ATMA-MODeRN

DEVELOPMENT OF A MULTI-OBJECTIVE TRAFFIC MANAGEMENT DECISION TOOL

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ABSTRACT

In policy documents concerning Transport sustainability plays an important role. Main goal is to achieve a transport system that is fast, clean, safe, quite and reliable. Further the transport system should contribute to the main goals concerning the emission of CO2 and energy use.
One of the ways to achieve all of this is through a better utilization of the existing infrastructure, for instance using traffic management measures.
However, it is not really known if all these goals can be reached, but also how these goals relate to each other and what measures should be taken to actually achieve all of this.
When the project started the main focus was on network efficiency in terms of travel times, delay etc. Other goals were considered but not as a main objective, more as a constraint. Traffic management was evaluated in terms of network efficiency, and one was satisfied when traffic safety, noise or air pollution had not become worse.
In ATMA these constraints have become objectives. It is studied how the objectives can actually be quantified in a workable manner, what the effects of specific measures are for the all goals, how reliability and the robustness of networks can be determined, and how a transport network can be optimized using multiple objectives. Further it is studies how traffic control can be improved, for instance using a distributed control, or an anticipatory control framework.
A consortium consisting of four knowledge institutes (University of Twente, Delft University of Technology, TNO and SWOV) and two companies (Vialis en Goudappel Coffeng) was formed
Initially also Siemens and Logica CMG were member of the consortium but they decided to withdraw.
Pilotregion initially was the province of Brabant. Mainly since the withdrawal of Logica CMG the city of Almelo was selected. The transport network that has been considered consists of alle main roads in the city, of provincial roads and of the highway A35. The network is very well monitored, measurement data are very well analyzed, much traffic management equipment is available and the city strives for innovation in a very active manner.
Results of ATMA are quit positive. It was proven that the transport system can be improved at all points. It is possible to improve air quality by a third, together with an improvement of

travel times, safety and CO2 emission in the order of 5-10%. From here each individual objective can be improved even more but not without a price. Improving one goal means deterioration of one or more other goals.
This is true for for instance network efficiency and noise or traffic safety. But improving travel times often als means improving air quality.
ATMA yields a set of solutions where the policy maker ultimately has to make the final choice by inserting the priorities. ATMA does not make decisions, but is merely an aid for making decisions.
Transumo contributed in a very positive way in the creation of this project. The consortium contained the right mix of skills and knowledge, but it would not have arisen by itself. Initially the focus in the project was very much on network efficiency, reliability and safety. Environmental issues only began to play a part after intervention of Transumo. Eventually environmental issues became relatively dominant. This also becomes obvious viewing the guidance group , where environment plays a significant role.
From a scientific point of view ATMA is a big success. The project has produced eight PhD projects, and many contributions in scientific journals and conferences.
Now that Transumo has come to an end, a considerable amount of initiatives on a national and international level have been started where (parts of) ATMA play a significant role.
Further the initiative has been started to roll out the ATMA project in the whole region of Twente, where Almelo is a part of, with a more prominent role for public transport. This role was already initiated in the top-up project Info-Rio. The project is about personalized information in public transport and is executed partially in Almelo, but mainly in Rio de Janeiro and Macae, both in Brazil.

1. INTRODUCTION

The ATMA-MODeRN project appeals to developments in the field of traffic and transportation, especially traffic management. Traffic management is based on existing infrastructure. Measures are taken to inform the travellers and to guide them in such a way that the existing infrastructure is utilized in the most efficient way. Traditionally, the main criterium for this is flow of traffic. Less congestion, less delays or higher travel speeds are common targets in this matter. The faster the flow of traffic in a network is, the better.
Since recent years the focus is changing. Apart from flow of traffic aspects like energy consumption, environmental impact, traffic safety and system’s reliability get an increasing role. These aspects are only used as constraints however in the process to reach the main goal: the flow of traffic.
Thus, the focus remains on the performance of the traffic system. To keep up with the times a more balanced approach is needed. In the ATMA-MODeRN project the aim is to create a real sustainable traffic system using the instrument of traffic management. All aspects mentioned are treated equally important in the decision process and parameters allow to put emphasis on those aspects that are most important in the specific situation at the specific time a decision has to be made by the traffic management system. The traffic system should

