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Impact of stakeholder cooperation for centralized route guidance and full automated vehicle compliance

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ABSTRACT

Route guidance in traffic management aims to improve traffic network performance aligned with a system optimum. However, service providers commonly offer user optimum travel advice that can negatively impact centralized route guidance. This paper quantifies and demonstrates the impact of different policy strategies for a centralized route guidance systems where road authorities and service providers work together in a coordinated approach. Cooperation through an intermediary is considered with various policy strategies that consider different approaches and levels of cooperation between road authorities and service providers, which are evaluated using traffic modelling. A use case for the ring network of Milan shows that cooperation between the two parties has the potential to get the best out of the measure by utilizing a system optimum approach, while still allowing service providers to offer individual travel advice. The results of the modelled case study clearly show that the two approaches of far-reaching cooperation and increased compliance have a greater positive effect on traffic network performance in terms of reduced delays, reduced congestion and total time spent. In addition, the future presence of connected automated vehicles (CAV) is also considered in which these vehicle demonstrate full compliance. This shows that with increasing percentage of CAVs that route guidance can have a substantial positive effect compared to low compliance or a smaller penetration rate of automated vehicles.

Keywords: Route guidance; traffic policy strategies; service provider cooperation; automated vehicle routing

INTRODUCTION

Traditionally, traffic management has been effectively applied through road-side interventions by (national) road authorities (RA) by influencing traffic flow, traffic demand and traffic characteristics to improve traffic throughput, safety and emissions. Increasingly, other sources of traffic information and guidance are being offered and used that are not centrally coordinated by RAs. A primary example is that of in-car navigation devices. Approximately 90% of the people in Europe own navigation equipment, while a survey in The Netherlands indicated that 80% of the people who travel for business or who go for a day out use a navigation application (*1*). And of these people, 35% receive online congestion updates and are able to change their routes based on real-time traffic conditions. Service Provider (SP) delivered information is offered as individual advice and operates on the principle of an on-trip User Optimum (UO), in which the travel time for that individual user is minimized based on current traffic circumstances (*2*). This is often contradictory to RA road-side traffic management information that is generally designed for (partial) System Optimum (SO), which entails that the total sum of all vehicle delays is minimized to enhance the total system performance (*3; 4*), often measured by traffic throughput. Hence, UO-focused advice offered by SPs acts as a system disturbing process and has been shown to lead to a deterioration in traffic performance (*5*).

In past years, there have been efforts to counter the increasing negative effects of SP travel and route guidance advice through cooperation between RAs and SPs to achieve common objectives and prevent deterioration of traffic performance. However, Koller-Matschke (*6)* found that there are some serious concerns about the commitment by SPs and RAs to collaborate. To illustrate this, a large field study with 20.000 participants in the region of Amsterdam (*7*) did not lead to a significant improvement of the traffic flow performance (*8*). The conclusion of the evaluation found that the committed penetration of participants was too small to influence the system performance and that the greatest benefits of system optimum routing were mainly obtained by non-participating vehicles. Houshmand, Wollenstein-Betech and Cassandras (*9)* state that such an outcome may lead to participating SPs becoming less competitive compared with non-participating service providers as it is unclear whether road users would accept this kind of route guidance and what the benefits would be for the network performance.

Previous studies have shown the full potential of full participation and compliance in a centralized SO route guidance system (*3; 4*). However, in practice, many road users are not influenced by traffic information (*10*-*12*) and not everyone is willing to accept it voluntarily (*13; 14*). Multiple regulation strategies with voluntary and mandatory elements have been suggested to improve the impact of the centralized route guidance systems (*15*). Regulations may solve the lack of compliance, but are often not the preferred alternative of policymakers and may even not be necessary.

A recent example of RA-SP cooperation was proposed and executed in the cooperation framework which was part of the SOCRATES$^{2.0}$ project (*16*). The SOCRATES$^{2.0}$ project brought road authorities, service providers and car manufacturers together and applied a coordinated approach for smart route advice and also tested this in multiple practical trials in Europe. In this approach, four intermediary roles (strategy table, network manager, assessor, and network monitor) coordinate the information flow between RA and SP and the given route advice to ensure that a good balance can be found between SO and UO travel and route advice. However, the results of the project remained inconclusive to the potential effects of this cooperation, mainly due to limitations in the execution in practice. The potential effects of cooperation in the case of an incident were shown in a simulation study (*17*). Harmonizing route guidance in the event of a tunnel closure was shown to lead to 17% less delay in the Stockholm network, for example. A final consideration is also made for future opportunities that connected and automated vehicles (CAV) may bring about. Their emergence and connection to real-time route guidance is hypothesized to make it easier to divert traffic en-route as many CAVs may demonstrate full compliance, especially in the case of drivers/occupants that are out of the driving loop (*18*). Studies have shown that a strong effect of CAVs can be reached, even with moderately low penetration rates (*9*), which may lead to even a moderately strict regulation strategy being very effective and satisfy road users, policymakers and service providers.

In this paper, we aim to operationalize the cooperation concept of the SOCRATES$^{2.0}$ to model and demonstrate if, and how much, RA-SP cooperation can lead to improvements in traffic performance beyond the current and future scenarios that SPs apply a counteractive UO approach to RAs SO approach. The approach will consider different regulation strategies for a centralized route guidance system in which SPs and RAs are assumed to work together to achieve common goals. The presence of CAVs with full compliance is also considered. In the following section, we present the applied methodology, which includes the actor's interaction and regulation, as well as policy strategies. Thereafter, we present the results of a case study applying the methodology to the ring network of Milan. Finally, we reflect on the strategies and draw our conclusions.

METHODOLOGY

Overview of methodology

The approach taken in this paper loosely follows that applied within the SOCARTES framework, which in turn is based on the state-of-the-art from science and practice, and is extended to use traffic modelling for impact assessment. An overview of the total methodology to determine the impacts of different policy strategies from the cooperation strategy is given in *Figure 1*. The **cooperation strategy** is constructed based on an **interaction scheme**, detailing the process from data acquisition to measure selection and influence on end users, together with the network layer approach that describes the **actor resources and objectives**, primarily from RA and SPs. **Policy strategies** are derived based on the cooperation strategy, which are translated into scenarios that are evaluated using a **traffic model** to finally determine the impact of each scenario quantified in terms of traffic throughput and performance. Each part of the methodology is described in detail in the remainder of this section.

