traffic can be guided and directed (including motorways, arterials and local roads). We must also consider what types of measures are required: the mechanisms for informing, controlling, and managing as well as the penalties and rewards that are available. The measures should be well coordinated and should be rapidly deployable. In addition, a transition from reactive traffic management to proactive traffic management is necessary. This requires a greater role for route guidance and traffic control under normal and incident-related conditions. Prediction is an important component of this vision.

Conclusion

In summary we can say that the trends and developments described here offer excellent opportunities for traffic management. But traffic management must meet a number of important requirements:



- Traffic management of the future must be more flexible in handling changes in supply and demand.
- Measures must be coordinated and used across the network.
- Traffic management must be proactive and can be used to achieve a range of policy objectives.
- Road authorities, private sector parties

and research/education institutions will need to strengthen collaborations.

Only then can we continue to deliver traffic management as a constructive contribution to the quality of the transportation system.



5. THERE IS STILL WORK TO DO!

We now understand the promise of proactive traffic management in the Netherlands. But we have also established that there will be significantly more required of traffic management in the future. How can we elevate the field of traffic management to the next level in the coming years? What steps are needed?

Flexibility in Supply and Demand

For traffic management to be really effective, it is necessary to influence both the demand and supply. At present, all road authorities have a variety of measures to accomplish this. But to take a significant step forward, the scope of these measures should be increased.

Influencing *travel demand* is challenging. Dynamic road pricing is a potentially effective instrument, but in the Netherlands deployment is limited to static

tolling and currently it is not deployed for traffic management purposes. There are also initiatives that reward road users for traveling outside of the peak periods. This form of pricing has been tested experimentally. It may be suitable for temporary situations, such as large-scale road construction with capacity impacts. A much broader deployable solution such as an overall kilometer charge, has thus far been proven politically infeasible. Therefore, in the short term it is appropriate to explore whether a limited pricing measure

such as high occupancy toll (HOT) lanes (where single occupant vehicles can pay to enter a carpool lane, with static or dynamic prices) as have successfully been implemented in the U.S., can be effective in the Netherlands.

Another way to influence demand is by providing traffic information. This way you can encourage travelers to reconsider their mobility behavior. The information must be of high quality and tailored to the individual. Then it may be possible to encourage users to travel at a different time,

change their route, choose a different destination or a different mode, or work and shop from home.

On the *supply side* there is much that can be done to increase flexibility. There has been effective use of peak and plus lanes as well as ramp metering installations, but these can be deployed even more intelligently. These systems can be implemented in a truly dynamic way so that actual conditions are measured in order to determine when they should and should not be activated. In addition the different installations can be coordinated more fully. Another possibility is to expand the number of reversible lanes and buffer lanes. Other countries, such as the U.S., apply these measures more broadly than the Netherlands.

When designing the infrastructure it is important to take into account the application of the full range of traffic management measures to be applied. The road network should be robust enough to deal with recurrent conditions. In addition, precisely because the network in the



Netherlands is overloaded and so vulnerable, it is important for traffic management measures to deal with nonrecurrent and unexpected situations – incidents, events, construction and other unusual circumstances. Currently we deploy traffic management measures at road construction sites, but it needs to be more comprehensive and more effective. The ability to ab-

sorb fluctuations in demand is enhanced by building in flexibility and redundancy into the network. Therefore, when extra capacity is needed, there is an opportunity to accommodate the demand.

More Cooperation

With a view to effectiveness, it is important for traffic management to be coordi-

5. **THERE IS STILL
WORK TO DO!**

nated and deployed network-wide. Only then can we really solve problems instead of shifting bottlenecks and problems to different locations. Such a network-wide approach requires cooperation among road authorities and between road au-

thorities and service providers (the private sector parties that provide traffic information). Given the large number of stakeholders, this is not a simple process.

Fortunately, the parties concerned in the Netherlands are already organized in

various ways. There is a platform where government agencies and private sector parties consider the possibilities and applications of traffic management, and there are regional collaborations that target regional traffic problems. In order to consider future strengthened collaboration, it may be useful to look at incident management: the cooperation is effective, there are clear agreements in place, leading to a better “product.”

