FINAL REPORTS SUMMARIES

Practical achievements of sustainable development require constant effort at both international and national levels, and call for an integrated approach of the social, economic and environmental fields between all levels of competency and decision-making.

Implementation of a policy focused on sustainable development also depends on the presence of effective scientific support at various levels, as was recommended by Agenda 21 adopted at the Rio Summit in 1992.

In this context the first "Scientific support plan for a sustainable development policy" (SPSD I) was approved by the Federal Government on 7 March 1996 on the proposal of the Minister of Science Policy and has been implemented by the Belgian Science Policy within the framework of a co-operation agreement between the State and the Regions.

This scientific support plan deals with several important aspects of the commitments made by Belgium with respect to sustainable development.

The programmes of this Plan covered various fields :*"Sustainable management of the North Sea", "Global change and sustainable development", "Antarctica", "Sustainable mobility", "Prenormative research in the food sector", "Levers for a sustainable development policy", "Earth observation by satellite", "Supporting actions"*. They were developped to support the scientific potential, to increase knowledge and to reduce incertainties in the concerned fields in order to incorporate aspects of the sustainable development concept into the design of concrete political measures.

The research's summaries of this programme are published in order to serve as a basis for reflection, as well as means of communication of the results, to better integrate research into a strategy of sustainable development of our societies.

SPSD I ended in 2001 and is followed by a second "Scientific support plan for a sustainable development policy" (SPSD II), which was approved in March 2000 by the Federal Government and which covers a period of six years (2000-2005).

SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY SPSD 1

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SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY FINAL REPORTS SUMMARIES

SUSTAINABLE MOBILITY

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SUSTAINABLE MOBILITY

05-159

Immers B., De Moor B., ``Traffic congestion problems in Belgium : mathematical models, analysis, simulation, control and actions.", in Report of Project *Sustainable Mobility*, (Belspo B., ed.), Belgian Science Policy (Brussels, Belgium), 2005, pp. 175-186., Lirias number: 181533.

FINAL REPORTS SUMMARIES

SUSTAINABLE MOBILITY

SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY SPSD 1

This booklet is realised in the framework of the Scientific Support Plan for a Sustainable Development Policy (SPSD I). The available publications are :

- *"Antarctica"*
- *"Levers for a sustainable development policy"*
- *"Earth observation by satellite" TELSAT 4*
- *"Pre-normative research in the food sector"*
- *"Global change and sustainable development"*
- *"Sustainable management of the North Sea"*
- *"Sustainable mobility"*
- *"Supporting actions"*

D/2004/1191/5
Published in 2004 by the
Belgian Science Policy
Rue de la Science 8
Wetenschapsstraat 8
B-1000 Brussels
Belgium
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CONTENTS

INTRODUCTION

Context and objectives of the research programme

Public and political opinions have grown much more towards environmental awareness over the past decade. Environmental changes and most definitively a growing consciousness that one must not mortgage the future of coming generations, have given rise to the concept of sustainable development.

'Transport' exemplifies the complexity of the challenge of sustainable development whereas it integrates the three pillars: the environmental, social and economic dimensions. Although transport is essential for the economic development and the population's wellbeing, travelling is not a goal as such. If it had no negative impact on the population's wellbeing, on the quality of the environment and on the economic development (pollution, traffic accidents, adverse effects on nature, on towns, congestion, etc), then the movement of people and services could grow unrestrictedly.

Several political documents at the international, regional and local level translate the challenges of sustainable development in transport matters into more tangible objectives: access to mobility for all, improvement of accessibility, increase of road safety and traffic liveability, reduction of the external effects of transport, an uncoupling of the link between economic growth and transport, etc.

Scientific research should provide a contribution to the resolution of the existing tension between increasing mobility needs on the one hand and the resulting social, economic and environmental problems on the other. The aim is to provide scientific input in order to find a balance between different, often conflicting, objectives.

The research programme "Sustainable Mobility" (1996-2000) forms part of this new vision. It was a continuation of the impulse programme "Transport and Mobility" (1991-1995), widening the scope of mobility to embrace environment, wellbeing and road safety aspects[1]. The programme was approved by the Council of Ministers on the 7th of March 1996. Monitoring and co-ordination were entrusted to the Belgian Science Policy. The programme ran from December 1996 to December 2000. The budget established in 1996 amounted to 7.762.661,78 €.

The "sustainable development" concept must be translated into concrete political measures. For this it is necessary to better understand all related factors, to trace

[1] For an assessment of both research programmes:
M. Beuthe and H. Meersman, "Transport and mobility: 10 years of research", Belgian Science Policy, 2001.