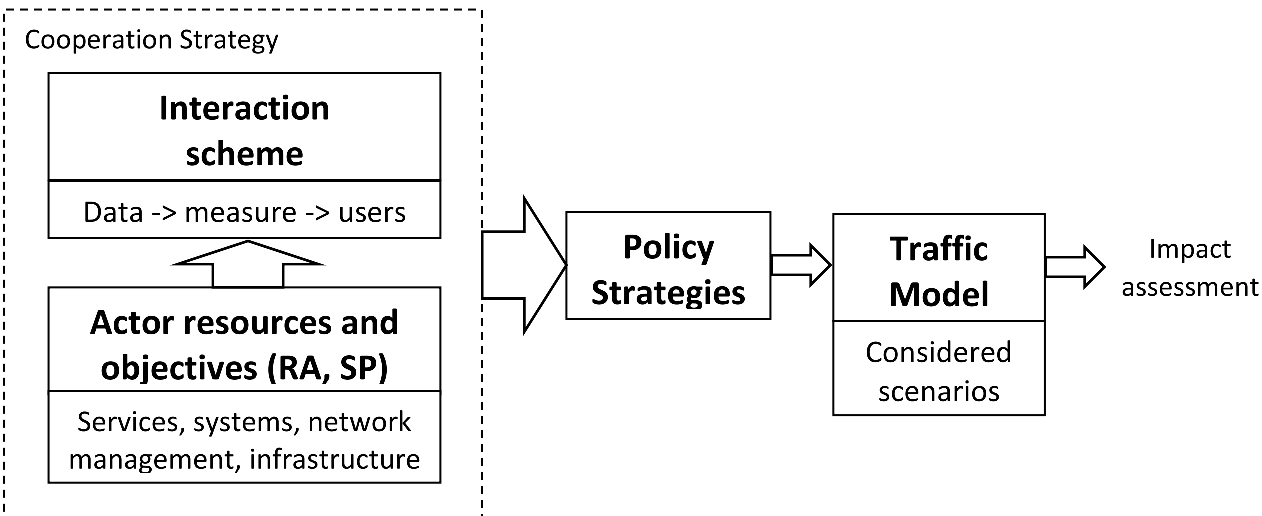

Figure 1: Research methodology for impact assessment of RA-SP coordinated route guidance

Cooperation strategy

Actors and cooperation

The cooperation framework in the SOCRATES$^{2.0}$ project describes the coordinated approach for smart route guidance. Four intermediary roles are established with an overall objective to enable coordinated end-user services possible:

- Network Monitor
- Strategy Table
- Network Manager
- Assessor

Each 'role' describes a critical process and the related actors required to construct the entire chain of events that allow coordination between RAs and SPs to take place using all available resources. The network monitor creates a uniform data foundation and combines the data collected by the service providers to create a commonly agreed view of the network. The strategy table focusses on the measures and interventions that should be taken, under the prevailing traffic and network conditions and which corresponding objective is pursued. The network manager is a technical platform that executes the measures and interventions as dictated from the strategy table, while the assessor acts as a feedback loop to verify the performance of the network manager to meet the objectives laid out by the strategy table. Four objectives are targeted in the strategy table, namely:

1. Safer, cleaner and more efficient traffic flow and better use of the road capacity
2. Better services to the road users and better quality of life for citizens,
3. Cost-effective traffic management by optimizing the use of existing road capacity
4. Economic growth and the creation of more jobs by reducing traffic problems and by creating new business opportunities.

While these in themselves can be viewed as abstract, a common denominator of these objectives is the reduction of congestion (*6*). However, this objective should not be sought at any cost. For example, excessive detours could help reduce congestion, but would lead to other detrimental effects. The reduction of the total travel time is therefore also considered as a main objective of the cooperation for smart routing. As congestion leads to a longer travel time, the reduction of congestion is also included in the objective to minimize the total travel time.

It should be noted that the implementation of these roles is not part of this study. It is assumed that all roles are implemented properly and when mentioning the intermediary, we refer to the combination of these separated roles as part of the cooperation strategy. The concept of separating the network management tasks by implementing an intermediary is a well-known principle in network industries, where a distinction is often made between the network management tasks and the actors that are responsible for these tasks (*19*). As such, the intermediary cooperation strategy considered from SOCRATES$^{2.0}$ is translated, based on Jaag and Trinkner (*19)*, to yield the tasks and responsibilities as shown in Figure 2. This especially highlight the different roles that RAs and SPs have in the cooperation framework.

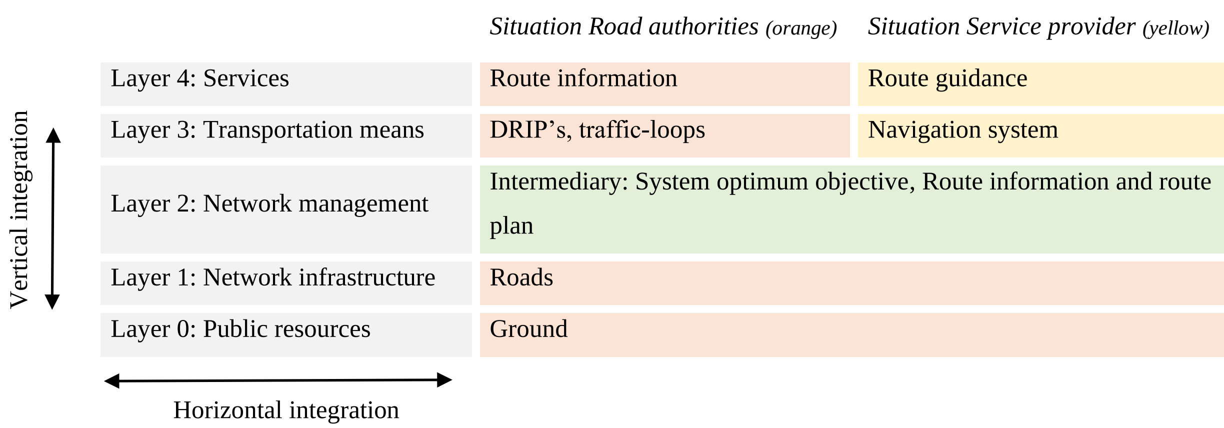

Figure 2: Segregation of Network layers vertical integrations per actor, suggested situation road network with in green the new intermediary, based on (Jaag & Trinkner, 2011)

Actor interaction

To further clarify interactions and cooperation between RAs and SPs upon implementation of an intermediary, the explicit flow of data and information is captured in the interaction scheme, shown in Figure 3. All actors may have data sensors and can obtain their own data from a variety of sources. In an ideal system, actors aggregate their data and share their data with the intermediary which aggregates all available data to one data set and which presents the common truth about the network state. The intermediary calculates the optimum routing and instructs all actors on which measures should be taken, which for route guidance will often be routing advice. The actors actuate the measures and the road users obtain the routing information.

In the option shown in Figure 3, one intermediary is established for road authorities while SPs share their data. In this case, all data of participating actors can be shared. The traffic management centers adapt their measure based on what SPs do. It should be noted that certain SPs may decide to operate partially within the cooperation or even entirely independently to it. In the figure, SP2 are the SPs that only share and obtain data to improve their service to offer the fastest routes for their users. This group does not execute the measures dictated by the intermediary and will not offer SO routing. SP3 represents SPs that act entirely independently. This group does not connect with the intermediary and is also not involved with data sharing, basically acting entirely independent to the cooperation, also in regard to the routing advice given, which is purely UO. It is assumed that the Traffic Management Centres (TMC) are completely compliant with the intermediary. From this is should be clear that engagement of SPs is important and that different levels of engagement can influence the extent to which the cooperation can be effective.