It is also useful to look internationally. For example, in the U.S., there are many collaborative partnerships based on Memoranda of Understanding and trust in each other’s good intentions. There is quite often a common goal, which makes it easier to share funding (pooled funding) for a joint project or research. In the U.S., the focus is mainly on corridors, but the method can equally well be applied to regional networks.

A positive development is that there is increasing coordination and coopera-



tion between the various road networks (motorways, provincial roads, and urban roads). However, the traffic engineering aspect of this deserves further investigation: how can traffic management measures be fully coordinated and deployed? There have been some instances of coordination of measures on a route or in a portion of a network, but there are not many control concepts available that can handle this. Therefore, these concepts must be developed and extensively tested, both in simulations and in field trials.

Another issue is the balance among modes of transportation (road, rail, public transport, cycling, pedestrians and water) and between passenger and freight transportation. On that level there has been little progress: the focus is still too much on the better use within a single mode.

Cooperative Systems

With the advent of cooperative systems – where infrastructure and vehicle systems communicate closely as one system – there will be more opportunities for coordination in the near future. In-vehicle



systems already play a small role in traffic management. Navigation systems and queue messages on the radio can influence the route choice of a road user. If vehicle-infrastructure communication is added, these measures will become more significant as tools for information and control. This is expected due to the increased vehicle-vehicle and vehicle-infrastructure

communications in the future. The fact that the various components of the traffic system can communicate means that the systems (compared with stand-alone systems in vehicles and infrastructure systems) are more intelligent and based on more than just current information. There is in a sense cooperation – or maybe it is better to talk of negotiation – among ve-

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hicles and the infrastructure (or a central traffic center or back office). Thus, new and more efficient, predictive measures will be possible. Examples are cooperative adaptive cruise control and intelligent navigation systems that provide advice re-

garding the current (and predicted) traffic and parking situations, possibly including multimodal travel information. All traffic management stakeholders (government agency and private sector) see opportunities with cooperative systems. It is impor-

tant to consider how cooperative systems should be designed: what systems, how to test them, and how to organize the development, deployment and maintenance.

Vehicle-to-vehicle (V2V) applications involving dedicated short range communication (DSRC) are expected to be developed mainly by the private sector, while government agencies are typically more interested in vehicle-to-infrastructure (V2I) applications. For both parties questions remain: who pays and who benefits? For government agencies there are further questions such as: in which equipment do we need to invest, what existing equipment must be replaced, and if so with what? There are still bottlenecks on the technical level (for example, standardization and security), organizational level (for example, privacy), the relationship with road users (for example, user acceptance) and scalability (such as complexity and manageability).



Proactive Traffic Management

“Prevention is better than cure,” so traffic management should preferably be proactive. As a first step, it is necessary for the “traditional” reactive traffic management measures to be in place. With the advent of more data, better forecasting models and smarter concepts for network-wide management, progress can be made toward proactive traffic management. In practice this will mean that we prevent spillback, distribute the flow better across the network, regulate the inflow on certain vulnerable parts of the network – all before the problems really start.

To move traffic management in the right direction, in the future a stronger program of control and route guidance will be needed than is now the case. Currently the majority of the efforts are aimed at providing traffic information and advice, and if an action is needed it is primarily left to the road user (a high degree of self-organization). But as we have seen, self-organization only works up to a certain point. During peak periods, with high traffic demand, and during nonrecurrent cir-



cumstances, it would be more efficient for a central traffic authority to manage traffic, for example, providing dynamic routing information to road users. This kind of system must take into account what the road user will find desirable, comfortable and acceptable. This requires deep insight into the preferences of users and a careful design of the user interface (in the

vehicle and along the roadside). After all, if road users do not see the usefulness of the measure itself or see disadvantages, they will not follow the guidance. Knowledge of human factors plays an important role. An information-ergonomic approach should be followed to develop safe and user friendly systems.

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Optimize for Multiple Policy Goals

The increasing interest in – or rather concern about – the societal effects of traffic means that traffic management must take into account more diverse goals than before. It is no longer sufficient to optimize solely on total flow or travel time, but it is also necessary to consider improvements in safety and quality of life (including air quality, noise, and energy consumption). In other words, a multi-objective optimization approach is now required.

To manage traffic according to multiple objectives, data covering the traffic flow (speeds, travel times, vehicle delay hours and reliability of travel time) are required, but we also need data on road safety and quality of life/livability. The objectives must be quantified, and we need methodologies that make it possible to understand and communicate the trade-offs.