MD/DD/11

TRAFFIC CONGESTION PROBLEMS IN BELGIUM: MATHEMATICAL MODELS, ANALYSIS, SIMULATION, CONTROL AND ACTIONS.

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1 INTRODUCTION

1.1 The stakes

Due to the ever-increasing need for transportation, there will be more and more traffic congestion in Belgium unless some far-reaching measures are taken. During rush hours every morning and every evening, the saturation point of multiple highways in Belgium is reached, resulting in traffic jams. These traffic jams impose costs to the community in several different ways as described in what follows.

Due to the European integration and the growing internationalisation of the economy, Belgium's role as a transit hub for goods increases. Moreover, several international companies have located their distribution centres in Belgium. These evolutions will create additional traffic on the Belgian highways in the direct future while requiring smooth flows of goods and predictability of travel times. The occurrence of congestion can slow the development and investments down, putting a brake on the expansion of the national economy.

On the level of individual companies, we see that companies are locating near accesses to highways in order to be able to quickly transport their goods. The delays caused by congestion result in a huge loss of productivity, not only due to a loss of productivity of the drivers but also as follows. Since storage is costly, more and more companies apply "just in time" transport strategies. Delays created by congestion force these companies to use larger and thus more expensive stocks in order to guarantee the reliability of the production process.

A time loss costs a company money, but congestion has also implications on the daily lives of most people. Getting caught in traffic causes stress and forces people to anticipate e.g. by leaving earlier for work. Stress has a negative impact on the health and the loss of time reduces the quality of life.

Besides lost time also fuel is spilled during queuing. This wasted fuel has both an economic and an ecological price.

Congestion sometimes creates potentially dangerous situations e.g. a traffic jam in an environment with reduced visibility is an accident waiting to happen.

As illustrated above, traffic congestion is a pressing problem that plays an important role in different areas of the community. The main goal of a strategy trying to reduce the impact of congestion on every day life will be the reduction of time lost in traffic jams or at least to make the loss of time more predictable (in the scope of travel time prediction).

1.2 The goal

Different strategies can be applied in order to tackle the congestion problem. Some of these techniques include:

- The construction of new roads in order to eliminate the most important bottlenecks or to eliminate "missing links" in the highway network.
- Stimulate the use of other modes of transportation such as public transportation, carpooling, transport of goods by train or by ship...
- Reduce the use of the cars by pricing policies and the development of a high-speed communications network in order to reduce the need of trips.
- An improved use of the existing infrastructure which can be implemented by road pricing, better transportation planning by the industry, improved traffic control (dynamic traffic management) in order to use the traffic capacity more efficiently...
- Implementation of Intelligent Vehicle/Highway Systems (IVHS) which applies a combination of control, telecommunication and computer technologies in order to assist the driver in reaching the desired destination while attempting to globally avoid congestion and improve safety.

Given the huge costs of congestion for the community and the urgent need for solutions, we investigated solutions applicable in the short term. Therefore, we chose for dynamic traffic management (DTM) in order to use the available traffic capacity more efficiently. The primary advantage of this approach is that it can be realised in the short term. Moreover, we can also use the existing infrastructure and only limited investments are necessary, especially relative to the cost of the construction of more roads.

The controllers in a DTM system anticipate the demand and the actual capacity. Based on the specific traffic situation, decisions are made in order to optimally use the available traffic capacity (e.g. using alternative routes, speed harmonisation...). This optimal usage of already available traffic capacity leads to a more sustainable mobility situation since we can avoid costly construction works and the corresponding loss of space and harm to the environment. Moreover, adaptive control can also prevent the occurrence of potentially dangerous situations thus increasing traffic safety for everybody.

A reduction of the transportation demand can also lead to sustainable mobility. This doesn't exclude adaptive control though. A realistic scenario is the combination of

measures in order to limit the (growth of) traffic demand and adaptive control. A detailed study of measures to reduce the transportation demand and their effects on the traffic situation and the community are beyond the scope of this project.

1.3 The targets

The target of this project was to develop mathematical models and software tools to simulate traffic and to develop DTM system controllers and to consult on their usage. Local, regional and federal governments and traffic instances can benefit from these tools to develop a traffic policy and to take control measures. This comprises amongst others:

The development and evaluation of models and methods to determine optimal control strategies to reduce traffic jams. These control strategies can be implemented using e.g. variable message signs, radio messages, and optimal control of traffic signs...