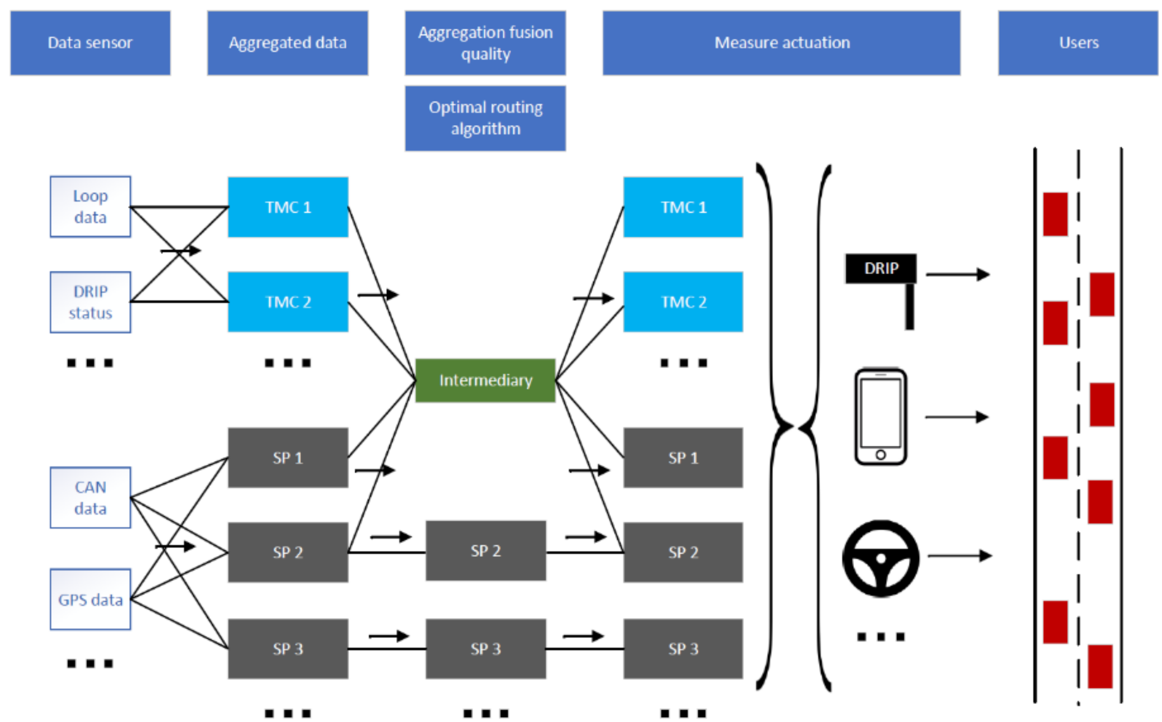

Figure 3: Interaction scheme with voluntary use of an intermediary with bypass behaviour, based on intermediary option three from proposed cooperation framework SOCRATES$^{2.0}$ (Koller-Matschke, 2018)

Policy strategies

From the scheme shown and discussed in the previous paragraph, it is clear that action by SPs will influence the effectiveness of the cooperation strategy and in turn the ability to guide traffic in a SO way. In this paper, we are interested to study what the effectiveness is of different regulation and policy strategies to obtain the best network performance under various conditions. Government has the ability to construct and enforce certain regulations obliging SPs to adhere to cooperation strategies and even complying road users to adhere to route advice. Below, we consider three levels of regulations that are analyzed later in Section 3 of this paper. The considered regulatory measures and policy strategies are as follows:

- **Ω_0: Base reference strategy: Status quo**
  In this strategy, no regulations are implemented and eventually, all vehicles will drive a perceived user optimum without perfect knowledge of the network.
- **Ω_1: Implementation of the intermediary with voluntary participation**
  In this strategy, an independent intermediary is established which makes cooperation possible and makes it possible for SPs to exchange data to improve their user optimum algorithm. The intermediary aggregates the data of all participating actors and determines the optimal set of measures based on a commonly agreed strategy table.
- **Ω_2: Compulsory SP participation with the intermediary services**
  In this strategy, the intermediary is active as in Ω_1, while all actors are obliged to use the services of the intermediary. When this regulation is in force, SPs cannot directly offer UO route advice to their users. SPs are obligated to execute the instructions of the intermediary and offer the congestion avoiding SO routing to their users.
- **Ω_3: Compulsory road user compliance of given route guidance**
  The final strategy builds on Ω_1 and Ω_2 by also making road user compliance of the given route advice mandatory. Road users are forced to comply with the route advice to achieve SO. In this case, all guided vehicles will avoid congestion to improve network traffic performance.

The following sub-section goes into the modelling process that is applied to investigate the effectiveness of these policy strategies.

Model setup

To address different policy strategies and scenarios, we make use of a macroscopic traffic model with route assignment and capable of demonstrating the influence of different forms of travel information and compliance. The MARPLE model is used for this and is detailed in this sub-section.

MARPLE

To study the impact of the policy strategies, a traffic assignment model is used, which distributes traffic over available routes. In general, there are five algorithms to do this: all-or-nothing assignment, capacity restrained assignment, incremental assignment, user equilibrium assignment and system optimal assignment (*20*). For this study, the Model for Assignment and Regional Policy Evaluation (MARPLE) was chosen (*21*) as it allows a user equilibrium to be simulated in a dynamic approach. MARPLE includes two user equilibrium assignment algorithms: the deterministic user equilibrium (DUE) and the stochastic user equilibrium (SUE). For the DUE, it is assumed that drivers have perfect information on the situation in the network. The SUE is used while the information over the network is incomplete and drivers choose their perceived fastest route. For this study, the SUE is an appropriate assignment approach. In the SUE, the completeness or quality of the information for the road user can be varied with the parameter θ. This parameter changes the size of the stochastic uncertainty for the SUE assignment, which indicates the chance that the chosen route is the fastest.

Different user classes can be defined in MARPLE. A user class represents a group of road users with the same routing behavior with different values of θ and thus with a different route choice behavior towards changes in the network situation. There are also habitual road users who do not change their route at all. Habitual routing behavior consists mostly of previous experiences of the driver. It is assumed that habitual drivers, who cannot be influenced by traffic information, will take the perceived fastest route according to uncongested traffic conditions.

Congestion avoiding user optimum algorithm

In this study, route choice by cooperative automated vehicles makes use of a congestion avoiding user optimum algorithm. A congestion avoiding approach can have a positive effect on the traffic performance (*22*). Congestion avoiding is implemented with a perceived time penalty for links above a certain flow/capacity threshold. With this time penalty, participating road users avoid routes over (nearly) congested links. This reduces congestion and for that reason the average travel time. In the best-case scenario, it also prevents congestion with the associated capacity drop. The applied time penalties are given in de scenario descriptions in the following section.

The use of congestion avoidance to achieve a better traffic performance works as follows. In case of congestion on a single link, all routes containing that link will get a perceived additional travel time in terms of a percentage of the current travel time. The congestion avoiding vehicles will prefer the detour if the additional travel time of the detour is shorter than the time penalty and that will reduce the inflow on the congested link. This means that the travel time of all passing vehicles will be reduced due to the vehicle that makes the detour, until the moment the congestion would be solved without the detour. A previous study showed that avoiding all congestion can lead to excessive detours which could lead to a reduced effect on the total travel time (*22*). The chosen time penalty approach will prevent this, because the time penalty value is the longest additional travel time that would be accepted which prevents excessive detours to occur.