Integrated Approach

Traffic management must be part of an integrated approach, in which traffic management takes its place next to mobility management, infrastructure planning and spatial planning. For example, if it is necessary to influence the traffic demand to enable effective traffic management, this must be aligned with mobility management measures that aim to influence the number of trips in an area or on a particular route. A shift to other modes can also help.

Linking traffic management to spatial planning is important and can have more of an influence on the strategic level. As previously noted, a well-designed network is the basis for effective traffic management. For example, taking into account the traffic volumes across the network can help to form an understanding of where flexible infrastructure features such as peak, plus, HOV, HOT or reversible lanes are needed.

Organization

Regarding the organization of traffic management, there are already many components in place in the Netherlands. Regional cooperation can nevertheless be strengthened further, which is important for the deployment of coordinated network-wide traffic management.

Another issue is the way in which government agencies and the private sector work together. This involves making good, clear agreements: who is responsible for what and under what conditions? For such a close cooperation there are some inspiring examples. For example, government agencies and private sector have good working arrangements in the field of incident management. We can look abroad to consider how national ITS organizations (with public and private members) have been established and what the pros and cons of these approaches are.

In terms of organization, a number of

behavioral aspects and human factors play important roles. Cooperation between various organizations and between different teams requires new ways of organizing. Cooperation in the field of operational traffic management must, for example, be initiated at the traffic management center. But how do you start? Full integration of traffic management tasks on different levels of the road network hierarchy may be difficult.

Another aspect related to organization concerns innovation. In current practice, after a long developmental process, including successful field trials, it is still rare that a measure is implemented on a large scale. The implementation path for innovations can be better organized, and again there needs to be close cooperation between public and private parties. Moreover, traffic management measures that have the potential to generate revenue have not received much attention. While the traffic situation is constantly changing, little effort is expended in the functional maintenance of traffic management measures.



Finally, there is an important role for research and education institutions. Both public and private parties could take better advantage of the knowledge development that takes place in the Netherlands. In the field of ITS, for example, results from many European research projects could be translated to the Dutch situation, which can create interesting new meas-

ures and systems. The research at universities in the Netherlands at this point is among the best in the world. It would be mutually beneficial for all parties to strengthen existing partnerships and examine new joint ventures.

Training and Education

No matter how well the traffic manage-

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ment system is organized, the work is ultimately carried out by individual employees. Training and education for these staff members also deserve attention. This relates not only to researchers, engineers and planners, but also to the field personnel, such as road inspectors, maintenance employees and operators, traffic engineers and traffic coordinators in traffic management centers. If we indeed wish for traffic management to be more proactive, broader and better coordinated, this requires new competencies and skills for these employees, obtained through continuing education and training.

Basic Facilities

Architecture

A basic provision for the high quality and (where necessary) uniform application of traffic management is the *traffic management architecture*. This consists of a description of all steps needed to achieve effective regional traffic manage-

ment: applied technology, organization, funding, interoperability, legal aspects, etc. When such a framework is in place, a clear overview, structure and a particular standardization (everyone uses the same definitions) emerge. An architecture also provides insight in the relationships between developments in traffic management in the medium and long term.

Clearly, simply having an architecture is not enough – it also needs to be used. It is especially important that traffic engineering functionalities and requirements are linked to technical developments, so that developments better match. That link is already partly implemented in the existing traffic management architecture. However, there are still assumptions, for example with regard to life-cycle penetration and effectiveness, which should be further clarified.

One well-known example of a (sub) architecture is the Sustainable Traffic Management (GGB) approach, which de-