be as safe, as fast, as clean and as reliable as it can be. In short, in ATMA-MODeRN we have several goals to achieve.
In multi-purpose traffic management it is unlikely that there is only one solution that is optimal for all aspects. That's why we search for a so called Pareto-set of solutions. These are solutions in which it is not possible to improve one aspect without worsening the others. A system has been developed that assists in making the choices. The project provides support to make the choices, but the choices themselves have to be made by others, the policy makers and traffic managers.

Summerized: goal of the project is to develop a tool that, in a given traffic situation, enables traffic management to be used to optimize several goals that me partly in conflict with each other.

For this approach, the network of the Dutch city of Almelo, 72,000 inhabitants, is used as test site. In the network of Almelo we find motorways, regional and municipal roads. The city already has a wide variety of traffic management instruments and has agreements with adjacent road authorities to use each other roads in case if necessary. The city follows an innovative approach in traffic management and although the network has its problems, there are enough possibilities for traffic management to be effective. The project is connected to the TINA traffic management initiative of the city itself, thus proving the outcome can be used in the real network. This fits with the name ATMA-MODeRN, which means Advanced Traffic Management – Multi Objective Decision aid for Regional Networks.
In the approach of ATMA-MODeRN goals are made more explicit and methods are developed to quantify the goals. For flow of traffic this is well known, but for safety, environment and reliability this is quite new. Also new was the anticipative approach, in which not the actual situation, but a short time future situation is the base for decisions. Traditionally traffic information is used to change (a part of) the routes drivers use in the network. In ATMA-MODeRN this is still the case, but the route changes should be more sustainable. Moreover, the approach also takes into a account special circumstances, like road works and accidents. Even under these circumstances, optimal sustainability by multi-criteria decisions of the system can be achieved.

2. RESEARCH SET UP / APPROACH

ATMA is about the development of a multi-objective optimalization framework that supports sustainable use of traffic management. The project has been executed by a consortium of knowledge institutes and the industry. It has been applied to the network and traffic management system of the city of Almelo, the Netherlands. As a result of the Transumo approach a combination of expertise emerged that normally not would have been formed. Moreover, the special attention for the relationship between environment, safety, reliability and traffic management has improved the cooperation between the environmental and traffic section within the municipal organization of Almelo. This means that multi-objective traffic management projects are not only technical, but also can improve cooperation between work fields environment and traffic, that are often more working against each other than with each other.

2.1. The project team

In the project team the organizations cooperating in the research were represented:

- University of Twente (Project manager prof. dr. ir. E.C. van Berkum [co-author of this paper])
- TNO (drs. M. Snelder)
- Technical University of Delft – 3ME (prof. dr. ir. B. De Schutter)
- CiTG (ir. F. Zuurbier)
- SWOV (ir. A. Dijkstra)
- Goudappel Coffeng (ir. L. Wismans)
- Vialis (ir. F. van Waes)

Besides the project team there was a project group in which the road authorities were included:

- City of Almelo (drs. R.P. Hulleman [author of this paper] and drs. B. Snellenberg)
- Regional Authority of Twente (drs. K. Ten Heggerler)
- East-Netherlands Section of the National Road Authority (Rijkswaterstaat; ir. J. Noordhof)

2.2. Approach

The project was divided into four parts (A through D):

A. Development of the optimalization framework and the execution by plugging the framework into the TINA system in Almelo (TINA = Traffic Integrated Network Almelo).
B. Definition of the sustainability aspects security, reliability and environment as well as optimal flow of traffic
C. Attention to specific topics like anticipative management, distributive management, tolling as a management instrument, management in relation to road works, safe route guidance, traffic flow in relation to weather conditions and steering route information.