Assumptions for the scenarios

The cooperation model with the specified policy strategies is converted into simulation input as shown in Figure 4, which shows how traffic is assigned to specific groups of routing behavior. This figure includes a number of assumptions. The scheme divides the traffic into two groups: human drivers and connected automated vehicles (CAV). All CAVs are influenced by service providers and have perfect compliance. Human drivers can be influenced by service providers, by the traffic management center or are not influenced at all. Research shows that 30% to 35% of the traffic can be influenced by traffic information (*1; 10-12*). Therefore, for human drivers it is assumed that 70% cannot be influenced (parameter A). For the sake of this study, the CAVs are assumed to have the same driving dynamics as the human driven vehicles. A commonly applied measure for routing traffic is the dynamic route information panel (DRIP). Unfortunately, the provided information is only relevant for 30% to 40% of the road users (*1*)and only 5% to 6% of the road users is willing to change route for small travel time benefits (*23*). Therefore, it is assumed that only 10% may be willing to change route (parameter B in Figure 4). This therefore means that 20% of the traffic can be influenced by information from the service providers (parameter C in Figure 4). Since 91% of the road users has navigation equipment available (*1*) and 25% of all road users are using it on a regular basis (*1; 24*), this assumption appears to be valid.

The distribution of the group which is influenced by the service providers depends on the scenario. Without implementing the intermediary, parameter H is set to 100% because no data is shared. While policy regulation Ω_1 is active, F, G and H can all be non-zero and the values depend on the scenario. With the regulation Ω_2 active, parameters G and H are 0% and F becomes 100%, which is the situation for which all road users influenced by the service providers, use the congestion avoiding routing. The compliance of the road users to reroute depends on the compliance algorithm, described in the following paragraph. Only in the situation where policy regulation Ω_3 is active will the compliance be 100%. In all other situations, vehicles who decline the congestion avoiding routing will route according to the user optimum algorithm with good knowledge of the network.

Implementation in the model

As shown in Figure 4, the different assumptions eventually lead to four groups of users. We define four different user classes in the model, which represent the road users that are considered. These user classes represent:

1) **Habitual drivers**, who take the shortest free flow route and stick with that (user optimum)
2) **Influenced drivers**, who are influenced by route guidance, but don’t always follow it;
3) **Completely compliant drivers**, who follow the route guidance;
4) **Social drivers**, who are willing to take socially beneficial routes (system optimum).

Each group has its own route choice behavior. The first group of users are the habitual drivers and they are not influenced by traffic information. Their routes are the shortest routes based on free flow travel time. For this group, the time penalty is not included (user class 1). The second group gets their information from service providers that act independently. Because a service provider represents a group of individual vehicles, there is some information available about the current traffic state. Because information is far from complete and some vehicles may not have an updated system, for the θ parameter a value of 2 is chosen (user class 2 – see previous MARPLE description). The third group only considers their travel time and uses the data of the intermediary to achieve this (user class 3). This means that there is no time penalty included and the θ parameter has the same value as for the second group. The final group of users will avoid congestion (user class 4). Therefore, a time penalty is added for routes with (nearly) congested links. The size of this time penalty is a percentage of the travel time, determined by the simulation. This group is connected with the intermediary and shares data, which means that the quality of traffic information is increased. Therefore, the θ parameter for this group has relatively high value and is set to 10. This value was also used in another study of route guidance during a tunnel closure (*21*).

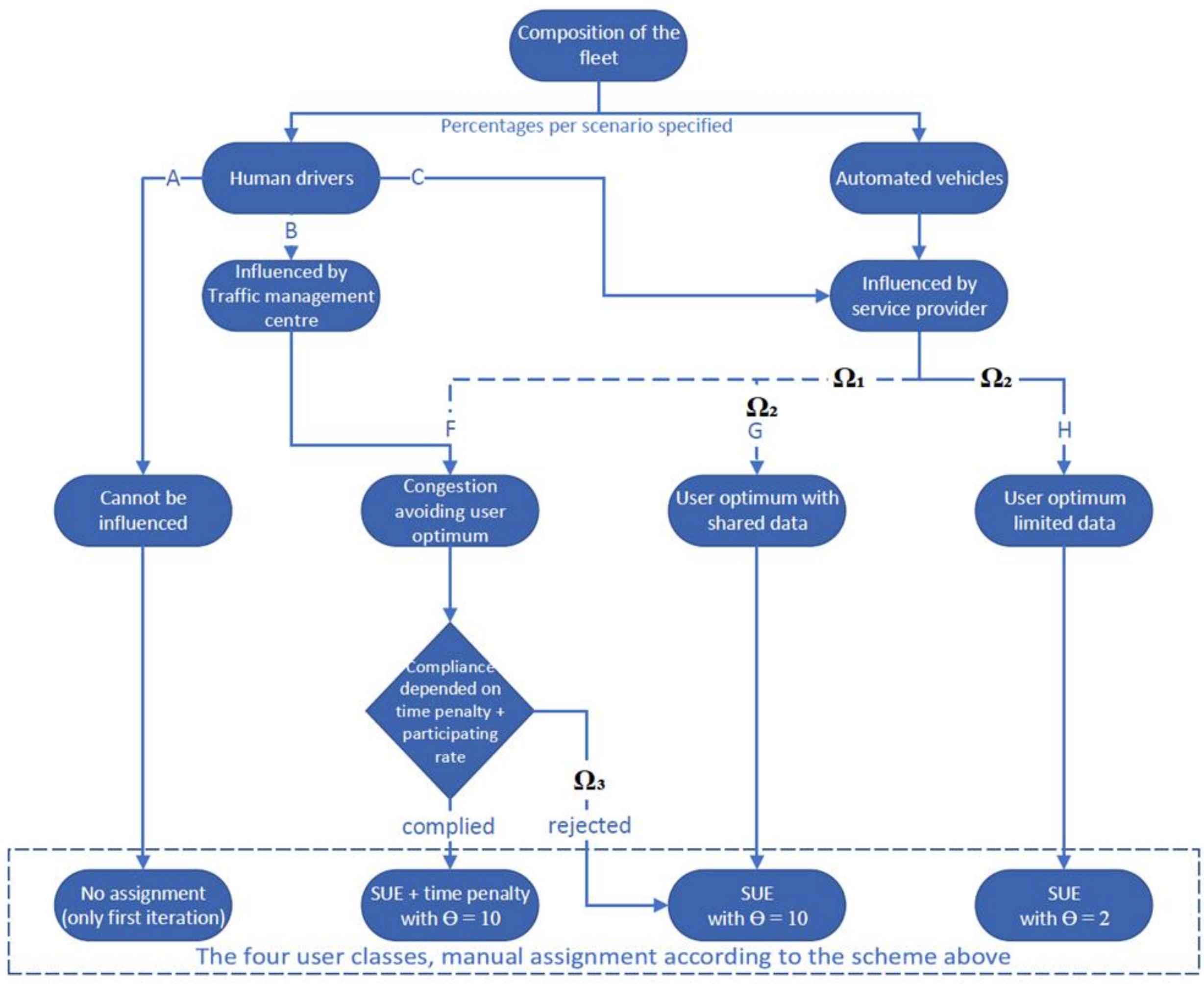

Figure 4 Scheme for assigning traffic to specific groups of routing behavior

Algorithm for compliance

Depending on the strategy scenario, different distributions of these user classes can be assumed to be present in a network. Not every road user is willing to accept a social route like the congestion avoiding approach. Initially, about 80% of the drivers are willing to accept it and this decreases to below 40% when the additional travel time increases (*13; 14*). Recent studies show that social demographic attributes have an influence on compliance (*14; 25*). However, in macroscopic simulation, these attributes are not taken into account. A variable that will be considered is the number of participants. In general, if drivers have the feeling that others make the social choice, they are more willing to accept the social alternative (*13*). For the algorithm to determine the compliance rate, the results of two studies (*13; 14*) are combined.