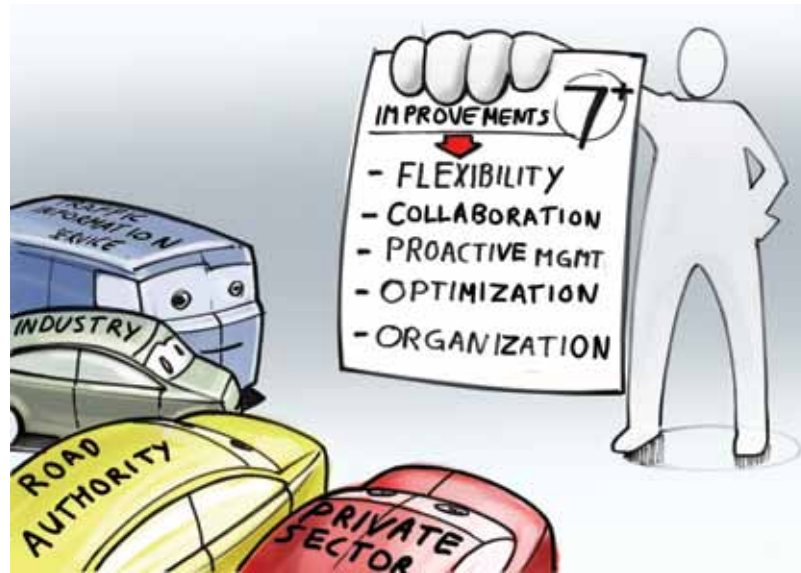
scribes in detail the steps toward a joint, broad-based network vision and an area-wide regional traffic management structure. GGB has already proven its value in practice in many regions in the Netherlands, but some gaps in the architecture have emerged. Therefore, now GGB *Plus* has been developed with a major new component consisting of the functional classification of the road network. In GGB *Plus* the roads are classified according to their function in the network, such as “main highway” or “urban road.” This offers opportunities to emphasize aspects such as safety and livability.

Monitoring

High quality, timely and complete traffic data are essential for the provision of timely and correct traffic information to road users and for the deployment of traffic management measures. In the Netherlands we obtain the vast majority of data from inductive loop detectors in the road.

There are minor quantities of other detection systems deployed and also vehicles play the role of sensor, but that is still not a dominant feature for data collection. Therefore, data fusion, which includes methods to combine data from different sources, is of interest. This calls for more intelligence in gathering and processing the data. The data must be collected at the right places, measured with the correct techniques and the data collected must be well combined. Defining the data quality requirements depends on what is done with the information. Data for traffic management for example has different requirements than data for policy development. It is certainly not necessary for all data to be collected with the same quality requirements. It is important to view the sensing, aggregating, quality assessment, archiving and distribution of sensor data holistically; at present these components are handled in a fragmented manner.

Another issue is traffic information around nonrecurrent events and incidents. Information is now available (traffic demand at events, duration of incidents,



and alternative routes), but is again too fragmented. At this time, more integration is needed among the service providers for providing the information, in order to improve response times and the ability to respond quickly to changing circumstances. For this to occur it is better that the road authorities accept greater responsibility. This is particularly true in situations

where traffic information can be crucial, such as disasters, major incidents, events, and severe weather conditions. An additional advantage is that the road authority is more visible to the road user.

Models and Prediction

With traffic models it is possible to provide quantitative insight into the effects

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of traffic management measures on, for example, safety, mobility and the environment. However, it is important to use the correct type of model for each situation. For example: for the assessment of policy level options, static models are often used, even if the policy option is traffic management. But static models are not suitable to determine the effects of traffic management. Dynamic models need to be deployed for this purpose.

In the future model developers will need to take action to improve this situation. There must be a better link between static and dynamic models. The functionality of dynamic models should be extended, so that it is possible to assess certain policy options. It is also important for model results to be presented well and clearly explained. Only in this way will policymakers and administrators take model results seriously into consideration when making decisions.

Also the real-time application of traffic

models is of interest. We have previously concluded that in order to allow proactive traffic management, we should be able to predict the traffic flow. Traffic models are essential for this purpose, but they need to be improved.

Finally we suggest that behavioral models – behavioral simulations of economic, psychological and social decision-making processes – require extra attention. These features should become more prominent in generic traffic models. Examples of applications include determining the effects of habitual behavior, the potential for price incentives to change behavior and the impact of personalized information. Further understanding is needed regarding the interdependence of these processes. For example, how can we encourage modification of habitual behavior using intelligent and personalized information? A further understanding of this would need to be based on the latest insights on human factors. That influence is not limited to a

specific behavioral level (strategic, tactical, operational). So the challenge is to exploit the interactions between these levels: e.g. departure time, speed, route choice and mode choice. These interactions also require connections between the macro-, meso- and microscopic models.