In the approach modal choice was not included, because the emphasis was put on the instrument of traffic management. Later the project team concluded that there should be attention to modal choice as an instrument to achieve the goals of the project. Therefore a top-up project was added:

D. Individual real-time travellers information in public transport. For this part of the project a research area in Brazil (state of Rio de Janeiro) was chosen: the city of Macae and the Metropolitan Area of Rio de Janeiro.

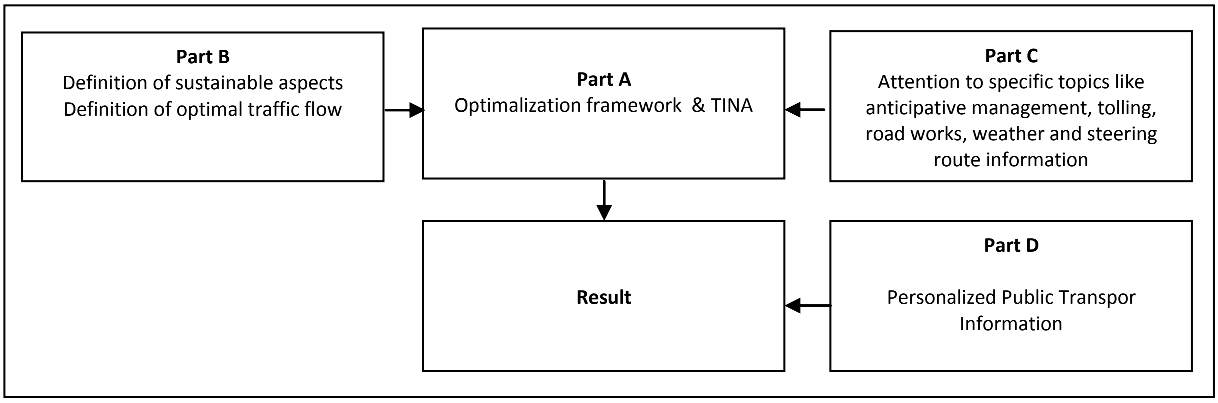


Figure 1 – ATMA MODeRN research model

2.3. Changes in the original research approach

At first, the research project aimed merely at optimalization of traffic flows by multi-criteria traffic management. Emphasis was put on safety and reliability of the traffic system itself, not on environmental aspects. Because of the increase of attention in science and society for environmental issues, these were later integrated in the project, even becoming crucial aspects of the research.

The goal of the project, to build an online decision supporting system for traffic management, was not achieved. The outcome is an offline system. This offline system allows the definition of a wide variety of scenarios that can cope with often occurring traffic situations. These scenarios have the same goal as the online system that was in mind: sustainable traffic management. The reason for this that during the project it appeared that the amount of data that has to be processed is too large to do this on a real time basis. The calculation capacity is not enough to guarantee that calculations can be made real time in all cases. As reliability and accuracy of the system were important criteria, the online system was replaced by the offline system.

3. RESULTS AND EFFECTS

In this chapter the results and effects of ATMA-MODeRN (parts A, B and C) are described. Part D, the top-up project InfoRio, will be dealth with in a separated paper. Description will start with part B, the aspects, because they can be seen as the goals the system must achieve.

3.1. Part B – The goals

Table 1 shows how the aspects are defined, based on the three P's (People, Planet and Profit).

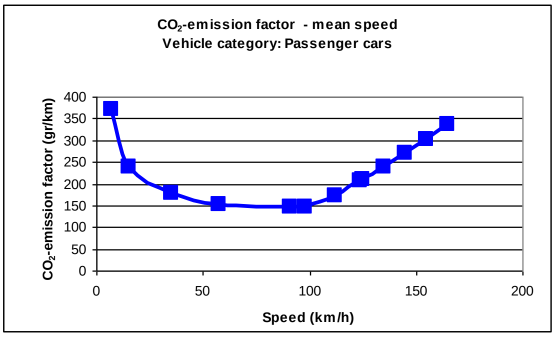
- **Traffic flow/congestion**. For flow of traffic or congestion in the network the inidicator is total trip time. The target is to minimalize the sum of trip times for all trips in the network. Because the system cannot change the amount of traffic, minimalization of the sum of total trip times is equal to minimalization of total loss of time in the network.