In this research, the following described equations are used to determine the distribution of drivers/vehicles over the user classes. In the equations, C is the compliance rate (percentage), p is the participation rate (percentage) and t is the time penalty (percentage of original travel time).

Equation 1 shows the compliance function for participation rates up to 10%:

$$C = 20 + 65 * 0{,}97^{t} \qquad (1)$$
$$Domain\colon \{p \geq 0 | p < 10\}$$

The compliance function for participation rates between 10%-100% is given by:

$$C = 20 + 15\frac{p-10}{90} + \left(65 - 15\frac{p-10}{90}\right) * (0{,}97 + 0{,}0225 * \frac{p-10}{90})^{t} \qquad (2)$$
$$Domain\colon \{p \geq 10 | p < 100\}$$

While a simplified compliance function is applied for the participation rate of 100%:

$$C = 35 + 50 * 0{,}9925^{t} \qquad (3)$$
$$Domain\colon \{p = 100\}$$

Note that for p=10 Eq. 1 and 2 give the same results. Eq. 3 follows immediately using p=100 in Eq. 2.

Case study

Network

The considered network for the case study is a representation of the network of Milan (see Figure 5). A ring-structured network is suitable for this study, because it provides multiple route options for many origin-destination pairs. This makes rerouting possible and non-congested route alternatives more likely to exist, hence the choice for this network.

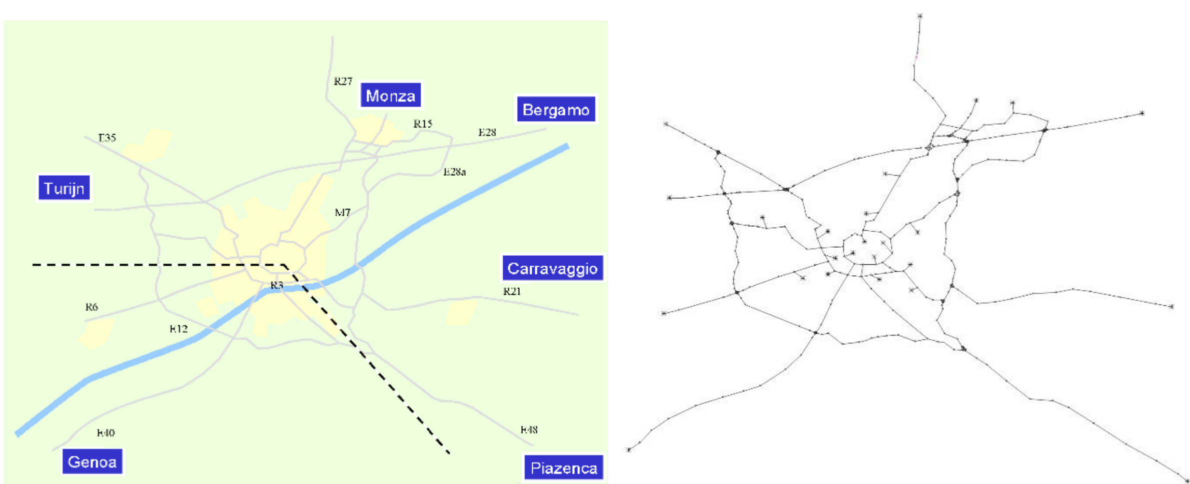

Figure 5 Milan network with ring structure

Scenarios

Four policy strategies are considered. However, for one strategy the resulting outcome in practice is not clear, as we will explain. In policy strategy Ω_1, 'regulated intermediary and free of obligations', three situations can occur. The first is that the data is only shared and the service provider's use is for their own benefit. The second one is that only a part of the service providers will participate. The third situation is that every service provider uses the service voluntarily. That last situation is the same as the policy where all service providers are forced to use the services of the intermediary. Therefore, in practice there are eventually five **strategy scenarios**:

1) Do nothing;
2) A regulated intermediary, free of obligations, only used for data sharing;
3) A regulated intermediary, free of obligations, partial commitment;
4) Obligated use of intermediary services, but voluntary use for road users;
5) Obligated use of intermediary services and mandatory use for road users.

For every strategy scenario, a distribution for the different user classes in the model is calculated for different penetration rates of CAVs. For the time penalty, values are chosen based on simulations for the first user class distribution with a time penalty between 0% and 40%. The time penalty with the best results is used for the other user class distributions. Furthermore, for each strategy scenario, we also consider the percentage of connected automated vehicles (CAV) that are assumed to demonstrate perfect compliance with route advice. We consider steps of 10% from 0% up to 100% with assumed full compliance. The inputs for simulation scenarios are presented in Table 1.

A time penalty is added to the normal travel time for congested links. This time penalty is determined by the flow-capacity ratio. When this ratio rises above a certain threshold, the time penalty is added. Three choices for the threshold were tested in advance: 90%, 95% and 99%. The 95% threshold gave the best results, as the 90% option left too much capacity unused and the 99% resulted in excessive congestion, because flows are not completely consistent and the link could be wrongfully denied a time penalty. The second choice is the number of extra iterations simulated after the time penalty is added. For this study, it is assumed that the iteration process continues until convergence is reached. This choice is motivated by the fact that the intermediary has good information about the network state and could instruct all vehicles to use the best route. Convergence is assumed if the maximum change in route flows stays below a certain percentage. In this study, this value is set to 1%.

Table 1 Strategy scenarios and user class setting for the model

Scenario 1 Do nothing					
CAV %	Time penalty	user class share [%]			
		1	2	3	4
0%	10	70	20	3	7
10%		63	28	3	6
20%		56	36	3	5
30%		49	44	2	5
40%		42	52	2	4
50%		35	60	2	3
60%		28	68	1	3
70%		21	76	1	2
80%		14	84	1	1
90%		7	92	0	1
100%	N/A	0	100	0	0

Scenario 2 A regulated intermediary, free of obligations, only used for data sharing					
CAV %	Time penalty	user class share [%]			
		1	2	3	4
0%	10	70	0	23	7
10%		63	0	31	6
20%		56	0	39	5
30%		49	0	46	5
40%		42	0	54	4
50%		35	0	62	3
60%		28	0	69	3
70%		21	0	77	2
80%		14	0	85	1
90%		7	0	92	1
100%	N/A	0	0	100	0

Scenario 3 A regulated intermediary, free of obligations, partial commitment					
CAV %	Time penalty	user class share [%]			
		1	2	3	4
0%	10	70	5	12	13
10%		63	7	15	15
20%		56	9	18	17
30%		49	11	21	19
40%	15	42	13	26	19
50%		35	15	29	21
60%		28	17	33	22
70%		21	19	36	24
80%		14	21	39	26
90%		7	23	42	28
100%		0	25	45	30

Scenario 4 Obligated use of intermediary services, but voluntary use for road users					
CAV %	Time penalty	user class share [%]			
		1	2	3	4
0%	15	70	0	12	18
10%		63	0	15	22
20%		56	0	18	26
30%		49	0	21	30
40%		42	0	24	34
50%		35	0	27	38
60%		28	0	29	43
70%		21	0	32	47
80%		14	0	35	51
90%		7	0	38	55
100%		0	0	41	59

Scenario 5 Obligated use of intermediary services and mandatory use for road users					
CAV %	Time penalty	user class share [%]			
		1	2	3	4
0%	25	70	0	0	30
10%		63	0	0	37
20%		56	0	0	44
30%		49	0	0	51
40%		42	0	0	58
50%		35	0	0	65
60%		28	0	0	72
70%		21	0	0	79
80%		14	0	0	86
90%		7	0	0	93
100%		0	0	0	100

CASE STUDY RESULTS

To show the impact of the centralized route guidance system with different regulation sets, the results from the described scenarios are presented and analyzed in this section. The network performance is analyzed using the total time spent (TTS), which is the aggregated time of all vehicles in the network, with the condition that the number of vehicles in each scenario is identical and that the network is empty at the end of the simulation time. Furthermore, the network performance is evaluated through consideration of network delays, given as percentage difference between scenarios of the aggregated delay over all vehicles and the observed queue lengths. Finally, we consider the effect of the applied time penalty values in a sensitivity analysis.

