Dynamic Tidal Flow Lane

on Provincial Roads in the Netherlands

Intelligent Transport Systems 2

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Preface

In the last two months we worked on this report as part of the subject Intelligent Transport System 2 on the University of Twente (Civil Engineering). We had the choice to come up with our own intelligent transport system and design it. We already heard something about dynamic road marking, which is a very interesting and innovative field of development in traffic management. Combined with some creative thinking, our transport system was born: the Dynamic Tidal Flow lane.

We would like thank some people for their help in our project. First Mohamed Mahmod, whom was our appointed supervisor, helped us out great and was very accurate in doing that. Nina Schaap and Bart van Arem were also of great assistance. In order to carry out the user acceptance assessment, the 100 respondents were essential to our research. Finally, thanks to Henri Stembord (Rijkswaterstaat) for updating us on the latest developments on DRM and helping us with some financial details of DRM.

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Management Summary

Pretext

From a congestion-free world we are now used to the daily traffic jams. Of course roads had to be constructed and expanded to keep up in the process. Today more and more intelligent methods of road expansion are used. One of these is Dynamic Road Marking (DRM). This technology enables road operators to prioritize directions in their demand of capacity.
In the case of provincial roads (80km/h) DRM is also applicable. These roads are appropriate for this system, because barriers are not a requirement like on highways is the case. The use of a dynamic lane enables the road operator to expand road capacity during rush hours.

There are still many questions unanswered in applying a Dynamic Tidal Flow (DTF) lane on provincial roads. This report focuses on the costs and benefits of DTF, the users' acceptance towards transition methods and the risks involved.

Recommendations

From the cost-benefit analysis it can be concluded that a DTF lane is not the solution to congestion problems on provincial roads. However, this analysis only applies to the N261. A DTF lane could be the answer on roads with stronger tidal flows and with less space available to expand. In the case of the tidal flow, it is very interesting to know what the maximum allowable intensity is for the calm direction during rush hours. More study should be conducted on these matters.
The current prices of DRM are known. But there is no notion, what the level of these prices will be, in case the DRM technology is widely used and prices drop. When these levels are known, there is more clarity whether DRM and the DTF lane in specific are serious options. Further research is required.

The users' assessed a transition phase with an active matrix sign above the road as most positive. A LED arrow on the road is a good second. A combination would be most optimal, but also very expensive. Depending on projects specifications, the road operator should select one of these three options.

Like any project, many risks are involved. Using the formulated mitigation actions, the five most relevant risks should be controlled and/or avoided.

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1 Introduction

Thanks to the technological progress made in the last decades, new tools have become available to the road operator to battle the growing congestion. Because of the high costs, environmental issues and often scarce space available, it becomes ever more difficult to just add a few lanes and increase capacity. Already these problems are being solved on another level: the tidal flow lane for example, is a great success. Also Dynamic Road Marking (DRM) offers very advanced traffic applications which have a great potential to solve traffic problems. This report will assess such an advanced application: the Dynamic Tidal Flow lane (DTF).

1.1 Field of interest

A 2x1 road with a DTF middle lane enables the road operator to switch the direction of the middle lane. This should have very positive consequences for delay times on congested roads dealing with tidal flows during rush hours. The application is especially useful for provincial roads which have little space to expand because of environmental reasons or developments along the road. Take the picture on the front page as example. If this road would expand to a 2x2 lane road because of tidal flow congestion, at least one line of trees would have to be chopped. With a dynamic tidal flow lane, this would not be necessary.

1.2 Research questions

The idea of DTF has not been applied yet and a lot of gaps in knowledge exist. This report aims to tackle some of these gaps:

1. Do the benefits exceed the costs?
2. In what fashion should the middle lane be closed?
3. What are the most relevant risks involved and how should they be dealt with?

1.3 Approach

First a stakeholder assessment plan is created, as preparation for research questions one and two.
The first research question is about the impact on traffic and the costs of road expansion. The impact and costs of conventional road expansion and DTF expansion are compared, leading to a conclusion. Parts of the stakeholder assessment plan are used to measure impact.
Closing the middle lane in order to switch directions is called a transition. It is unknown what the road user desires in terms of signals. To find out what is acceptable, using the stakeholder assessment plan, a user acceptance assessment is carried out. A questionnaire is used to obtain the necessary data.
In order to answer the third research question, a risk analysis using the RAID approach is conducted. The end results are mitigation actions to control or avoid key risks.

1.4 Structure

First a background (chapter 2) and a description of the application (chapter 3) is presented. In chapter 4 a stakeholder assessment plan using the CONVERGE approach is described. Following this assessment plan is a cost-benefit analysis (chapter 5) through an impact assessment and financial analysis. The second assessment is the user acceptance assessment (chapter 6). This assessment targets to measure the user acceptance of different transition methods available to close the middle lane. Chapter 7 describes the risk assessment. Key risks are described and mitigation actions for these risks are proposed. Finally, conclusions and recommendations are included in chapter 8.

2 Background DRM

This chapter serves as an introduction to DRM. First the need for DRM and its history is discussed. Next DRM in foreign countries is shortly mentioned.

2.1 Need for DRM

Dynamic Road Marking has an enormous potential to use road networks more flexible and efficient. It is especially useful in tidal traffic flows. A tidal flow occurs in case a road experiences congestion during the morning rush hour in direction A to B and during evening rush hour in direction B to A. Tidal flows often have one characteristic common: greatly inefficient use of the road capacity. DRM could be applied on very different ways to use the road capacity more efficient by adapting to the demand of capacity. Some promising applications are dynamic rush-hour lanes, dynamic on- and off ramps, dynamic marking in case of road works and dynamic bus lanes.

2.2 DRM in the Netherlands

In the Netherlands, DRM began its existence in the Programme for Innovation 'Roads to the Future'. DRM fitted in the Dutch national policy of a more optimal utilization of the existing infrastructure. Since the programme started, the technology of DRM instruments as well as the traffic application has steadily developed.

In order to develop DRM, pilots were carried out from 1999 to 2005. These are shown in table 1.

Table 1. DRM Pilots in the Netherlands [Rijkswaterstaat, 2005a]

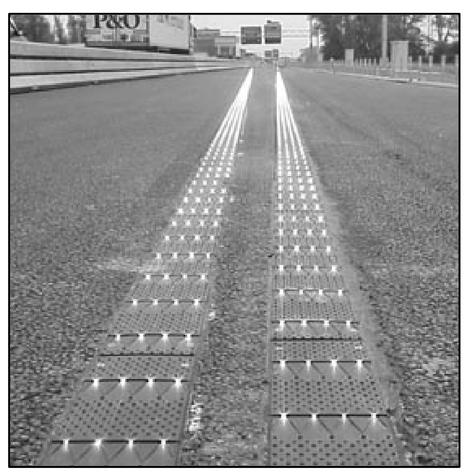
Year	Pilot (location)	Primary target
1999	A15 (between Papendrecht and Wijngaarden)	Technology and transport oriented
2001	A12 (near Utrecht)	Technology and transport oriented
2003	A44 (near Amsterdam)	Technology
2004	RWS test centre (Delft)	Light technology
2004	A50 (near Schaarsbergen)	Transport oriented
2005	A2 (near Den Bosch)	Transport oriented

An important conclusion was the better utilization of capacity; this was especially the case at pilots experimenting with a dynamic rush hour lane.

Most problems occurring mainly concerned the lightning and user behaviour. Some of light technologies could not withstand the forces caused by traffic and broke down. In the beginning there were problems concerning the amount of electricity needed, but this was later solved using technologies which required less electricity like LED lights. At one pilot the lining had a very low visibility during bright sun shine. At present the lightning problems are solved and some DRM systems can be functional and able to withstand forces from traffic.

Besides technology, users tend to experience DRM very negatively if it is suddenly switched on. An introductory section or time period is needed to avoid this behaviour. If such a section or time period was applied, most drivers did understand the dynamic marking and complied with it.