- **Traffic safety**. For traffic safety the total amount of accidents with injuries is used as indicator. The calculation is based on the relation between the exposure (number of vehicle kilometres) and the risk per type of road (ratio of the number of accidents with injuries per type of road). It is important to note that this method only takes into account the changes in the routes people use, not the effect of behaviour on these routes (e.g. speed and differences in speed). Target is to minimalize the number of accidents with injuries.

Road type (Sustainable safe definitions)	*Risk (R_{md}) injuries/million vehicle kilometers*
Through-road	0.07
Non-urban distributor roads	0.22
Urban distributor roads	1.10
Non-urban access roads	0.43
Urban access roads	0.57

Table 1 – Overview of used risk figures

- **Climate**. For climate the sum of CO_2 emission is used. The calculation is based on a discrete emission function that relates vehicle speed (in discrete steps of 5 km/h) to the emission factor (per vehicle category at that speed). Target is to minimalize the total amount of CO_2 emission in the network.



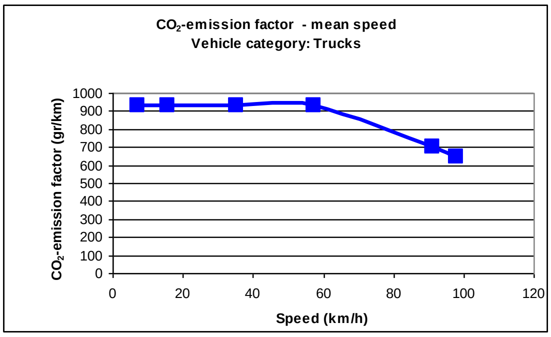


Figure 2 – Emission functions CO_2

- **Local air quality**. For local air quality a weighted sum of NOx emission and a weighted sum of PM_{10} emission. There are more substances that are relevant for air quality, but as these two are most important in the Dutch situation, related to EU-standards, they are chosen. Air quality is always an issue of the a specific site. On one intersection it may be a problem at a adjacent intersection is maybe not. A huge amount of data is necessary to calculate the air quality at all sites in the vicinity of the network. These data include distance to and type of buildings, road surface, weather conditions etc. Normally, all this information is not available as standard. Therefore the calculation is simplified by relating the emission to several characteristics of the roads and intersections, such as road surface and the density of the build-up area around. The method takes into account the varying emission factors per type of road and type of vehicle, due to the varying traffic flow situation. The emission factors are derived from the CAR-model and a Dutch research called ‘Emissions and congestion’ (TNO, 2001, in Dutch). Target is to minimalize the total weighted NOx emissions and the total weighted sum of PM_{10} emissions and not to have a site where EU-standards of maximal emission are exceeded.

- **Noise**. For noise, the same approach is used as in local air quality. The amount of noise in dB(A) is calculated for all sites along the road network according to the same (simplified) characteristics of the roads and intersections, such as the road surface and the density of the build-up area around. Target is to minimalize the total weighted noise emission and not to have a site where Dutch standards for maximal noise hinder are exceeded.
- **Reliability**. Reliable networks have the availability to fulfil the functions they are designed for even in situations that differ a lot from the situations they are designed for. Reliabilty is seen as a relationship between the structure of the network and the variety of trip times in varying situations. At first is defined what reliability (and robustness) is. Than indicators are identified that show how reliable or vulnerable a network is. Than measures are defined that make a network more reliable (less vulnerable). Some of these measures are evaluated to find out how effective they are. Trip time (-expectation, -variation, -stability) depends on the variations in demand and supply of road capacity. Six aspects make a reliable network: prevention, redundancy, compartmentation, elasticity, flexibility and balance. Based on desk research a vulnerability indicator is developed. This indicator shows per road section whether there is enough spare capacity on alternative routes in the network in case due to a disturbance, like an accident, the capacity of that road section is reduced or lost completely. Within the project, several evaluation methods are developed. Two of those were applied to the network of Almelo. Target is to minimalizing the vulnerability of the network.