The development of new and the evaluation of existing simulation- and analysis tools, which can be embedded in a multi-functional software package with a graphical user interface (GUI). In this GUI traffic information can be represented in a graphical way (on digital maps with colour codes to picture problems, traffic densities or average speeds), which can allow for an early detection of emerging traffic jams and an efficient (on-line) evaluation of traffic control measures.

In this project we used dynamic traffic control measures (using e.g. controllable traffic signs, Dynamic Route Information Panels (DRIP's)) to control traffic flows based on an actual or a predicted traffic situation. These traffic measures are directed by the Advanced Traffic Management Systems (ATMS). In an ATMS sensors detect the traffic situation on the main roads and this information is transmitted to a central traffic management centre. After processing in the traffic management centre the different traffic control mechanisms are operated in order to control the traffic flows. In this project we focus on the models and software tools which can be applied in the ATMS. In order to assess the effect of a control measure, we start from a model describing the traffic situation. This can be either a mathematical or computer simulation model or a combination of both. As soon as we have a model describing the traffic situation with sufficient accuracy, we can use mathematical or computer techniques in order to develop optimal traffic control measures. (Aimed at the reduction of traffic jams, maximising the throughput...).

1.4 Evolutions

After a study of the current situation in traffic modelling and control the above goals are translated in the work plan in Figure 1.

After a study of the available traffic models and computer simulation models it became clear that there is already an abundance of traffic simulation packages commercially available. It was decided to buy two microscopic simulation packages: Paramics and Aimsun2. These packages simulate traffic on the level of independent vehicles. The development of a software package to visualise the traffic simulation was discarded given the existing packages. In the mean time, the focus was shifted towards the proper tuning and the calibration of Paramics and Aimsun2 models, which is a non-trivial task.

In order to be able to focus and to get a better feeling with the practical problems that arise when developing a simulation of traffic and a control strategy, a case study was defined. This case study deals with the traffic on the E17 Ghent – Antwerp of which traffic measurements are available. A map of our case study is presented in Figure 2.

2 ACTIVITIES AND RESULTS

2.1 The activities

The project aims to investigate and model the traffic states on freeways and to calculate the effects of several measures and the optimisation of these measures so that the traffic regime becomes more efficient. A more efficient use of freeways results in a reduction of the lost time and relieves the pressure to construct new highways.

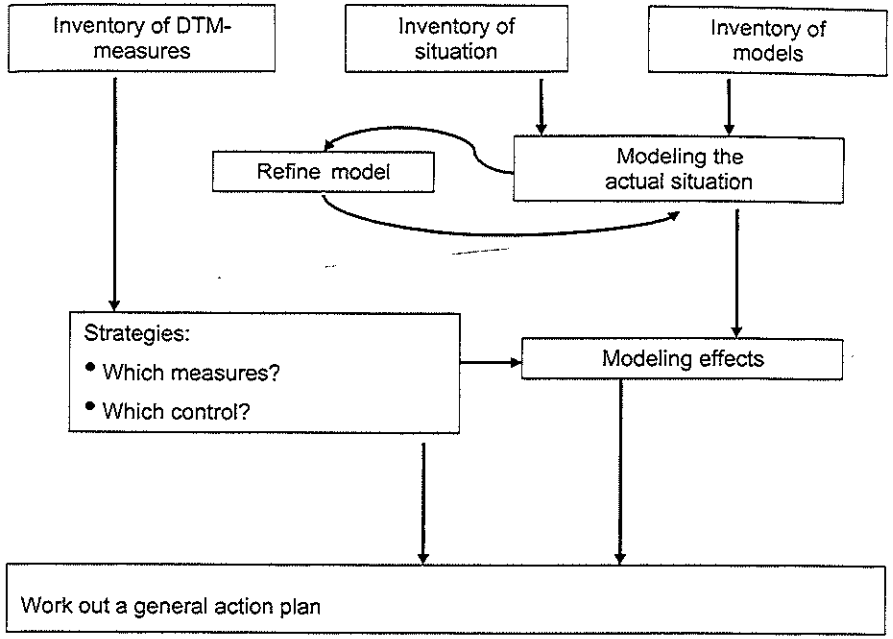

Fig. 1: scheme of activities

During the project a set of steps was worked out. An overview of the activities can be found on the scheme in Figure 1.

In what follows we give a more detailed description of the different activities that were set-up.

- Inventory of Dynamic Traffic Management measures

Within the DTM context, a set of measures can be taken to tune the traffic demand (the amount of people that wants to make a trip) and the supply of the traffic system in a dynamic way. When focussing on the highway level, a list of possible measures has been compiled. After an extensive literature study an overview was made.