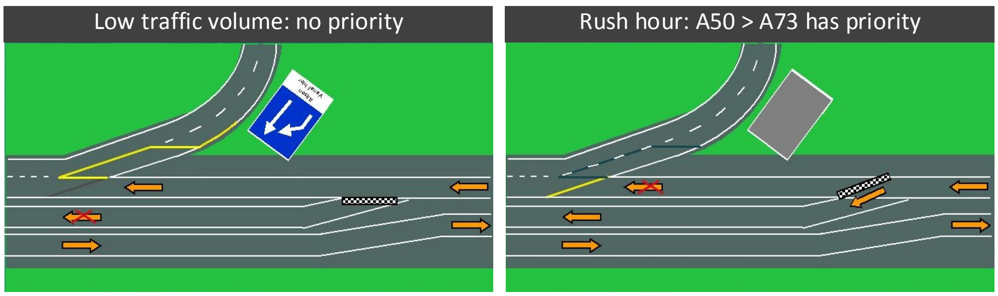
Figure 1. DRM in the Netherlands (Source: Heijmans, The Netherlands)



The pilots were very informative, but it is also apparent that DRM as an instrument is not yet fully developed. Examples of knowledge gaps are the factual quantitative surplus value of DRM applications for traffic management, the costs at large scale applications and the legal status which DRM should have in traffic regulations. The cooperation of public and private stakeholders is also not clear yet [Rijkswaterstaat, 2005a].

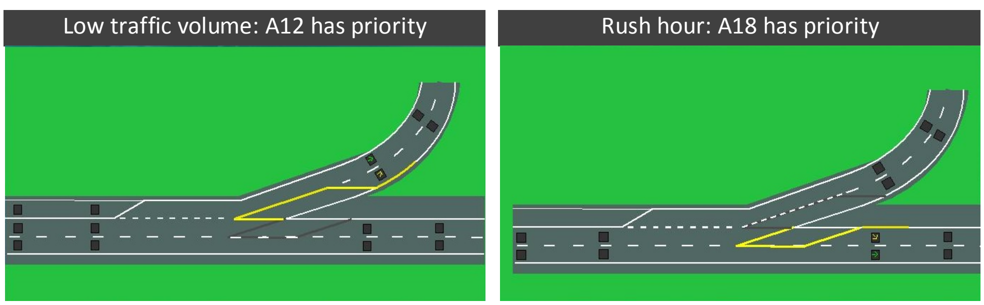
Since October 2007 a DRM is functional at a ramp on a junction (A50/A73) near Ewijk. Experiences are positive, the big disadvantage to this point are the high costs. Because DRM is not used massively, overhead costs are high. Figure 2 shows the junction with the DRM implemented.

Figure 2. DRM junction Ewijk (source: Rijkswaterstaat)



DRM is planned for implementation in 2008 on another junction (A12/A18) near Ouddijk. Just as in Ewijk, priority can be given to through traffic or to joining traffic, shown in figure 3.

Figure 3. DRM junction Ouddijk (source: Rijkswaterstaat)



2.3 DRM in foreign countries

DRM already has been implemented in three countries: Germany, Norway and Spain. In Frankfurt Am Main (Germany), where the Bundesautobahn A5 separates from the A66, DRM is applied. In normal traffic conditions one exit lane is available, but during rush hours DRM creates a second exit lane. This measure is indicated during rush hours by two parallel lines of lights, 700 meter in length.

In Oslo (Norway), DRM is applied for the purpose of lane shifting for road works in a tunnel. In Sevilla (Spain), DRM is used on the ring road SE30. A road section with Tidal Flow is indicated with DRM [Rijkswaterstaat, 2005].

3 Dynamic Tidal Flow Lane

This chapter describes the application. Its domain, function, operation, advantages and issues are discussed.

3.1 Domain and function

The specific application considered in this report is for use on the provincial roads in the Netherlands. These roads have 2x1 or 2x2 lane designs. In this report, the 2x1 version with a maximum speed of 80 km/h is relevant. With these speeds a physical barrier is not a requirement. Provincial roads that do not have sufficient capacity during rush hours, and have rush hours behaving like a tidal flow, are of particular interest for the application.

A provincial road equipped with a DTF middle lane can be switched from direction. It is closed and opened through changing the dynamic marking along this middle lane. The road marking can be shown as a continuous line or as striping. Figure 4 illustrates this transition.

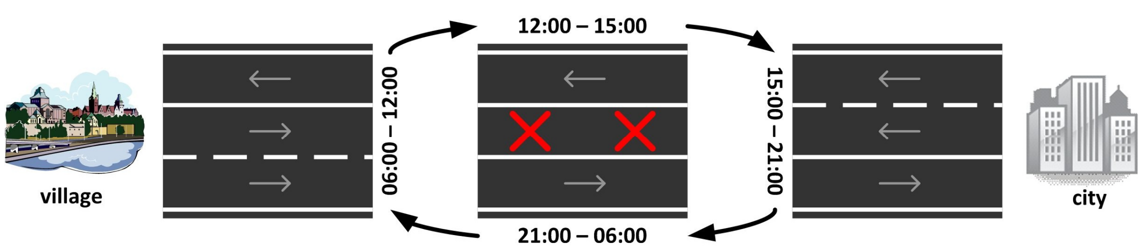
3.2 Operation

To give the reader a more practical view of the application, the operation of the application is discussed next.

3.2.1 Transition

It is essential that the transition occurs in a safe manner. It has to be absolutely clear to drivers to which direction the middle lane is assigned. Figure 4 shows in schematised fashion the functioning of the application. The chosen time periods are fictional, the grey arrows and red crossed are only put in to clarify the picture.

Figure 4. Transition middle lane



In the morning rush hour the middle lane is assigned for traffic driving from the village to the city: the 'busy' direction. Ten minutes before noon drivers are signalled of the coming closure of the middle lane. At noon the middle lane is closed.

3.2.2 Technology

The technology lies outside the scope of this report. It is assumed that the technology is durable and has the same appearance as fixed white marking. The common technology most manufacturers use, is LED lights (appendix 2).

3.3 Advantages

There are major advantages of this application compared to expanding a 2x1 road to 2x2 road:

- Less space required than conventional expansion. This could result in less costs and a higher support of the public.
- The LED lights could make conventional lighting above the road unnecessary.

- Function is expandable. Not only could the DRM be used for tidal flow, but it could also be transformed later. Examples are dynamic bus-lanes, road works, emergency services, accident control or other applications.
- Use of the road is more optimal.

3.4 Issues

Apart from the R&D issues concerning DRM, the interaction of this application with the road user is very important. If interaction fails, and it is not clear to the driver which actions are desired, than traffic flow could be distorted and safety of road users could be in danger. Especially in the case of the transition phase, user acceptance is very important.

Besides the user acceptance, it is unknown whether a DTF lane is cost-effective. Especially benefits (increasing efficiency of traffic flow) are not measured in monetary units yet.

4 Stakeholder Assessment Plan

In this chapter, an assessment plan is made for two stakeholders: road operator and road user. The goal is to achieve a better understanding of these stakeholders and the functioning of the application. For each stakeholder, the CONVERGE approach (Ertico, 1998) is followed. This approach is a guidebook for assessment of transport telematics applications. CONVERGE identifies seven key stages which constitute a generic assessment process:

1. Definition of user needs
2. Describing applications
3. Defining assessment objectives
4. Pre-assessment of expected impacts
5. Assessment methods
6. Data analysis
7. Reporting results

This order of stages is used in the assessment plans for the road operator and road user.

4.1 Definition of user needs

How can the application be designed to best meet the users' needs? The user needs of a decision maker (road operator) and a direct user (road user) are described in this subsection.

4.1.1 Road operator (decision maker)

In the Netherlands the responsibility for provincial roads (mostly N-roads) is divides among the twelve provinces. The needs of the road operator are:

- Safety (accident prevention/management)
- Smooth traffic flow
- Efficient traffic flow

In the last years also the environment has a role in the decision making. Because of its minor role, it will not be considered in this report.

In order to use the DRM application effectively, and pursue a smoother and more efficient traffic flow while sustaining safety levels, it is important that drivers fully understand the indications given by dynamic markings and be able to follow these indications. The user needs of road users are essential.