Objective	*Measure*	*Remark*
Congestion	Total travel time (h)	Because fixed demand is assumed minimizing total travel time is equal to minimizing vehicle lost hours.
$\min Y = \sum_a \sum_t \sum_m \frac{q_{am}(t)\ell_a}{v_{am}(t)}$ (1)		
Traffic safety	Total number of injuries	Calculation based on using the relation between exposure and risk per road type.
$\min F = \sum_a \sum_t \sum_m \sum_d q_{am}(t)\delta_{ad} R_{md} \ell_a$ (2)		
Climate	Total amount of CO_2 emissions (grams)	Calculation based on average speed based discrete emission functions per vehicle type used within the Dutch study Effects of speed limit enforcement on CO_2 emissions (*16*).
$\min G = \sum_a \sum_t \sum_m q_{am}(t) E_m^{CO2} \quad v_{am}(t) \quad \ell_a$		

(3)		
Air quality	Weighted total amount of NO_x emissions (grams) Weighted total amount of PM_{10} emissions (grams)	Calculation based on a traffic situation based emission model using discrete emission functions per Level of Service, vehicle type and per road type. Emission factors derived from the emission model CAR and the study Emissions and congestion (*17*). Two substances NO_x and PM_{10} are assessed.
$\min F^s = \sum_a \sum_t \sum_m \sum_d w_a q_{am}(t) \delta_{ad} E^s_{md} \quad v_{am}(t) \quad \ell_a, \quad s \in \{\mathrm{NO}_x, \mathrm{PM}_{10}\}$ (4)		
Noise	Weighted average Sound Power Level at the source (dB(A))	Calculation based on the standard calculation method (RMV) used in the Netherlands.

$$\min W = 10 \log \left(\frac{\sum_a \sum_w \delta_{aw} \ell_a 10^{\frac{\bar{L}_w - \eta_w}{10}}}{\sum_a \sum_w \delta_{aw} \ell_a} \right), \quad \text{with} \quad \bar{L}_w = 10 \log \left(\frac{\sum_a \sum_t \delta_{aw} \ell_a \sum_m 10^{\frac{L_m \quad v_{am}(t)}{10}}}{\sum_a \delta_{aw} \ell_a} \right)$$

(5)
with
Y : Objective function congestion (= total travel time) (h)
Z : Objective function traffic safety (= number of injuries)
G : Objective function climate (= total amount of CO_2 emissions) (grams)
F^s : Objective function air quality (= weighted total amount of emissions of substance *s*) (grams)
W : Objective function noise (= weighted average sound power level at source) (dB(A))
$q_{am}(t)$: Vehicle type *m* inflow to link *a* at time *t* (veh)
$v_{am}(t)$: Average speed of vehicle type *m* on link *a* at time *t* (km/h)
R_{md} : Injury risk of vehicle type *m* for road type *d* (injuries/(veh*km))
$E_m^{\mathrm{CO2}}(\cdot)$: CO_2 emission factor of vehicle type *m*, depending on average speed (grams/(veh*km))
$E^s_{md}(\cdot)$: Emission factor of substance *s* of vehicle type *m* on road type *d*, depending on average speed
(grams/(veh*km))
$L_m \ \cdot$: Average sound power level for vehicle type *m*, depending on the average speed (dB(A))
$\bar{L}_w$: Weighted average sound power level on network part with urbanization level *w* (dB(A))
ℓ_a : Length of link *a* (km)
δ_{ad} : Road type indicator, equals 1 if link *a* is of road type *d*, and 0 otherwise
δ_{aw} : Urbanization level indicator, equals 1 if link *a* has urbanization level *w*, and 0 otherwise
w_a : Level of urbanization around link *a*
η_w : Correction factor for urbanization level *w* (dB(A)))