- Inventory of traffic situation

The second inventory aimed to analyse the actual traffic situation on highways. A section of the E17 highway (Ghent – Antwerp) was chosen as a characteristic 'congestion' section for the highways in Belgium. On this section recurring congestion can be observed during the morning rush hour. The considered section is unique thanks to the fifteen detection cameras that register the presence and the speed of all cars every 500 meter. These cameras were installed within the framework of a European project.

The analysis of the data after pre-processing leads to the identification of several congestion patterns. The typical congestion waves and detailed flow data made an extensive bottleneck analysis possible. Also the infrastructure was described to enable the modelling process.

- Inventory of traffic models

We can discern two levels within this inventory. At the first level, an inventory of theoretical models was made. Several types of dynamic models can be distinguished: cellular automata, gas kinetic models, macroscopic models and micro simulation models. Only the last model type treats each car individually. We chose for the micro simulation model because the effects of measures that intervene on the individual driver and his vehicle can be simulated.

At the second level, several commercial micro simulation packages were investigated. The Smartest study served very well for this purpose[1]. This European study aimed to detect the gap between the market and the producers of micro simulation models. Therefore an overview of the various existing packages was made.

Based on the Smartest study we decided to buy the packages Aimsun2 and Paramics.

- Modelling the actual situation

With the micro simulation packages the case study that was chosen within the inventory of the situation, was modelled.

In a first step the model was set up. The package needed the infrastructure, regulations and traffic demand as input. The fifteen camera detectors were modelled as well. Subsequently the model was refined. Within this calibration process the output of the real camera detectors and the output of the modelled camera detectors were compared. Several parameters, procedures and algorithms were adapted and rewritten. As result of the calibration process the traffic state on the E17 was modelled well.

[1] http://www.its.leeds.ac.uk/smartest/append3d.html

Fig. 2: Study area

- Strategies

A general strategy was designed to improve the efficiency of the traffic and to prevent congestion if possible. This strategy consists of two steps. The first step is to make a selection of the DTM-measures from the inventory: "Which DTM-measures?". The second step is to design the algorithm to optimally control the set-up: "Which control?".

The first important step in the process of controlling traffic is a thorough study of the traffic situation at the location we want to control. Based on this study, we can choose certain DTM-measures from the inventory.

The situation assessment is important since, depending on the situation, one measure may have a higher potential to improve the traffic situation than another.

In order to be able to optimally control the DTM-measures, it is necessary to define control objectives. These control objectives can be e.g. maximise the throughput of a highway section, limit the length of a queue on an on-ramp... given the current situation. Based on a traffic model and the current situation, we looked for the control inputs maximising the control objective. In this case, this resulted in a non-linear optimal control problem with constraints.

Solving a non-linear optimal control problem with constraints requires extensive simulation of the system you want to control. In our case, we needed many simulations of the highway. In practice there proves to be a time constraint on the time we can spend on our optimisation problem: we have to find the solution fast enough to be able to implement it in real-time. Therefore, we also looked into macroscopic models which simulate the highway in less detail but which are less computationally intensive and thus faster.

Finally it is important to note that in order to control a complex system with multiple on-ramps and off-ramps, we will need to co-ordinate the control of the different DTM-measures in order to prevent counter productive results.

- Effects

After a strategy and the measures are chosen, the optimal controller can be coupled to the micro simulation model of the E17. In this way the effects of the measures can be calculated and evaluated in a study comparing a simulation with and without control.

2.2 The results

- Inventory of DTM-measures

An overview of several DTM measures was made.

- Analysis of the traffic situation

The study of congestion leads to the observation of a wide range of theoretical congestion patterns in the study area.

- Modelling

The calibration of micro simulation models with the help of microscopic traffic patterns leads to a congestion pattern that matches the observed patterns very well.

- Strategy

Since the traffic model needs to be simulated several times in order to find an optimal solution in terms of the control objective, we use less detailed macroscopic models for control purposes.

The next step is the optimal control of DTM-measures. We decided to focus on ramp metering as DTM-measure. The goal of ramp metering is to keep the traffic

throughput on the highway as high as possible by preventing the traffic density from becoming too high. This is achieved by limiting the number of cars that is allowed to enter the highway through the on-ramps. The advantage of ramp metering is that the effects of the ramp metering set-up on traffic can easily be assessed since cars are obliged to stop at the red light at the on-ramp. After choosing for ramp metering we have to define the control objective. Even though we want the flow on the highway to be as high as possible, there are limitations. We cannot allow the queue at the on-ramp to grow too long. Therefore, we defined the following control objective: the total time spent by all the cars on the highway and all the cars at the on-ramp must be minimal. This provides a trade-off between throughput through the highway and the length of the queue at the on-ramp. Simulation experiments show an improvement of the total time spent on highway and on-ramp.