4.1.2 Road user (direct user)

The road users considered for the development of the application are the drivers (stuck) in the tidal flow: mostly commercial (e.g. trucks) and commuter traffic. The user needs of these road users are:

- Safety
- Comfort
- Congestion-free roads

In order to fulfil these needs, two conditions have to be met: indications given by the DRM has to be fully clear and drivers should have enough time to respond to and act according to the indications.

4.1.3 Other stakeholders

Other stakeholders whom are affected by the application are:

- Manufacturers of DRM
- Researchers
- Organized lobbies (ANWB)
- National road operator (Rijkswaterstaat and ministry)
- Residents alongside provincial roads

The national road operator is Rijkswaterstaat, and has operational responsibility for the national highways. Rijkswaterstaat is supervised by the Ministry of Transport and Public Works. The ministry does not only carry out transport policies but also develops them. The policies are aimed at accessibility, safety and liveability [verkeerenwaterstaat.nl, 2007], and concur with the policies of the provincial road operators.

4.2 Application description

The key characteristics of the application need to be clear for an effective assessment plan. Four key characteristics are distinguished: application name, major technologies, functionality and demonstration sites. Table 2 shows the content of these characteristics.

Table 2. Description of application

Application: Dynamic Road Marking	
Technology	• Light: 5 tested technologies (Appendix A) using LED (4) or halogen (1) • Cables for energy and communication • Operator interface
Function	Changing direction of the middle lane
Demonstration sites	Netherlands: dynamic rush hour lane, on and off ramps (pilots) Germany: dynamic exit lane (functioning) Norway: dynamic lanes for road works (functioning) Spain: tidal flow section (functioning)

4.3 Defining assessment objectives

Two assessments will be carried out: an impact assessment for the road operator and a user acceptance assessment. In this subsection the assessment objectives are described. First the user needs of the decision maker (road operator) are translated to assessment objectives. If the needs of the road operator are fulfilled, the needs of the road user are also fulfilled.

Table 3. Decision makers, user groups involved and objectives

Application	Decision Maker	Objectives
Dynamic Road Marking	Road operator	• Smoother traffic flow • More efficient traffic flow • Maintain safety levels

These objectives will be translated to assessment objectives for the impact assessment and the user acceptance assessment. The objective of the impact assessment is to measure the effectiveness of the application in terms of traffic flow. The objective of the user acceptance assessment is to estimate users' attitudes to different transition methods of the application. It would be very dangerous in case road users would not understand the signals. Table 4 summarizes the assessment objectives.

Table 4. Assessment objectives, assessment category and user groups

Assessment category	Assessment objective	User groups involved in validation
Impact assessment	Measure effectiveness	Road operator
User acceptance assessment	Estimate users' acceptance towards different transition methods	Road user (driver)

4.4 Pre-assessment of expected impacts

A pre-assessment of expected impacts is necessary to get a good idea of the nature and scale of likely impacts. First, the expectations of the impact assessment are written down in the table below.

Table 5. Expectations Impact Assessment

Assessment	Target group	Impact
Impact assessment	Road operator	Lower delays (hours)
User acceptance assessment	Road user	Negative to positive

4.5 Assessment methods

The assessment methodology is an important step in the assessment plan, and more extensive than the other steps. This stage is conducted through six steps: definition of indicators, reference case, data collection, conditions of measurements, statistical considerations and the integrity of measurement. These steps are summarized at the end.

4.5.1 Definition of indicators

Indicators are used for estimating the performance or impacts of a transport telematics application. This will give an idea of how far the objectives will be achieved by the application. Two basic requirements have to be taken into account when defining indicators:

- The indicators must be able to reflect clearly the related performance or impact.
- The indicators must be capable of reliable assessment using the experimental tools and measurement methods chosen.

The indicator for the impact assessment will be delay. Delay is expressed in time (minutes) and is caused by vehicles driving below their desired speed. For example, (overtaking) trucks often cause delays. Delay is often used as a performance indicator for transport systems.

The indicator for the user acceptance assessment will be expressed as the scale for usefulness and satisfaction running from -2 to +2.

4.5.2 Reference case

The reference case for the impact assessment is a 2x1 lane situation. From this point onwards the road operator has three possibilities: conventional expansion to a 2x2 lane road and expansion to a DTF lane. The DTF lane possibility can be configured in two ways: an optimal configuration and only used in rush hours (for legal reasons).

The user acceptance requires a reference case with a transition. The reference case is a matrix sign above the road with green arrow pointing to the right (option 1). This is the most conventional option and regarded as useful and satisfying to users. The four tested transition methods are:

2. White arrow (LED) on the road
3. Red cross (LED) on the road
4. Red blinking cross (LED) on the road
5. White blinking continuous line

4.5.3 Data collection

A real-life experiment would be unpractical for many reasons. That is why the application and the reference cases are modelled in the transport model AIMSUN to measure the effectiveness. Through using a screenshot, from Google Maps, the road can be simulated. AIMSUN requires traffic intensities to load the links. The selected N-road must have tidal flow conditions and congestion at rush hours. Measuring of acceptance can be done best through the simulation of the five methods. The user should ‘drive’ in the different simulated scenarios.

In this project the users' acceptance is estimated by using the VanderLaan scale. The scale aims to assess the acceptance of advanced transport telematics through measuring usefulness and satisfaction of the user. The technique is simple and consists of nine 5-point rating-scale items. These items load on two scales: a scale denoting the usefulness of the system, and a scale designating satisfaction. The scale enables researchers to check on validity of the results [Van der Laan, 1996]. Table 6 shows the nine items.

Table 6. VanderLaan scale (usefulness: 1,3,5,7,9 – satisfaction: 2,4,6,8)

1.	useful	¨ ¨ ¨ ¨ ¨	useless
2.	pleasant	¨ ¨ ¨ ¨ ¨	unpleasant
3.	bad	¨ ¨ ¨ ¨ ¨	good
4.	nice	¨ ¨ ¨ ¨ ¨	annoying
5.	effective	¨ ¨ ¨ ¨ ¨	superfluous
6.	irritating	¨ ¨ ¨ ¨ ¨	likeable
7.	assisting	¨ ¨ ¨ ¨ ¨	worthless
8.	undesirable	¨ ¨ ¨ ¨ ¨	desirable
9.	raising alertness	¨ ¨ ¨ ¨ ¨	sleep-inducing

It is advisable to record the age of the respondent. This is because older drivers may have different opinions than young drivers. The role of driving experience is not clear yet. That is why the respondent should be asked if he or she owns a driving license.

4.5.4 Conditions of measurements

Because the impact assessment is modelled and the methods within the user acceptance assessment are simulated, environment conditions are fully controlled. That makes it easy to match conditions.
In the simulation, the input data has to be the same for each case. Also the road has to be equally drawn. In the questionnaire the roadside, inside of the car, etc. have to be completely similar in all simulated transition methods. Practically only the marking and/or signs may differ.

4.5.5 Statistical considerations

The VanderLaan scale has nine items measuring scales usefulness and satisfaction (Table 6). This division in these nine items is used to measure consistency of the items in the usefulness and the satisfaction group. Cronbach's α is used to calculate the correlation between items and will generally increase when the correlations between items increase. Cronbach's α is defined as:

$$\frac{N}{N-1}\left(\frac{s_X^2 - \sum_{i=1}^{N} s_{Yi}^2}{s_X^2}\right)$$

Where:

N	the number of components
s_X^2	is the variance of the observed total test scores
s_{Yi}^2	is the variance of component *i*

The VanderLaan method states that reliability is sufficiently high if Cronbach's α is above 0.65.

4.5.6 Integrity of measurement

The three considerations of the assessment process are completeness, insularity and disturbance.

- Completeness: the simulation has to be realistic enough to be complete. That is also the case for the traffic model.
- Insularity: no factors have been identified as missed and having a significant effect on the performance of the application and the reference application.
- Disturbance of the validation process: there may be accidental or intended bias introduced into the measurement process by such factors as: respondent fatigue, policy response bias and

justification bias. The questionnaire takes a maximum of 10 minutes, so it is not expected that respondents get tired and rush through the questionnaire. Respondents do not have direct interests in the topic, so policy response bias is unlikely. In case the questionnaire can be filled in anonymous, a justification bias is not likely to happen.

4.5.7 Summary

Table 7 summarizes the steps.