Network Performance

The results of the TTS for the Milan ring network (Figure 6) show that with increasing compliance and regulation, the TTS for the network is reduced. Strategy 5 (Obligated use of intermediary and mandatory use for road users) shows an improvement compared with the base scenario of doing nothing by 0.4% for 0% automated vehicles, while an improvement of 1.1% is achieved with 100% automated vehicles. Both 3these numbers are substantial improvements when considering the whole network, which is an indication that the regulations improve traffic flow. We see that the current implementation of the intermediary without commitment leads to only 0.06% improvement and finally to an improvement with automated vehicles of 0.27%. It also shows that more regulation lead to better traffic performances.

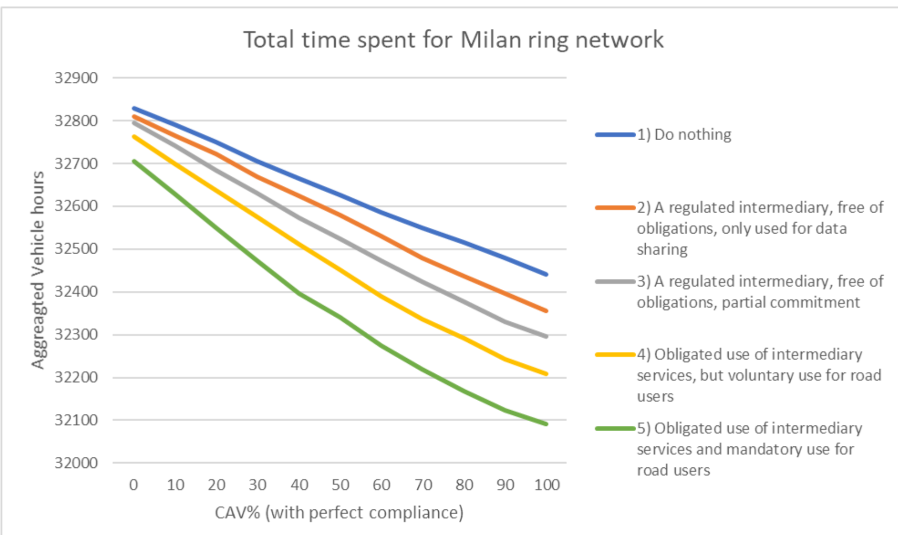

Figure 6 Total time spent for Milan ring network

When this is translated to savings in delays, the total delay is reduced by 0.4%, 1.0%, 2.1% and 4.2% respectively for the strategy scenarios with 0% automated vehicles (Figure 7). With 100% automated vehicles, the delay savings increase to 1.4%, 4.1%, 7.3% and 12.5%. Logically, a reduction in the queue lengths is also visible, as shown in Figure 8, with reductions ranging across the network from 500-3000m. Also, note from Figure 8 that the largest queue reductions are not necessarily for the strategy scenarios with the highest delay reductions. This is due to different degrees of rerouting through the network. It should be noted that due to the complexity of the network and limited rerouting options in some places, not all congestion could be eradicated.

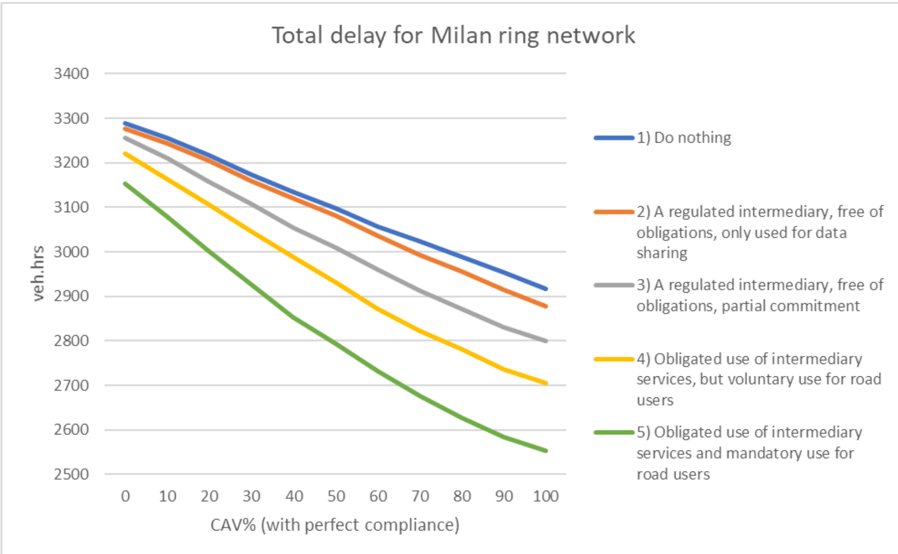

Figure 7 Network delay

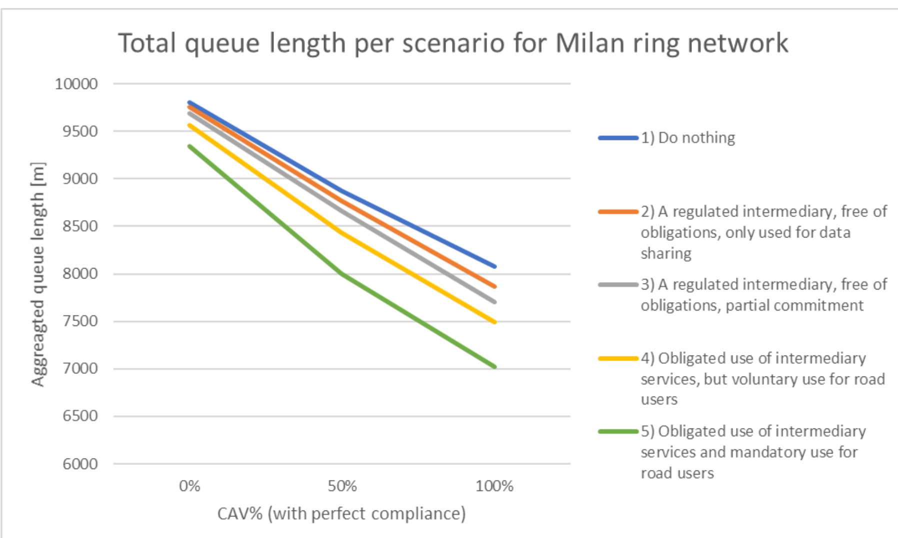

Figure 8 Queue lengths per scenario

Sensitivity time penalty

As the time penalty is a key variable in the analysis, we show the effects of different time penalty values with a sensitivity analysis. Figure 9 shows the relative effect of the time penalty in TTS for selected scenarios compared with the outcome of applying no time penalty at all. A selection of scenarios is varied in the number of participants with congestion who avoid rerouting. With more participants, the optimum of the time penalty shifts towards larger time penalties and the result becomes more sensitive if the penalty is set too high. Changes to the sensitivity can be explained by the change in the actual number of vehicles that avoid congestion. If this change gets larger, the effect becomes increasingly marked as more road users switch to a user optimum route. The reason for the shift in optimal time penalty can be explained by the reason that with fewer participating vehicles the potential of the scenario is reached faster. For example, consider an ideal situation where 20% of the vehicles must make a detour to avoid congestion with a time penalty of 20%. When only 10% of the vehicles participate, congestion is not be solved. This means that the difference in travel time between the congested route and the detour route is smaller. With a smaller difference, it is beneficial to lower the time penalty to balance the volume of vehicles that change route through increased compliance.