When a highway has multiple on-ramps which are located close to each other we have to prevent that drivers try to escape from the metered on-ramp. One way to prevent this is to meter all the on-ramps in a region. It is obvious that the metering installations will influence each other since the distances between the on-ramps are limited. Therefore we looked into co-ordinated control of ramp metering installations in order to prevent counter productive situations. The co-ordinated ramp metering set-up results in an even more optimal control at the cost of an increased computational effort.

The project has informed the Flemish road administrator of the congestion situation on the case study location and the possible measures that can be taken.

3 RESEARCH ACTORS AND CO-OPERATION

3.1 Presentation of the research units

Transportation Planning and Highway Engineering

Transportation Planning and Highway Engineering is a research unit of the Department of Civil Engineering. The department of Civil Engineering is a part of the Faculty of Applied Sciences of the KULeuven.

There are two part-time professors and five research assistants. The main objectives are education and research.

The unit is responsible for three courses within the education of civil engineers and for the module 'accessibility and environmental problems of traffic' within the postacademic course in Transportation Planning. This new course is the result of a co-operation between four Flemish universities.

The unit does research on the mathematical description of the transportation system. More information of the research themes can be found on the website: http://www.kuleuven.ac.be/traffic/

SISTA

SISTA (Signals, Identification, System Theory and Automation) is a research group within the ESAT (Electrical engineering) department of the Katholieke Universiteit Leuven.

SISTA's main areas of research are mathematical modelling and deterministic and stochastic theories for signals and systems in order to find solutions for fundamental problems in engineering disciplines like digital signal processing, system identification and computer aided design of controllers, design of networks, non-linear and complex dynamic systems... The research scope ranges from development and analysis of fundamental concepts to application directed research and industrial projects. The goal is to bridge the gap between fundamental theoretic concepts and applications in multiple fields, like process optimisation and automation, telecommunication, mechatronics, biomedical sciences...

For a complete list of SISTA's deliverables, we refer to SISTA's publications page on the internet: http://www.esat.kuleuven.ac.be/sista/publicat.htm.

3.2 Dynamics and management of the network

The official partners within the network are the two research groups participating in the project: the Transportation Planning and Highway Engineering unit and SISTA. As became clear in the description of the research groups above, both groups have a different background, which allows for complementary contributions to the project. The Transportation Planning and Highway Engineering group is mainly focussing on the study of congestion dynamics, analysis of highway data and modelling of highways on a microscopic level. SISTA on the other hand is working on macroscopic highway modelling and on control strategies and algorithms for advanced adaptive highway control. During meetings of members of both research groups the co-ordination of the research was discussed.

Besides the official partners, there are also non-official partners who made a contribution to this project. The Antwerp division and the modelling division of the

Flemish transportation administration supported us very well. The technical division provided the relevant traffic data.

The non-official partners were invited for the user group meetings.

4 EVALUATION AND PERSPECTIVES

4.1 Evaluation of the project

DTM measures have the potential to make the traffic system more efficient. This translates in an enhanced reliability of the system and an increased efficiency of the highway capacity usage, both achieved with minimal investments. Also the loss of natural resources that occurs during congestion and the probability of accidents due to congestion (shock waves), decrease seriously.

In this project, the main topics of research were the modelling of congestion and control of DTM systems. The modelling of traffic on highways is important in order to be able to assess traffic situations, to predict future traffic situations but also to be able to develop controllers for the DTM systems and to assess their expected impact on the traffic system.

A real life situation (E17 Ghent - Antwerp) was studied and a micro simulation model of this area was built. Optimal control of ramp metering as a means of DTM was investigated. The findings of this research, combined with the modelling expertise as well as with the results of the micro simulation are strong assets that can be of importance to the government.

4.2 Perspectives of the project

The results of this project can be the basis for further fundamental research or for research focussed on practical implementations. The microscopic models could be further refined and more attention could be paid to the tuning strategies when modelling a specific situation. The current research on optimal control of ramp metering could be extended to a wider range of DTM measures. Also the integration of the control of different types of DTM measures is an interesting research topic that needs further attention. These are only some of the research opportunities that became apparent during the project.

The research results were presented in publications, conferences and during the project meetings that were organised every six months.

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INTEGRATION OF TRAFFIC AND ECONOMIC MODELS FOR THE ASSESSMENT OF URBAN TRANSPORT POLICY (ITEM)

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