Table 7. Summary assessment methods

Item	Impact Assessment	User acceptance assessment
Assessment objective	Measure effectiveness	Estimate users' acceptance towards different transition methods
Indicator	Delay (minutes)	Usefulness and satisfaction
Reference case	2x1 lane road, 2x2 lane road	Matrix sign
Methods of measurement	Transport model	Online questionnaire/simulation
Measurement or simulation conditions	Morning rush hour (traffic data from real road)	Only marking/signs change in simulation
Statistical confidence level	Not applicable	$\alpha > 0.65$
Overall definition of success	Lower delays	Positive assessment of one or two transition methods
Integrity of measurement	OK	Disturbance is unlikely

4.6 Data analysis

The data analysis for the impact assessment is very straight-forward. The output from the transport model can be exported into a software programme like Excel and results can be compared.

Analysing data for user acceptance assessment is more complex. First data (scores, age and driving license) has to be exported in Excel. Then the results have to be checked through Cronbach's α. If this test holds, the results can be averaged for usefulness and satisfaction. This can be done for all respondents or the different age categories.

4.7 Reporting results

The results are eventually most important for the road operators. The impact assessment helps them to make the decision for the implementation of DTF lane application. The user acceptance assessment helps to design the dynamic lane. The report, aimed at the road operators, should be divided in three parts:

- Part I — Key validation results at project level
- Part II — Detailed validation results
- Part III — Comparison of validation results across sites

The decision-maker (road operator) is especially interested in the first part. The second and third parts are the more detailed parts of the report.

5 Cost-benefit Analysis

This chapter will evaluate costs and benefits of the DTF lane to conclude whether this application is cost-effective or not.

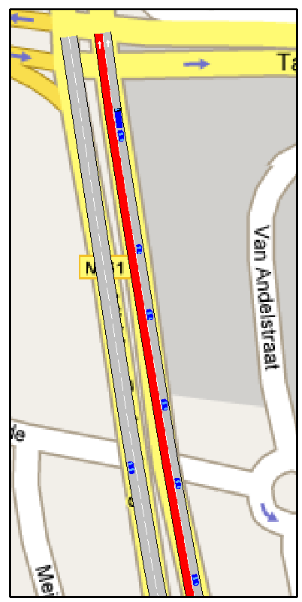
5.1 Impact Assessment

5.1.1 Goal

The goal of the simulation is to investigate what the impact on traffic flows is for the four different scenarios. These scenarios are the 2x1 lanes, 2x2 lanes and 2x1 + DTF lane. The DTF lane scenario is divided in two scenarios. The first scenario functions only during rush hours (from 6:00 – 10:00 and from 15:00 – 20:00). The second system functions the whole day (from 3:00 – 9:00 and from 9:00 – 3:00). The DTF lane is opened for the direction which has the highest intensity. Logically the first, less optimal DTF system, causes a lower decrease in delay times than the second. However, this scenario is used for legal reasons. In the Netherlands road operators are obliged to do a research on the environmental impacts (MER study) when planning a tidal flow lane. However, a few tidal flow lanes in the Netherlands can only open in rush hours because the effects on air quality were not researched sufficient.

5.1.2 Method

Figure 5. Screenshot in AIMSUN



The impact assessment is simulated through the micro simulation program Aimsun. This computer program has the possibility to simulate different scenarios on the road. The output of Aimsun is converted to Access and Excel. In Excel, the different situations are compared and the final results calculated. First the N261 is modelled in Aimsun. A Google Maps screenshot is imported in Aimsun and a vector is drawn over the road. Two centroids, at the beginning and ending of the road, are placed: one for the departures and one for arrivals. These centroids are linked to the road.
The four centroids require an O/D matrix to distribute vehicles on the road. The vehicles are separated in cars and trucks and loaded on the network from 0:00 till 24:00. The average workday intensities were extracted from the traffic website of the province Noord-Brabant. Intensities for Saturday and Sunday are harder to come by, so a ratio for these days is used. This is acceptable, because there is less congestion in the weekend and delays are lower. The weekend adds 15% delay times.
The next step is defining scenarios. The scenarios are linked to an experiment with their own configuration. A dynamic lane is not available in Aimsun, so this is simulated by a 2x2 lanes road. One of the four lanes is always closed. A transition (two lanes closed) takes up fifteen minutes.
The last part of the method is performing the simulation. Each scenario is simulated five times to increase reliability of the simulations. These five replications are averaged.

5.1.3 Results

The total delay times for the four simulations are shown in the table below.

Table 8. Delay times on workdays

Scenario	Total delay on workday
2x1 lanes	325 hours
DTF1 – rush hours	257 hours
DTF2 – optimal	214 hours
2x2 lanes	83 hours

The results of the simulation are as expected.

- The 2x1 lane scenario has the highest delay times and the 2x2 lane scenario the lowest.
- The delay times of the DTF lane scenarios are in between. The DRM scenario, which only operates in the rush hours, has higher delay times.

Unfortunately the DTF lane scenarios still have high delay times, during the rush hours, for the direction without the DRM lane. This could be caused by trucks. Most car drivers desire an estimated speed of 85 km/h, but the trucks only drive at approximately 75km/h. This means that vehicles behind a truck experience delays. However, an experiment shows that trucks are not to blame. More information on this is available in the text-box.
Still the DTF lane scenarios provide less delay than the 2x1 lane scenario. Especially in rush hours, the direction with the highest intensity has much lower delay times because of the second lane.

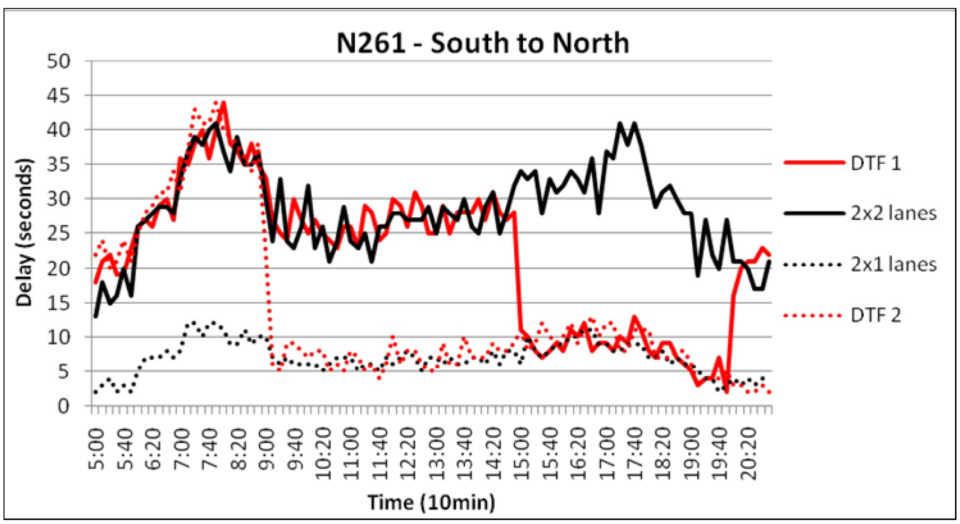
Chart 1 shows the individual delay times for every ten minutes. It is visible to which direction the DTF lane is assigned. For the first configuration this happens on 09:00, the transition in the optimal configuration occurs on 15:00.

The influence of trucks on delay
Through two new experiments, the influence of trucks on delay times is measured. In the first experiment only 20% of the trucks was assigned, in the second no trucks are assigned.

Scenario	20% trucks	No trucks
2x1 lanes	278	263
DTF1 - rh	220	204
DTF2 - opt	182	166
2x2 lanes	63	56

The results show that a smaller part of trucks does not increase the benefit in delay times of an optimal DTF lane compared to a 2x1 lanes road.

Chart 1. Delay times



5.1.4 Conclusion

The results of the simulation do look very realistic. The 2x2 lane is simply the best option in case of the N261, because the delay times are much lower. Nevertheless, the results show that DRM reduces delay times significantly. Two external situations would positively effect the decision for a DTF lane:

- There is not a lot of space around the road, so expanding to 2x2 lanes could be problematic.
- There is a matter of high tidal flow. In the direction with only one lane during the rush hours the intensities must not be higher than about 1000 veh/hour. Otherwise this lane causes too much delay times.