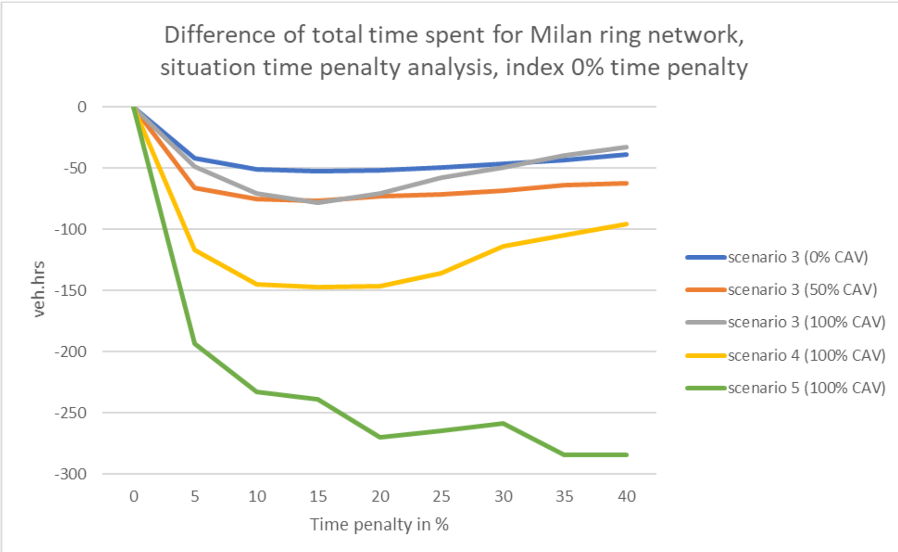

Figure 9 Relative effect of the time penalty per regulated scenario

DISCUSSION AND LIMITATIONS

The focus of this study is on the potential to utilize strategy policies for route guidance with different stakeholders (road authorities and private parties). The study shows encouraging results that cooperation between these stakeholders can improve traffic flow rather than be detrimental if stakeholders would be counteractive with different approaches. There remain challenges in regard to the implementation of the approach, however the existence of the SOCRATES$^{2.0}$ project demonstrates a willingness for parties to work together and the case study here shows that it has value. Based on literature, it could be expected that strict regulations for cooperation may not be required and the full potential of cooperation could be reached if all service providers participate. However, our results show that this is does not need to be the case. While network characteristics play an important role, regulation of intermediaries still yields good results with the need for obligatory involvement.

While the concept of coordination makes cooperation possible, it could lead to some undesirable side effects, especially where multiple coordination centers exist, unbundling may lead to flawed coordination (*26*). Because a country like The Netherlands has five regional traffic centers to control the highway network, this could lead to an issue in the future. As only a single region is considered in this study, flawed coordination is not a concern. Another consideration to be taken is the potential lack of competitive incentives (*19; 27*). Because the intermediary takes overall network management tasks, service providers cannot compete with providing the fastest route. This may lead to a reduction of investments in the future because investments do not lead to exclusive rights to harvest the benefits of the investment.

In this study, we include and assume that the future introduction of connected automated vehicles (CAV) will play a significant role in the ability to control traffic. This is based on the assumption that CAVs will show near perfect compliance. For the sake of this research, this is a suitable assumption, especially as the penetration rate of CAV in traffic is varied to allow its influence to be shown. However, we do concede that it can also be argued that full compliance will not be the case, even if that could also be potentially one option for regulators to employ if they wished. Furthermore, the presence of CAVs in this study is only considered with regard to their compliance. Any difference in vehicle dynamics are not considered to allow the main premise of stakeholder cooperation to be properly tested.

An important component of the approach is the application of the time penalty. Detours are a main part of rerouting in which drivers may perceive they have a longer detour. The perceived detour depends on the application of the time penalty. With a time penalty of 20%, no one can change route to obtain a travel time benefit of more than 20%. This means that that a specific road user will not suffer more than 30 seconds on average compared with the unregulated situation but can perceive a detour of at most 20%. Because people may dislike this, the maximum time penalty can be reduced at the expense of a slightly decreased positive impact on the system. In our case for example, a reduction of the time penalty from 15% to 10% has minimal impact on the results while the compliance of the policy may improve enough to make it acceptable for policymakers. The applied penalties are calibrated for use on the Milan ring network, however for other networks, we hypothesis that a time penalty between that approaches the difference in travel time in free-flow conditions would suffice. For the impact on the traffic flow, the adjustment of the time penalty is crucial. A too large time penalty can negate time gains by offering overly long detours and can lead to a reduction of compliance. A limited reduction of the optimal time penalty can have a slight reduction to the traffic flow performance while it can have a significant impact on the support of the policy

In other studies, instead of a congestion avoiding algorithm a system optimum algorithm is sometimes used. A system optimum algorithm will achieve the optimum instead of approaching the system optimum state with the congestion optimum algorithm. For this reason, the applied algorithm can be considered to be too simplistic to investigate the maximum potential of the system. However, because a complete system optimum algorithm is often too complex for simulation software, the applied approach to avoid congestion could be more realistic and actually resemble real traffic reactions than an artificial system optimum, which is known to never completely exist in practice. In the applied simulation model, MARPLE, the concept of information for routing in MARPLE is supported by literature (*28*), even if other models often apply alternative approaches. The idea of changing theta as a parameter to distribute traffic over alternative routes is plausible. If we consider the case of little available information for road users, the chance of choosing the slower route becomes more likely. A shortcoming a macroscopic DTA model like MARPLE is the omission of the capacity drop. While not unusual in macroscopic models, it can have an impact especially where congestion is present. When congestion is avoided in a simulation this may boost the impact of regulation more than if a capacity drop was present.

CONCLUSIONS

Route guidance has the potential to improve network performance and traffic flow, however counteractive approaches by Road Authorities and Service Providers (SP) can be detrimental to this. Cooperation between the two has the potential to get the best out of the measure by utilising a System Optimum approach, while still allowing SPs to offer individual travel advice. In this paper, we have shown the potential impacts of different policy strategies for collaboration between RAs and SPs based on the pilot project SOCRATES. Cooperation ranges from regulation of SPs, with and without obligation to cooperate, to full mandatory cooperation and enforcement of specific route guidance advice. Additionally, various levels of user compliance are considered, including mandatory and voluntary compliance options and the investigation of the potential of connected automated vehicles with full compliance to influence performance.