Traffic Management Centers

The field of traffic management has developed initially from the needs and requirements of road authorities. But since then a lot has changed: the private sector is playing an increasingly larger role, there are in-vehicle systems to be taken into account and the possibilities of mobile communication are increasing exponentially. These changes have led to a range of new tools and opportunities for traffic information and traffic management. The role and necessity of facilities along and above the road, in terms of effects, time, costs and depreciation, have become points of discussion. For traffic management centers this

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has a number of important consequences:

- Traffic management centers will be deployed in the near future for network wide traffic management of all road authorities together. They will therefore be at the service of regional cooperation – and not at the service of only one road authority.
- Traffic management centers will increasingly focus on the interplay between informing, controlling and managing traffic flows.
- Traffic management centers in the future will be inextricably linked with cooperative systems, including vehicle-to-vehicle and vehicle-to-infrastructure systems, with roadside devices and in-vehicle systems.
- Traffic management centers will in the future be the platform from which both road authorities and service providers operate. Both parties should work from a common platform.

The traffic management center of tomorrow will also play a significant role for the application of prediction models and decision support systems. These tools support the traffic manager, for example, in the preparation of traffic management scenarios. In this new context, the questions of education, training level and the workload of the traffic manager will require further attention. We need to consider the optimal ways for the work to be accomplished and for the training to be provided, so that the traffic managers can do their work as effectively as possible.

Further Innovation

In the preceding sections many topics were discussed, but it is important to continue to look for further innovations outside the traffic world that may be of interest for traffic management. For example, we try to make full use of new information and communications technology (ICT) developments. So far there has been

little rigorous focus on the influence of social media on the use of traffic information.

In addition, it is prudent to keep an eye open for developments in other sectors. A study of analogies can determine whether developments and innovations elsewhere may also be useful for application in traffic management.

PRIVATE SECTOR

ROAD AUTHORITY



GOVERNMENT

UNIVERSITIES

6. FUTURE RESEARCH AGENDA

If we want to fulfill the true future potential for traffic management we must take the necessary steps forward. This is not a simple matter. Most of the first steps require further investigation. That is why we close this brochure about the future of traffic management with a recommended research agenda.

In this chapter we identify the various research themes resulting from the discussion above. We have grouped the research themes under several categories. The bold themes are the most urgent.

To indicate where the greatest interest may lie in a particular research question – and which kind of organization would most likely lead the research effort – we have assigned each research topic to four categories:



Strategic/Policy

These are themes that are particularly important for policy.



Operational/ Road Authorities

Themes that are important for the road authority.



Knowledge Application

Themes that are important both for policy and road authorities and for which the knowledge is present to apply them.



Knowledge Development

Research topics for which it is difficult to find a direct client and so could be advanced by universities or research organizations.

Flexibility in Supply and Demand

Flexible infrastructure (more flexible deployment of the available capacity) is an effective way to temporarily address capacity shortages or spikes in traffic demand. But where and when exactly is it useful to deploy flexible infrastructure?

Dynamic road pricing is potentially a powerful tool to influence demand, but it is also politically sensitive. It is therefore necessary to explore what other less far-reaching possibilities there are to apply pricing. Perhaps a high occupancy toll (HOT) lane is an option.

Mobility management is used successfully at road construction sites. Mobility management for recurrent conditions and/or nonrecurrent/incident conditions should be examined, such that better tuning is possible between traffic management and mobility management.

More Cooperation

Much is expected from coordinated network-wide traffic management. There are already actions in place aimed at implementing this, but further examination and development

is needed. Network-wide traffic management also has consequences for the design and organization of traffic management centers.

In the near future we expect a great deal from cooperative systems. But how will these systems actually contribute to a better transportation system? Which specific applications are on the horizon and when will they be introduced? Who is responsible and what is the relationship between roadside devices and in-vehicle systems?

In the U.S. there is a well-established system for pooling research funds (see www.pooledfund.org). Regional parties together create a fund to tackle a specific problem or to conduct research. The question now is how this financing mechanism can be adopted in the Dutch situation.

More coordination is needed between the various road networks (motorways, provincial roads, urban roads) and modes of transport (car, public transport, bicycle). It is necessary to examine how the interfaces between the road networks and the networks of the other modes can be better planned, designed, managed and operated.