5.2 Delay in financial terms

For each scenario the decrease in delay times can be converted to monetary units. These benefits (the delay time has decreased) can be compared with construction and operation costs later on.
Table 9 shows that each motive of travel has its own value of time. These values are used in calculating delay costs. For example, in case a truck driver experiences congestion causing a delay of 2 hours, the damage is 84.70 euro.

Table 9. Value of time

Mode	One hour delay
Cars – work trips	€ 8.57,-
Cars – business trips	€ 29.67,-
Cars – other trips	€ 5.92,-
Trucks – freight	€ 42.35,-

The amount of cars and trucks are imported in the O/D matrix in Aimsun. The division of motives in car trips are given by percentages for each hour [Thomas, 2007]. From statistics are the partitions known for the different motives. In rush hours, these are mostly work trips. The rest of the day mostly attracts business and other trips.

Aimsun determines the amount and the delay of vehicles for each ten minutes. The delays can be multiplied with the amount of vehicles for the total delay. These total delays can be divided in trucks and cars (three motives). Next, the delay is converted to hours. This delay can be multiplied with the value of time. The sum of all the hours is the total delay cost for one day.

It is assumed that the delay in the weekend adds 15% in delay times. The costs of all days in a year are shown in the table below.

Table 10. Total delay costs

Mode	Costs for yearly delays
2x1 lanes	€ 1.500.000
DTF1 – rush hours	€ 1.250.000
DTF2 – optimal	€ 1.000.000
2x2 lanes	€ 410.000

5.3 Project in financial terms

The project is determined to last for 10 years. The main costs of road expansion can be split up in three parts: construction costs, costs for DRM implementation and the energy consumption of DRM. Also other costs are estimated. Maintenance costs are not taken up in the analysis, because costs are analysed for the life cycle only. Accidental maintenance costs are included in 'other costs'.

The construction costs are based on figures from website bouwkosten-online.nl. The costs are estimated at € 497 per meter for expansion to a 2x2 road and € 226 per meter for a DTF lane expansion.

The costs for implementing DRM are estimated at € 650,000 per kilometre. This includes the lights, cables and construction. This figure is retrieved from Rijkswaterstaat and based on a DRM project in Ewijk, mentioned in the background (Chapter 2). Currently the costs are very high, because DRM is not yet massively produced. On this moment Rijkswaterstaat (*Dienst Verkeer en Scheepvaart*) is working out DRM scenarios in order to estimate future costs. Unfortunately, no figures are available yet. In this report the costs of DRM are used through three scenarios: € 650/m (100%), €488/m (75%) and €325/m (50%). The system, including operation controls, is expected to last for up to 10 years [Rijkswaterstaat, 2005b]. € 25,000 per year is added for extra signs

Energy consumption is determined on the basis of the amount of lights, the energy need (Watt) and the price of energy:

- Every five cm four lights next to each other on two lines make 160,000 lights per km.
- Energy consumption is 9 mW for each light (Appendix 5).
- The current energy tariff is € 68.42 / MWh [Endex.nl, 2008].

Thus each kilometre of DRM costs € 863 per year.

The other costs include boarding, adaptation of junctions, organization costs and accidental costs. These are estimated at € 200,000 per year. Table 11 shows the costs on a yearly basis.

Table 11. Yearly costs

Scenario	Road constr.	DRM	Energy	Other costs	Yearly costs
DRM Scenario 1	€ 153.680	€ 459,000	€ 5,900	€ 200,000	€ 818,580
DRM Scenario 2	€ 153.680	€ 361,250	€ 5,900	€ 200,000	€ 720,830
DRM Scenario 3	€ 153.680	€ 246,500	€ 5,900	€ 200,000	€ 606,080
Expansion 2x2	€ 338.096	€ 0	€ 0	€ 200.000	€ 538.096

5.4 Conclusions

Table 12 displays the yearly netto benefit of each scenario. The optimal DRM configuration is used for the benefits of the DRM scenarios.

Table 12. Yearly costs and benefits

Scenario	Costs	Benefits	Netto
DRM Scenario 1	€ 819,000	€ 500.000	-€ 319,000
DRM Scenario 2	€ 721,000	€ 500.000	-€ 221,000
DRM Scenario 3	€ 606,000	€ 500.000	-€ 106,000
Expansion 2x2	€ 538,000	€ 1.090.000	€ 552,000

Unfortunately all the DRM scenarios cost more than they contribute. It is clear that a DTF lane is not an option on the N261. The costs for implementing DRM are calculated to be on a level of 23% of today’s prices to be cost-effective.

So why is a DTF lane no option for this road, could it be an option on other roads? That is possible, but some conditions have to be met.

- Unless costs for DRM will not decrease dramatically to levels below 23%, benefits have to be higher. Tidal flow conditions have to be stronger: less traffic on the calm lane and more on the busy lane.
- Conventional expansion is less attractive with high construction costs. In the city, for example, expanding a small road to a 2x2 road requires lots of expensive territory. Another example is a bridge, having to broaden a bridge is extremely expansive. A DTF lane could be a real solution in these situations.

6 User Acceptance Assessment

The goal of this assessment is to measure the user acceptance of different signal methods. The methods are targeted at the driver to make clear he/she has to switch to the right lane because the transition from two lanes to one lane is about to take place.

6.1 Questionnaire

A website is constructed, on which the questionnaire was placed: www.ex-plore.nl/its2. Besides the questionnaire, the research purposes are explained and the visitor is informed about the questionnaire.
The methods are represented by a flash animation. This movie-like image gives the respondent the feeling that he/ she is driving in a car on the DTF middle lane. In each scenario, the driver is pointed out, with different methods, to leave the middle lane and switch to the right lane. The following transition methods will be investigated:

1. Matrix sign above the road with green arrow pointing to the right
2. White arrow on the road
3. Red cross on the road
4. Red blinking cross on the road
5. White blinking continuous line

Figure 6 shows a screenshot of scenario 3 in the questionnaire.

Figure 6. Scenario 3 simulated: Red cross on the road

The respondent has to assess the different methods which the nine items of the VanderLaan scale (more on this in chapter 4). After assessing the items, the respondent has to fill in his age and whether he owns a driving license. The respondent could also give remarks if desired.

6.2 Data processing

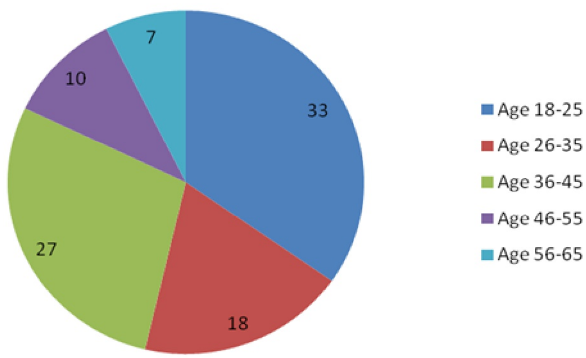
If the respondent submits the questionnaire, the choices of the respondent are automatically mailed. This data is copied to Excel through the use of an automatic script (Excel macro). In Excel, the scores are linked with the matching values (-2, -1, 0, 1, 2). The first step is now completed.

The second step is to convert the input data to a useable data which is progressed to final results. Again an automatic script is used to generate a table with all the input data (age, driving license, scores and remarks). The average values for the nine items are extracted and averaged over all the respondents. These values are the scores for the transition methods. In total, there are ten scores (five methods * (satisfying + usefulness)). These scores are calculated for the total group of respondents independent of the age. The age could be important for the choices, so also for five age categories, the scores are calculated. This results in a total of 60 scores. These scores show the satisfying and usefulness for the five transition methods dependent of age.

6.3 Respondents

There are 95 respondents who submitted useful data. Four responses were not useful, because these did not contain scores to all items. Of these 95 respondents only three people do not own a driving license. This is very low; it is impossible to compare people with a driving license and without one.
The figure below shows the amount of respondents in the different age categories. As expected, most respondents have an age from 18 to 25, because a lot of colleague participated. In spite of this, there were sufficient respondents in the age categories 26-35 and 36-45. The last two age categories have only 7 and 10 respondents. This may influence the results, because the amount is too low to have representative results. This will be discussed in the subsection with results (6.5).