The results of a modelled case study of the Milan ring network clearly show that both far-reaching cooperation and increased compliance have a greater positive effect on traffic network performance in terms of reduced delays, reduced congestion and total time spent (even with rerouting). A comparison is made against a ‘do nothing’ reference scenario in which SPs offer user optimum advice and RAs recommend system optimum advice. Even with some regulation and without obligation to participate, improvements in performance are experienced in network performance of a few percent in most indicators. While full obligation for SPs to provide system optimum advice and full compliance does offer significant network performance improvements, potentially ranging about 10% for some indicators, this may be unrealistic to expect this level of cooperation in the future. Nevertheless, the study has demonstrated the potential benefits of any time of cooperation and therefore come with a strong recommendation for road authorities and service providers alike to continue to seek for cooperation to aid traffic performance in the future.

A final aspect of this research considered the impact of fully compliant connected automated vehicles. This showed that with increasing percentage of CAVs with complete compliance, that route guidance can have a substantial positive effect compared to less compliance or a smaller penetration rate of automated vehicles. With this comes the recommendation for authorities and car manufactures alike to consider the positive effects of full cooperation and compliance as CAVs continue to make ground in terms of capabilities and market share.

AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: B.D. van den Burg; model development: H. Taale; analysis and interpretation of results: S.C.Calvert, B.D. van den Burg, H. Taale; draft manuscript preparation: S.C.Calvert, B.D. van den Burg, H. Taale. All authors reviewed the results and approved the final version of the manuscript.

REFERENCES

[1] KiM. De rol van reisinformatie in het wegverkeer. Policy report, Den Haag: Ministerie van Infrastructuur en Milieu., 2017.

[2] Bilali, A., G. Isaac, S. Amini, and N. Motamedidehkordi. Analyzing the impact of anticipatory vehicle routing on the network performance. *Transportation Research Procedia,* Vol. 41, 2019, pp. 494-506.

[3] El Hamdani, S., and N. Benamar. Autonomous traffic management: Open issues and new directions.In *2018 International Conference on Selected Topics in Mobile and Wireless Networking (MoWNeT),* IEEE, 2018. pp. 1-5.

[4] Kuru, K., and W. Khan. A framework for the synergistic integration of fully autonomous ground vehicles with smart city. *IEEE Access,* Vol. 9, 2020, pp. 923-948.

[5] Boyce, D., and Q. Xiong. User-optimal and system-optimal route choices for a large road network. *Review of network Economics,* Vol. 3, No. 4, 2004.

[6] Koller-Matschke, I. Proposed cooperation framework & bottlenecks.In, SOCRATES2. 0. Retrieved from https://SOCRATES2. org/download_file/112/184, 2018.

[7] Calvert, S. C., M. Snelder, T. Bakri, B. Heijligers, and V. L. Knoop. Real-Time Travel Time Prediction Framework for Departure Time and Route Advice. *Transportation Research Board 94th Annual Meeting*, 2015.

[8] Wilmink, I., E. Jonkers, M. Snelder, and G. Klunder. Evaluation results of the Amsterdam, Netherlands, practical trial with in-car travel and route advice. *Transportation Research Record,* Vol. 2621, No. 1, 2017, pp. 38-45.

[9] Houshmand, A., S. Wollenstein-Betech, and C. G. Cassandras. The penetration rate effect of connected and automated vehicles in mixed traffic routing.In *2019 IEEE Intelligent Transportation Systems Conference (ITSC)*, IEEE, 2019. pp. 1755-1760.

[10] Gan, H., and S. Chen. Why do drivers change routes? impact of graphical route information panels. *Institute of Transportation Engineers. ITE Journal,* Vol. 83, No. 8, 2013, p. 38.

[11] Iraganaboina, N. C., T. Bhowmik, S. Yasmin, N. Eluru, and M. A. Abdel-Aty. Evaluating the influence of information provision (when and how) on route choice preferences of road users in Greater Orlando: Application of a regret minimization approach. *Transportation Research Part C: Emerging Technologies,* Vol. 122, 2021, p. 102923.

[12] Reinolsmann, N., W. Alhajyaseen, T. Brijs, A. Pirdavani, V. Ross, Q. Hussain, and K. Brijs. Dynamic travel information strategies in advance traveler information systems and their effect on route choices along highways. *Procedia computer science,* Vol. 170, 2020, pp. 289-296.

[13] Bonsall, P. W., and M. Joint. Driver compliance with route guidance advice: the evidence and its implications.In *Vehicle Navigation and Information Systems Conference, 1991, No. 2*, IEEE, 1991. pp. 47-59.

[14] Mariotte, G., L. Leclercq, H. G. Ramirez, J. Krug, and C. Becarie. Assessing traveler compliance with the social optimum: A stated preference study. *Travel Behaviour and Society,* Vol. 23, 2021, pp. 177-191.

[15] Bagloee, S. A., M. Tavana, M. Asadi, and T. Oliver. Autonomous vehicles: challenges, opportunities, and future implications for transportation policies. *Journal of Modern Transportation,* Vol. 24, No. 4, 2016, pp. 284-303.

[16] SOCRATES$^{2.0}$. SOCRATES2.0 Cooperation Framework.In *SOCRATES2.0*, 2020.

[17] Taale, H. Cooperative Route Guidance-A Simulation Study for Stockholm. *Delft University of Technology.*, 2020.

[18] Chen, H., F. Wu, K. Hou, and T. Z. Qiu. Backpressure-Based Distributed Dynamic Route Control for Connected and Automated Vehicles. *Ieee Transactions on Intelligent Transportation Systems*, 2022.

[19] Jaag, C., and U. Trinkner. A general framework for regulation and liberalization in network industries.In *International Handbook of Network Industries*, Edward Elgar Publishing, 2011.

[20] Saw, K., B. Katti, and G. Joshi. Literature review of traffic assignment: static and dynamic. *International Journal of Transportation Engineering,* Vol. 2, No. 4, 2015, pp. 339-347.

[21] Taale, H. Marple, beschrijving en handleiding. *Report, Rijkswaterstaat-Dienst Verkeer en Scheepvaart*, 2020.

[22] Summerfield, N. S., A. V. Deokar, M. Xu, and W. Zhu. Should drivers cooperate? Performance evaluation of cooperative navigation on simulated road networks using network DEA. *Journal of the Operational Research Society,* Vol. 72, No. 5, 2021, pp. 1042-1057.

[23] Wardman, M., P. W. Bonsall, and J. Shires. Stated preference analysis of driver route choice reaction to variable message sign information. 1996.

[24] Knapper, A., N. V. Nes, M. Christoph, M. Hagenzieker, and K. Brookhuis. The use of navigation systems in naturalistic driving. *Traffic injury prevention,* Vol. 17, No. 3, 2016, pp. 264-270.

[25] van Essen, M., T. Thomas, E. van Berkum, and C. Chorus. Travelers' compliance with social routing advice: evidence from SP and RP experiments. *Transportation,* Vol. 47, No. 3, 2020, pp. 1047-1070.

[26] Brunekreeft, G. Network unbundling and flawed coordination: Experience from the electricity sector. *Utilities Policy,* Vol. 34, 2015, pp. 11-18.

[27] Armstrong, M., and D. E. Sappington. Regulation, competition and liberalization. *Journal of economic literature,* Vol. 44, No. 2, 2006, pp. 325-366.

[28] Mede, P. H. J. v. d., and E. C. Van Berkum. The impact of traffic information: dynamics in route and departure time choice. *Delft: Delft University of Technology.*, 1993.