Table 2 – ATMA MODeRN goals

3.2. Part A – Network optimalization

Network optimalizations means the search for a combination of traffic management tools that is able to reach the minimalization targets that are described above. This multi-objective optimalization problem is in fact a bilevel problem. The upper level is a Network Design Problem (NDP) and deals with the measures to be taken. The lower lever is a Dynamic Traffic Assignment (DTA) and deals with the reaction of drivers on these measures and the effects in terms of traffic speeds and traffic volumes. At first, the bilevel problem is discreted in time and space and is tough to cope with for traditional optimalization methods. In the ATMA project several methods have been used: genetic algorithm, simulated annealing and grid search.

Goals is that we can choose a set of traffic management measures to optimize the performance of the network for all five targets described. However, because we deal with multiple targets it is not clear when a certain solution is better than another. To solve this problem the concept of dominance is introduced. Solution number 1 dominates solution number 2 if it scores for at least one target better and for all other targets not worse. This way a Pareto set of solutions is derived. Solutions in this set are not dominated by others. See table 3.

		Optimized designs for each objective						
Measure	*Min*	*Reference*	*Congestion*	*Traffic safety*	*Climate*	*Air quality NO_x*	*Air quality PM_{10}*	*Noise*
Total travel time (h)	4952.23	2	**0**	37	3	5	5	60
Total number of injuries	0.0432	20	20	**0**	20	12	13	13
Total amount of CO_2-emissions (Ton)	95.5	7	7	5	**0**	1	1	7
Weighted total amount of NO_x emissions (Kg)	779.19	1	1	7	0	**0**	0	19
Weighted total amount of PM_{10} emissions (Kg)	38.65	2	1	5	0	0	**0**	15
Weighted average L_w at the source (dB(A))	71.66	4	4	2	3	3	3	**0**

Table 3 – Results of uni-objective optimalization on other goals (%)

The table shows that minimalization of trip time is almost identical with minimalization of NOx and PM_{10} emissions. This is an interesting conclusion, that sets the mind at ease. Even more interesting is the conclusion that CO2 emissions can vary a lot while the quality of traffic flow is almost the same.

Traffic safety and noise show a more difficult relationship with traffic flow however. These targets are opposite. The better the flow of traffic, the worse the safety and noise hinder.