Chart 2. The amount of respondents for the different age categories



6.4 Validity

The reliability of the research depends on the respondents. If a respondent is not very serious, the results could be negatively influenced. The VanderLaan method can measure consistency through Cronbach's α, this was explained in chapter 3. The VanderLaan method states that reliability is sufficiently high if Cronbach's α is above 0.65. The validity is measured for all 60 scores.

In the table below the reliability values for all methods and age categories are summarized.

Table 13. Reliability, by using Cronbach's α, of the questionnaire results

Scenario	Item	all	18-25	26-35	36-45	46-55	56-65
Matrix signs	Usefulness	0,79	0,54	0,81	0,87	0,84	0,87
	Satisfying	0,68	0,62	0,74	0,75	0,32	0,74
Red cross	Usefulness	0,90	0,83	0,96	0,90	0,91	0,90
	Satisfying	0,80	0,69	0,87	0,78	0,79	0,86
Flashing Line	Usefulness	0,81	0,81	0,83	0,80	0,89	0,77
	Satisfying	0,79	0,81	0,82	0,77	0,75	0,68
Arrow	Usefulness	0,86	0,55	0,84	0,90	0,87	0,95
	Satisfying	0,74	0,62	0,80	0,71	0,52	0,87
Flashing red cross	Usefulness	0,87	0,79	0,92	0,91	0,83	0,88
	Satisfying	0,82	0,81	0,84	0,85	0,73	-0,36

The values of the table results in the following conclusions:

- The proven reliability of all scores is the most important result. The lowest Cronbach's α value is 0.68, which is just higher than 0.65.
- For the respondent age 18-25 (mostly students) the reliability is not proven for all ten scores. The satisfying and usefulness values for the matrix signs (method 1) and the arrow (method 4) are not above 0.65. The students were probably not very serious during the research.
- The fourth age category (46-55) is reasonably reliable, only the satisfaction for the matrix signs and the usefulness for the arrows are below 0.65. The other values are at least 0.73.
- The oldest respondents (56-65) have a reliable value for nine of ten scores. The satisfying score for the flashing red cross is very unreliable. Strangely most respondents in this age category rated it undesirable, but pleasant and likeable. These items all belong to the satisfying scale, which causes an unreliable value.

6.5 Results

The results of the questionnaire contain 60 scores which are discussed in this subsection. The values of the table below represent the averages of all the average scores of each respondent for usefulness and satisfying. The scale has a maximum value of +2.0 and a minimum value of -2.0.

Table 14. Final results of the questionnaire (green = positive, red = negative)

Scenario	Item	all	18-25	26-35	36-45	46-55	56-65
Matrix signs	Usefulness	0,93	0,76*	1,17	1,07	0,94	0,60
	Satisfying	0,53	0,48*	0,79	0,59	0,43*	0,04
Red cross	Usefulness	0,52	0,59	0,46	0,40	0,50	0,83
	Satisfying	-0,39	-0,58	-0,49	-0,23	-0,40	0,18
Flashing Line	Usefulness	-0,75	-0,78	-0,74	-0,78	-0,52	-0,83
	Satisfying	-1,26	-1,31	-1,21	-1,39	-1,00	-1,07
Arrow	Usefulness	0,71	0,84*	0,93	0,51	0,50	0,60
	Satisfying	0,61	0,79*	0,71	0,37	0,43*	0,64
Flashing red cross	Usefulness	0,36	0,36	0,23	0,30	0,44	0,80
	Satisfying	-0,94	-1,15	-1,03	-0,74	-0,73	-0,75*

Table 14 results in the following conclusions:

1. The usefulness for the matrix signs is for all age categories the highest except for the age category 56-65. They give the highest score to the red cross and the arrow. The reaction time of older people is lower and they want to focus themselves on the road. This could explain why this group likes the matrix signs less.
2. The second-best scenario is the arrow on the road surface. The usefulness and satisfying of the arrow is for all age categories positive.
3. People prefer an arrow (an instruction) in stead of a cross (a prohibition).
4. The respondents think the non-flashing cross is more useful than the flashing cross, except for the age category 56-65. However, the satisfying is very low, so both transition methods remain bad options.
5. The flashing line has a very low satisfying and usefulness score. Many people do not understand the flashing line and perceive it as annoying.

6.6 Final results

The column 'all' in Table 14 is not very representative, because the respondents are distributed differently over the age categories than the average group of people on the road. This is why the scores of each age categories are multiplied with the real percentage of driven kilometres. This information is available in the SWOV COGNOS database.

The scores for the different age categories (SWOV uses other age categories) are calculated again and multiplied with the percentages of **Error! Reference source not found.** (Appendix VI). This results in the scores which are given in Table 15.

Table 15. Scores for methods multiplied with percentages

Option	Item	Score
Matrix signs	Usefulness	0,97
	Satisfying	0,48
Red cross	Usefulness	0,56
	Satisfying	-0,25
Flashing Line	Usefulness	-0,72
	Satisfying	-1,16
Arrow	Usefulness	0,63
	Satisfying	0,51
Flashing red cross	Usefulness	0,46
	Satisfying	-0,79

It is very clear that the matrix sign has the highest usefulness score. The satisfying scale of the arrow is just higher then the satisfying of the matrix signs. However, the scores of the different age categories should still be taken into account.

6.7 Conclusion

The matrix sign could be sufficient, but has a low satisfying score for the respondent age 56-65. The arrow scores overall a bit lower, but is a good alternative. Probably the combination of a matrix sign and an arrow on the road surface results in a high usefulness and satisfying for all age categories.

7 Risk Analysis

The RAID (Risk Analysis for ITS Deployment) scenario approach is used as guideline in this risk analysis. The risk analysis is aimed at identifying risks and creating mitigation actions to avoid or control risks. This only applies to risks with probability/impact values of high/medium, medium/high or high/high.

7.1 Stakeholders

In the stakeholder assessment plan, the stakeholders' needs have been discussed. In the risk assessment it is more relevant to look at what power stakeholders have.

7.1.1 Road operator

In this case the province is the road operator. The province has the authority to arrange (temporary) traffic measures. The province can also give permits for traffic measures, special vehicles and cargos and road races when necessary [brabant.regelingenbank.eu, 2002].

7.1.2 Road user

The road user actually has the power to avoid a DRM enabled road and to ignore the markings. Avoiding the road causes an increase in travel time, which is an unusual and improbable choice. Road users could ignore the markings because of unclear markings, creating hazardous traffic conditions. Drivers can participate in questionnaires or simulations so that researchers can investigate the acceptability of DRM.

7.1.3 Manufacturers

Several manufacturers are involved: manufacturers of the DRM hardware (light, cables, etc.) and the DRM software. Manufacturers' interests lie in profit and knowledge. Suppliers and contractors play an indirect part through the manufacturer.

7.1.4 Researchers

Researchers are required to develop knowledge about hardware and software for the implementation of DRM. Researchers are organized in universities and public bodies like Rijkswaterstaat in the Netherlands. Because the road operator in the Netherlands is a public body, Rijkswaterstaat plays an important role in research. Also an institution like TNO is important.

7.1.5 Organized lobbies

Through media and procedures organized lobbies can practise quite some power against road planning. Road user lobbies like the ANWB in the Netherlands can enlarge or decrease the social basis drastically through the media. Environmental lobbies are notorious for frustrating procedures through lodging in objections.

7.1.6 National road operator

The national road operator in the Netherlands is Rijkswaterstaat. Rijkswaterstaat is in charge of constructing, managing and developing the national infrastructural networks in the Netherlands on the road and water. This specific DRM application on the provincial roads is not within the authority of Rijkswaterstaat, although Rijkswaterstaat could offer some support in the form of finances and knowledge.

7.1.7 Residents alongside provincial roads

Residents do not have the means like organized lobbies have, but because of their big involvement they can be very persisting in their actions.

7.2 Deployment scenario

The elements composing a deployment scenario are included in table 8.