Proactive Traffic Management

Knowledge Development To achieve the desired coordinated network-wide traffic management we need prediction. Further research is needed to determine which concepts can be used and what further development is needed for forecasting models.

Operational/Road Authorities The quality of the traffic information can be improved. We should examine under what circumstances which particular information is necessary and useful, and which traffic data must therefore be obtained.

Operational/Road Authorities Operational traffic management is extremely important in nonrecurrent situations and incidents. In that respect, the quality of decision support tools in traffic management centers must be enhanced. This includes a need to better assess and predict the traffic situation. The effects of measures would need to be included.

Optimize for Multiple Policy Goals

Knowledge Development **Knowledge Application** *Multi-objective traffic management would consider more than just mobility but also accessibility, safety and quality of life. What methods are available for such an integrated assessment, and what optimization techniques are suitable?*

Integrated Approach

Operational/Road Authorities **More research into the role of human factors is important to ensure that road users understand and comply with the traffic management measures that are applied. Human factors knowledge should therefore be included in traffic management by default. Research is needed in this area, for example in the development of systems, the implementation of operational measures and the application of traffic management.**

Strategic/Policy The robustness of the network has to do with the coordination between the planning of the infrastructure (the structure of the road network) and the operational application of traffic management. It is necessary to examine how coordination can be improved, for example by exploring where in the Dutch network redundancy is needed.

- Strategic/Policy**
- Operational/Road Authorities**
- Knowledge Application**
- Knowledge Development**

There is a gap between the desired traffic engineering functionalities and technical developments. It is necessary to examine how a better match between these two domains can be achieved. On one hand, it involves a better use of available technologies, and on the other hand, to let the desired functionality drive the technological developments.

It is always useful to examine developments in other fields and see if there are any analogies with traffic management, in particular about the way in which transport (particles and information) is regulated and managed.

The functional maintenance of traffic management components is an important issue. But what are the optimal investment levels in functional maintenance?

Organization

In the Netherlands the effectiveness of traffic management is sometimes doubted. In the U.S. it appears that this is less of a problem. In some states and metropolitan regions “branding” for traffic management is a normal course of action. The question is how important the application of traffic management in Netherlands is and how we can shape a branding initiative in the Netherlands.

There is currently discussion about the roles of road authorities and the private sector on the distribution of traffic information. An important research question is under what circumstances it is useful and desirable for a road authority to provide information. What would be the quality requirements of that information and what is the most appropriate division of responsibilities between government agencies and the private sector? What business models are needed?

Not only in providing traffic information, but also in applying traffic management initiatives the private sector will play a larger role. It is necessary to examine how the roles and responsibilities between government agencies and the private sector can be divided and harmonized. To what extent can international ITS organizations serve as examples?

Basic Services and Other

■ Traffic management uses all kinds of data and data sources. It is important to examine how the data can be gathered, analyzed and combined more intelligently, taking into account the differences in quality. Improvement is needed quickly given current inefficiencies in the system that relies on fixed sensors (for example, during conditions of low flow, incidents or poorly tuned sensor controllers).

■ ■ There is insufficient insight into the validity of models and therefore, there is a lot of debate about the results of model-based studies. Research into the accuracy of driver behavior models is needed. This includes multiple levels (for example, lane changing and route choice behavior) and the interactions between them.

■ In modeling there is sometimes a gap between policy and policy-supporting models. On one hand, from the policy side better models should be developed, while on the other hand, the results of model-based studies can be better presented. The question is how that could be done.

■ Social media are strongly on the rise. We have to think about the role they could play in providing traffic information safely and effectively, both outside and in the vehicle.

- Strategic/Policy
- Operational/Road Authorities
- Knowledge Application
- Knowledge Development

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About TrafficQuest

TrafficQuest, the Center of Expertise in traffic management, is a collaboration between Rijkswaterstaat, TNO and TU Delft.

In the world of traffic management a lot is happening and developments move quickly. Traffic Quest helps to keep track of these developments by systematically collecting, developing and transferring knowledge. The partners in TrafficQuest together cover the entire spectrum including the fundamental, theoretical knowledge about traffic management, and the operational expertise about the application of traffic management in practice. The activities of TrafficQuest consist of answering specific questions, giving advice on projects, conducting research on specific topics and to establish and disseminate knowledge.

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