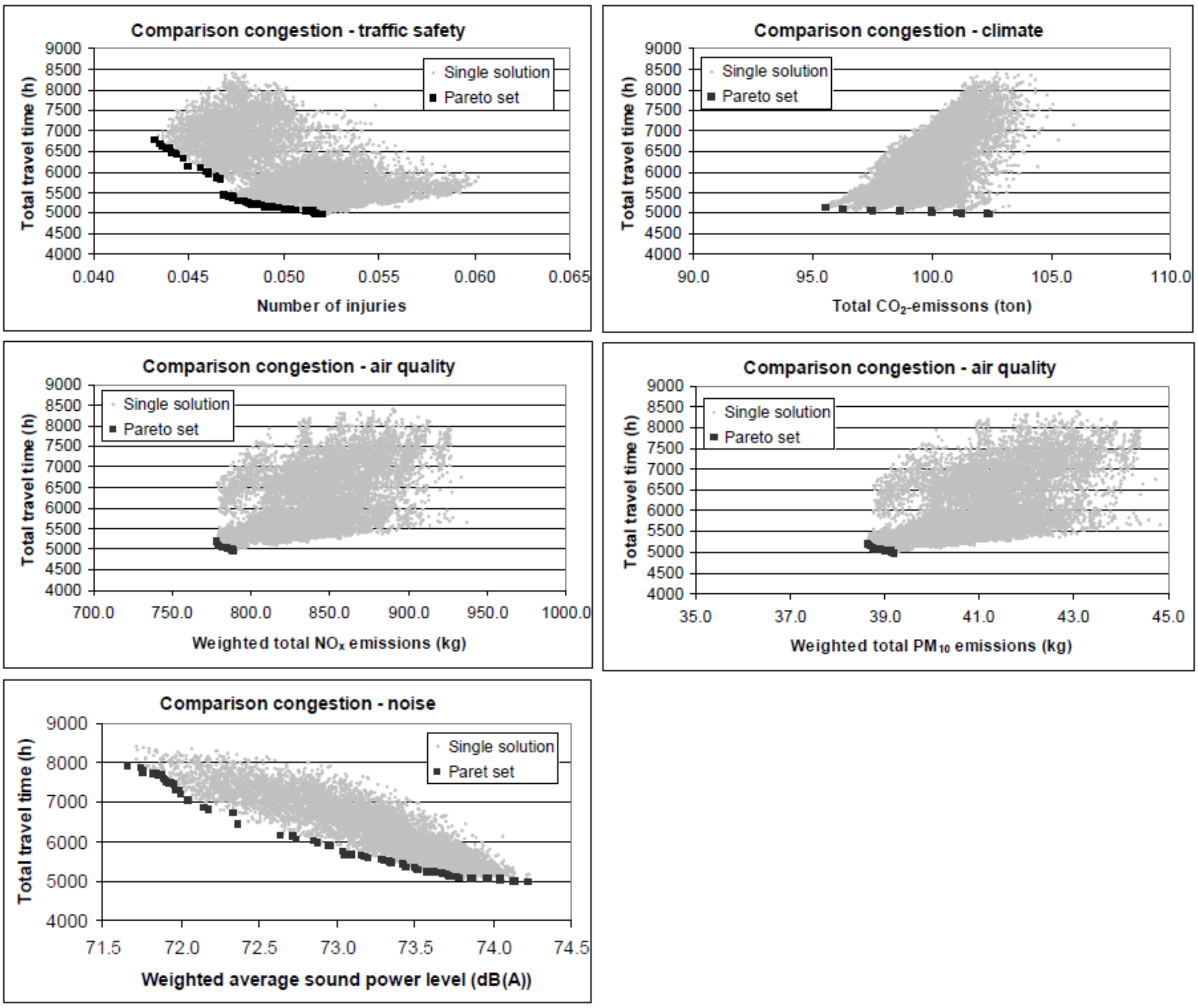


Figure 3 – Exposition Pareto set: traffic flow versus the other targets

3.3. Part C - Specific topics

In this paragraph some specific topics get some extra attention. As explained in paragraph 2.2. a variety of specific topics explored in the project of which some of the most interested get a short description here.

3.3.1. Safety and choice of routes used

As has been stated above: safety and good flow of traffic are not going along. The question is how choice of routes used can be influenced to create more safety. To answer this question, at first the relationship between network structure and choice of routes is studied. Next step was to define whether a simulation model can be used to describe for any network the choice of routes. For this purpose, the existing S-Paramics model is used. To define the safety of routes indicators have been developed based on the characteristics of the infrastructure and of the traffic on that infrastructure (e.g. speed). In addition, a survey among drivers was held. This showed that drivers choose their route because of trip speed and directness. Traffic safety is not a issue for them. Safety therefore needs to be improved by improving the infrastructure or by increasing trip times. This can be done by traffic management measures and so can be part of the set of measures in the multi-objective management system.

3.3.2. RG++ Optimal route guidance in an online and real time setting

RG++ is a method of route guidance that is used for active rerouting on a network. This means that it takes into account the effect that route guidance has on the traffic flows in the network. The route guidance can be based on any target the traffic manager wants to achieve (trip time, CO_2 emission, NOx/PM_{10} emission, noise hinder, traffic safety etc.) RG++ calculates the optimal recommendations to drivers,, that, when followed, lead to a better performance of the system (based on the target set). The route recommendations are provided for important nodes in the network and recommend the best route to drive to another node in the network. These recommendations can be brought to the driver by means of variable message signs or in-car systems. RG++ calculates the best routes based on the real time traffic data and is capable to calculate in real time recommended routes.