Table 16. Deployment scenarios

Geographical scope	Interurban
Main trends for ITS development planning	ITS strategies focused on the provision of Telematic infrastructures to improve the efficiency and safety of the transport network, and on the provision of public transport service
Level of public and private co-operation	The public sector (universities and public bodies) is leading and ruling the ITS development. Private stakeholders have a big part in developing the light technologies.
Estimated time horizon	2008 – 2010: Research and Development 2011 – 2020: Low market penetration (<5% penetration)

7.3 Risks

The risks are shown below with high probability / medium impact or medium probability / high impact. A complete list of risks is included in Appendix III.

1. Development runs over-budget
2. Lights wear too fast
3. Junctions turn in to chaos
4. Energy costs are too high
5. Dynamic marking not clear to driver

7.3.1 Development runs over-budget

Description: Because of many setbacks the development of the application costs much more money than anticipated.
Category: Cost & benefits
Consequences: The development could be stopped or used for another application. Either way implementation could be prevented.
Probability: Medium, budget problems can occur quite easily without strict budget management.
Level of impact: High, the consequences could be very severe.
Risk rating: Orange

7.3.2 Lights wear too fast

Description: The (LED) lights rapidly become obsolete
Category: ITS infrastructure
Consequences: The lights have to be replaced more often than anticipated, resulting in more maintenance costs.
Probability: High, in the pilots the problem has occurred.
Level of impact: High, higher maintenance costs are a burden for a road operator and a reason to cancel implementation of the DRM application.
Risk rating: Red

7.3.3 Junctions turn in to chaos

Description: Junctions are not correctly adjusted to the new dynamic markings.
Category: Safety
Consequences: Pre-sort lanes to the junction and the junctions themselves turn in to chaos, increasing the risk for accidents occurring.
Probability: High, the junctions have to be adjusted.
Level of impact: High, without good road planning the junctions will be very unsafe.
Risk rating: Red

7.3.4 Energy costs are too high

Description: During implementation the energy costs for operating the lights are much higher than expected.

Category: Cost & Benefits

Consequences: Costs probably outrun benefits being a serious threat for continuation of the project. Researchers would have to go back to the drawing board to look for other less energy consuming light technologies. Another consequence is the negative environmental one. Environmental lobbies could be seriously troublesome.

Probability: Medium, in a pilot conducted there were problems with energy use, but energy consumption is a very predictable factor.

Level of impact: High, unexpected high operation costs are unacceptable.

Risk rating: Orange

7.3.5 Dynamic marking not clear to driver

Description: The dynamic markings are not clear for all drivers. This problem especially occurs during the transition from two lanes to one lane and vice versa.

Category: Safety

Consequences: The markings have to be clear for all drivers, otherwise it will result is very unsafe situations.

Probability: Medium, DRM is very new for Dutch drivers, but other traffic measures like rush hour lanes and tidal flow lanes have showed that drivers can adjust to new traffic measures quite easily.

Level of impact: High, unclear signs pose a threat to traffic safety.

Risk rating: Orange

7.4 Mitigation actions

Mitigation actions are formulations of strategies addressed to deal with the risks labelled with red or orange risk rating.

7.4.1 Development runs over-budget

Strategy action: Have a strict budget control system in place.

Action by whom: Ministry of Transport and Public Works (Ministerie van V&W)

Action type: Risk avoidance

Scenario: Development

7.4.2 Lights wear too fast

Strategy action: Thorough tests should be conducted in a controlled environment. The lights can be supplied with a test certificate only if the tests are completed successfully. The tests are completed successfully if the pre-defined criteria have been reached.

Action by whom: The tests can be carried out by an objective test institution like the Dutch TNO. The criteria are set by public bodies (road operator and Rijkswaterstaat) in cooperation with TNO.

Action type: Risk avoidance

Scenario: Development

7.4.3 Junctions turn in to chaos

Strategy action: The total road section with all its junctions and other discontinuities has to be designed to a safe integral solution.

Action by whom: Rijkswaterstaat and road operator

Action type: Risk avoidance

Scenario: Development

7.4.4 Energy costs are too high

Strategy action: During development energy use of available light technologies should be calculated and be considered in the decision making process. During deployment energy use (costs) should be monitored closely. If costs are higher than pre-defined level, the road operator can take action in time. The road operator should consider which action to take before deployment takes place.

Action by whom: Rijkswaterstaat and road operator

Action type: Risk avoidance and controlling

Scenario: Development and deployment

7.4.5 Dynamic marking not clear to driver

Strategy action: Driver acceptance assessment, especially investigating the transition. Besides this assessment signs should be put in place along the road to inform drivers about the new traffic situation.

Action by whom: TNO

Action type: Risk avoidance

Scenario: Development and deployment

7.5 Recommendations

The road operator (province), Rijkswaterstaat and research institutions play a major part in controlling and avoiding risks. This was also proven to be the case in the mitigation actions for the five most relevant risks:

- Development runs over-budget
- Lights wear out too fast
- Chaos on junctions
- Energy costs are too high
- Dynamic markings are not clear to driver

All these five risks can probably be controlled and/or avoided if the formulated strategy actions are adopted in development and deployment.

8 Conclusions and Recommendations

8.1 Conclusions

This report assesses the Dynamic Tidal Flow lane through a cost-benefit analysis, a user acceptance assessment and a risk assessment. All serving to answer the research questions below.

RQ 1: *Do the benefits exceed the costs?*
For this specific case, the provincial road N261, the benefits of decreased delay times did not exceed the costs of constructing a DTF lane. The DTF lane did however had very positive effects on delay times, but expansion to a 2x2 road caused a larger decrease of delay times and costs less. Probably, there are roads in the Netherlands where a DTF lane would be cost-effective, if these conditions are satisfied:

- The traffic experiences a more extreme tidal flow than is the case on the N261. On the N262 the intensity during rush hours on the calm direction was still too high.
- Space is scarce or not available. If this is the case, a DTF lane would be a cheap option compared to conventional 2x2 expansion.

RQ 2: *In what fashion should the middle lane be closed?*
The goal of the user acceptance assessment was to investigate which transition methods users prefer. In other words: how should the DTF lane be closed, in order to switch directions, according drivers? This question was answered using a web-based questionnaire according the VanderLaan scale. The results, tested on validity with success, produced two winners: an arrow on the road (LED lights), and a matrix sign above the road. The matrix sign could be sufficient, but has a low satisfying score for the respondent age 56-65. The arrow scores overall a bit lower, but is a good alternative. Probably the combination of a matrix sign and an arrow on the road surface results in a high usefulness and satisfying for all age categories.

RQ 3: *What are the most relevant risks involved and how should they be dealt with?*
The risk assessment produced five risks which are most relevant to stakeholders to prevent and/or control: development runs over-budget, LED lights wear out too fast, chaos on junctions, too high energy costs and unclear dynamic markings. All these five risks can probably be controlled and/or avoided if the formulated mitigation actions are adopted by the correct stakeholders in the development and deployment stages.

8.2 Recommendations

From the cost-benefit analysis it can be concluded that a DTF lane is not the solution to congestion problems on provincial roads. However, this analysis only applies to the N261. A DTF lane could be the answer on roads with more extreme tidal flows and with less space available to expand. In the case of the tidal flow, it is very interesting to know what the maximum allowable intensity is for the calm direction during rush hours. More research should be conducted on these matters.
The current prices of DRM are known. But there is no notion, what the level of these prices will be, in case the DRM technology is widely used and prices drop. When these levels are known, there is more clarity whether DRM, and the DTF lane in specific, are serious options. Further research is required.

The users assessed a transition phase with an active matrix sign above the road as most positive. A LED arrow on the road is a good second. A combination would be most optimal, but also very expensive. Depending on projects specifications, the road operator should select one of these three options.

Like any project, many risks are involved. Using the formulated mitigation actions, the five most relevant risks should be controlled and/or avoided.

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Thomas, Tom (2007) percentages van het aantal aankomsten en vertrekken per motief per uur. Universiteit Twente, Enschede.

9.2 Websites

Energy Prices (Endex)
http://www.endex.nl/

Google Maps
http://maps.google.com/

Information on road operators (Verkeer en Waterstaat)
http://www.verkeerenwaterstaat.nl/onderwerpen/organisatievenw/over_venw/missie_en_kerntaken/

Information on road operators (Brabant)
http://brabant.regelingenbank.eu/regeling/284-beleidsnota-wegenbeheer-kadernota/

Road Construction costs (Archidat)
http://www.bouwkosten-online.nl/

Traffic information (Noord-Brabant)
http://www.brabant.nl/Besturen/Feiten%20en%20cijfers%20over%20Brabant/Brabant%20op%20Kaart/Verkeersintensiteiten.aspx

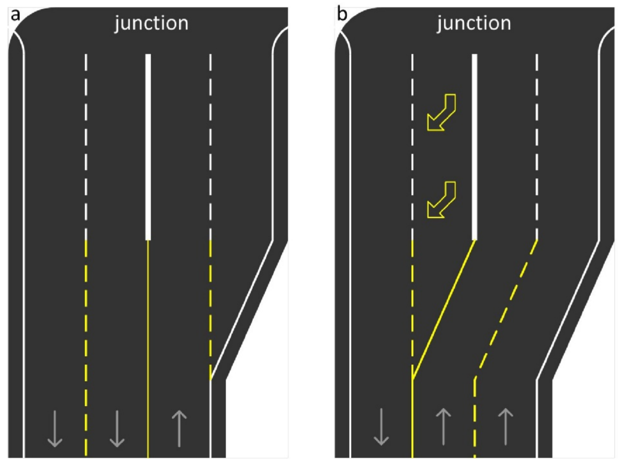
Travel information (SWOV COGNOS database)
http://www.swov.nl/cognos/

Value of Time (Rijkswaterstaat)
http://www.rijkswaterstaat.nl/dvs/themas/leefbaarheid/economie/publicaties/index.jsp

Appendixes

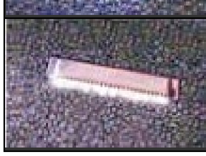
Appendix I: Junctions

Although junctions are not be a topic of discussion, a practical point like the adjustments of junctions to the application are meaningful to work out, in order to get a clearer view of actual implementation of the application. The road with DRM becomes a 2x2 lane road at junctions. Extra DRM has to be applied at the section where the 2x1 lane road merges into the 2x2 lane road. **Error! Reference source not found.** shows this solution in scheme for the morning (a) and evening (b) rush hour. Dynamic arrow markings are also a requirement. For clarity the dynamic markings are in yellow, the static markings in white.



Appendix II: Light technologies

In the table below the tested technologies on the Dutch highway A44 are shown [Rijkswaterstaat, 2005].

Illustration	Supplier, manufacturer, contractor	Fitting, light source, dimensions	Interval between elements on A44
	ITS, Swarco - Futurit, Van den Berg infrastructuren	Metal, LEDs, 150 mm in diameter	50 cm
	Nils Traffic BV, Nils Traffic BV, Possehl	Bioresin, LEDs, 750 x 220 mm (lxb)	Continuous system existing of joined mats
	ITS, Astucia, Nettenbouw	Steel with plastic lens, LEDs. 100 mm in diameter	50 cm
	BTI, Advanced Light, Sprangers	Aluminium & steel, halogene, 182 mm in diameter	60 cm
	Heijmans / Philips, Heijmans / Philips, Heijmans W&V techniek	Cast iron, LEDs, 50 x 265 mm (lxb)	25 cm

Appendix III: Risk rating scheme RAID approach

Risk rating	Probability	Impact
Red	High	High
Orange	High Medium	Medium High
Yellow	High Medium Low	Low Medium High
Green	Medium Low	Low Medium
Blue	Low	Low

Appendix IV: Risks

The risks below are below the risk rating of orange.

Delays in implementation

Description: Serious problems in implementing the application cause it to have serious delays.
Category: Deployment & operation
Consequences: Higher costs
Probability: Medium
Level of impact: Medium ⇒ *Risk rating*: Yellow

Lights break down suddenly

Description: The (LED) lights suddenly break down due to technical problems
Category: Deployment & operation
Consequences: Especially in the dark, a break down can cause very dangerous situations.
Probability: Low
Level of impact: High ⇒ *Risk rating*: Yellow

Lights cause epileptic reactions with some drivers

Description: The DRM implemented, a very small percentage of drivers react epileptic to the flashing light markings.
Category: Traveller acceptance
Consequences: Unsafe situations
Probability: Low
Level of impact: Medium ⇒ *Risk rating*: Green

Safety standards for markings get more stricter

Description: In the final stages of development the government imposes stricter regulations for road marking. The designed dynamic marking do not meet these new regulations.
Category: Framework architecture
Consequences: If talks with the government about the new regulations do not work out, the application should be redesigned. Delays and more costs are the result.
Probability: Low
Level of impact: Medium ⇒ *Risk rating*: Green

Bugs in software

Description: During operation bugs appear in the software which disrupt the correct functioning of DRM.

Category: Deployment & operation

Consequences: Possible consequence is the temporary shutdown of the middle lane until the software bugs are solved. This extra maintenance brings more costs with it.

Probability: Low

Level of impact: Medium ⇒ *Risk rating*: Green

Private stakeholder stops cooperation

Description: An important private stakeholder breaks up in the development phase, because the stakeholder is of opinion its interests are not considered sufficient by the public stakeholder..

Category: Organisation and Institutional Issues

Consequences: Private stakeholders are considered important, as they are seen as the primary stakeholder who develops the light technology. Breaking up cooperation is a sure set-back to development.

Probability: Low

Level of impact: High ⇒ *Risk rating*: Yellow

Bad publicity in the media

Description: Through lobbies the project receives very negative attention in the media.

Category: Framework architecture

Consequences: Negative attention in the media can cause procedural objections handed in by residents or lobbies. Also less cooperation of other stakeholders could be a problem.

Probability: Low

Level of impact: Low ⇒ *Risk rating*: Blue

System is overtaken by another technology

Description: In the final stages of development, another technology which serves the same purpose with the same quality but for less money is discovered. This new product could be on the market in five years time.

Category: Technology maturity

Consequences: This is a sure set-back for the developed DRM. The development being is its last stages, should probably be continued to ensure some return on investments. However, the technology cannot be applied on other roads, being an inferior technology, resulting in a much lower return on investments.

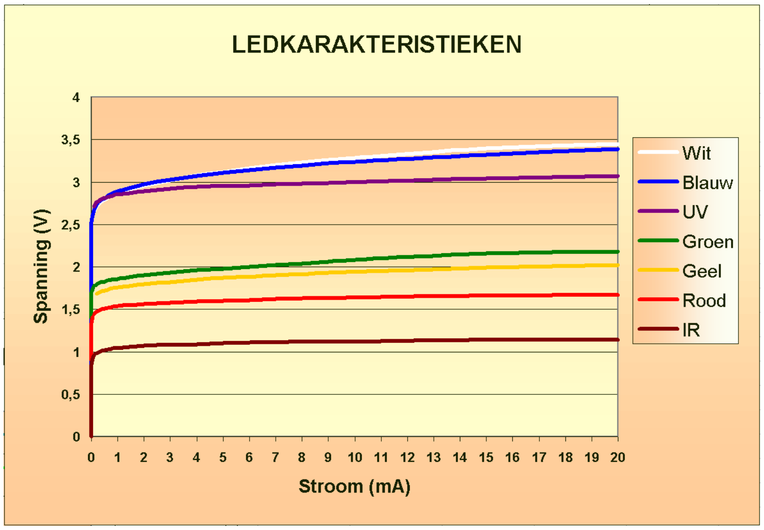
Probability: Low

Level of impact: Medium ⇒ *Risk rating*: Green

Appendix V: LED Characteristics

Ampere: 3 mA
Voltage: 3 V
Power: 9 mW

$$V = \frac{W}{A}$$



Appendix VI: Percentages of driven kilometres by age categories

In the table below the total driven kilometres in 2006 sorted by age category is given [SWOV, 2007].

Groups	Kilometres (billion)	Percentage
18 - 24	4,9	5,27%
25 - 29	7,9	8,56%
30 - 39	23,2	25,10%
40 - 49	24,1	26,12%
50 - 59	19,1	20,66%
60 - end	13,2	14,29%
Total:	92,4	100,00%