3.3.3. IMPreC and Decentralized traffic management

IMPreC and Decentralized traffic management are two projects in which advanced methods for coordinated traffic management in networks are developed. IMPreC is based on predictions made by a traffic model. The predictions are used to calculate the best way to manage traffic to avoid problems that are predicted. Decentralized traffic management uses agents and distributed techniques. During the ATMA-MODeRN project other performance criteria (e.g. various emissions) than flow of traffic are introduced in these techniques. Outcome of these projects is that the performance of the network can improve between 10 and 20 %, depending on the actual situation and the performance criterium chosen.

4. RESULTS

During the ATMA-MODeRN project, a lot of knowledge has been developed, but it was not possible to develop an online decision model that supports traffic management that can optimize targets for the five aspects flow of traffic, traffic safety, air quality, CO_2 emission and noise hinder. Although the results of the online model were very promising, an online decision model that calculates traffic management and rerouting measures real time is not feasible yet. The vast amount of calculations that have to be done in a short period of time make it at the moment impossible to make it function online/real time..

Offline results however are very promising too. An offline system has been developed which has been tested in a simulated environment. The results show substantial benefits on all goals. In Almelo an improvement of air quality of 35 % is possible, while safety (10 %) and flow of traffic (7 %) improve too. Similar results were achieved in smaller test networks, showing that this kind of results are not a coincidence.

It is interesting that the strategy to achieve those results was quite simple. Reroute traffic in such a way that it is concentrated on the main roads in the network and facilitating the traffic on those roads by optimization of traffic light controls and other traffic management systems.
It is expected that a in a congested network, when there is only a little capacity left on non-congested roads, the results will be more modest.

The project also resulted in more understanding of the relationships between the various goals. In ATMA-MODeRN the relationship between the three P's People, Planet and Profit has been formulated in a specific way. It is clear however that optimal flow of traffic and good air quality go hand in hand. CO_2 reduction can be achieved even without substantial improvement in traffic flow. For safety and noise hinder the case is more difficult. They do not profit from increase in traffic flow, to the contrary, they profit most when traffic is more congested. On the bright side however we can conclude that in most cases, if the specific characteristics of the network are studied, specific measures can be taken that increase the flow of traffic as well as traffic safety.

5. NEXT STEPS IN ALMELO

The results found by ATMA-MODeRN in Almelo are very positive. Substantial profits can be made and for most goals this appears to be quite easy. Almelo was chosen for the project because the city has already an advanced traffic management system, an innovative approach and agreements with neighbouring road authorities. The results have encouraged the city to free recources to implement a part of the results of the project. This project, called TINA-2, will be implemented in two steps. Step one has started in March 2010 and will be ready before the end of the year. In step one city's monitoring system will be extended with a system that monitors the routes drivers use. Furthermore the existing variable message sign managing system will be updated and extended, while two variable message signs will be relocated to improve the cities capability to provide drivers with reroute information. Besides, a part of the existing parking guidance system will be renewed en integrated with the TINA-2 management system. This allows rerouting of city centre inbound traffic to free parking facilities while dealing with the same five goals. Of course, in the city centre especially air quality, noise and safety are of importance.

The second and last phase will be implemented in the summer of 2011 and then the multi-criteria, offline decision facility will be able to reroute traffic in order to gain optimal circumstances regarding the five goals. This system will operate automatically, because a 24/7 operator facility is not available in Almelo.

A result of the implementation of TINA-2 will be that the city's network will gain reliability too, because the rerouting will of course also take place when unexpected congestion or an incident occurs. This will also contribute to the value of the city's network for inhabitants and companies. Reliability of the traffic and transport network contributes to the city's economy, which is of course an important issue for the city's government.

Widening the Almelo system to the whole Region of Twente, with 350,000 inhabitants in the metropolitan area and 620,000 in the Region as a whole, is under discussion. Here history may be repeated. Ten years ago the city of Almelo developed a GPS-based traffic light pre-assumption system for public transport and emergency services and in the meanwhile, after the implementation in Almelo, the system has been installed in the whole Twente Region.

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