TRAFFIC FLOW IMPACTS OF A CONGESTION ASSISTANT

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ABSTRACT
This paper presents the results from a microscopic traffic simulation study that was conducted to investigate the impacts of a so-called Congestion Assistant on traffic efficiency and traffic safety. The Congestion Assistant is an in-vehicle system that supports the driver with an Active pedal when approaching a traffic jam and a Stop & Go when driving in a traffic jam. Six variants of the Congestion Assistant with different equipment rates on a four-lane highway with a lane drop were assessed. The traffic simulation tool was calibrated and validated using measured loop data on a segment of the Dutch A12 highway. The Congestion Assistant was found to reduce the amount of congestion significantly, especially due to the Stop & Go. This function led to more efficient car-following behavior by adapting smaller headways and eliminating the reaction time of drivers. The Active pedal of the Congestion Assistant hardly influenced traffic efficiency; rather it affected traffic safety through a safer approach to a jam.

INTRODUCTION

Modern societies are increasingly confronted with problems in traffic and transport, such as congestion, accidents and emissions. High expectations rest on driver support systems to contribute to the solution of these problems [1]. Current research efforts focus on the potential effects of these systems on traffic efficiency, safety and emissions. Because most driver support systems are not on the market yet, simulation facilities, such as traffic flow models, are applied. In this paper, we present a so-called Congestion Assistant that can improve traffic efficiency and traffic safety during congested traffic conditions on highways. An innovative aspect of this system is its combination of driver support systems: the Congestion Assistant consists of an Active pedal when approaching a traffic jam and a Stop & Go when driving in a traffic jam. Furthermore, the traffic simulation tool that we used was calibrated and validated using speed and flow data of the Dutch A12 highway. This resulted in a reference situation with a realistic congestion build-up. Before discussing the set-up and the results of the study, we first elaborate on earlier research into driver support systems that are related to the functions of the Congestion Assistant.

It is expected that particularly Adaptive Cruise Control (ACC) can compensate for the unfavorable human behavior that causes congestion [2]. An ACC system can control the speed and distance to the preceding vehicle more accurately than human drivers can. Drivers sometimes brake harder than necessary or unintentionally change their speed (e.g. due to driver distraction), which can induce a traffic jam in dense traffic. ACC can eliminate these driving behaviors. Besides, an ACC system can take away the spacing that is needed because of the reaction time of drivers. Therefore, more road capacity can be created, because vehicles can follow each other more closely at high speeds. Accordingly, no traffic efficiency benefits will be obtained if ACC systems imitate average car-following behavior. This statement was confirmed by Minderhoud [3] who studied the impacts of difference ACC systems on highway traffic. He concluded that ACC with a time gap below 1.2 s increased the road capacity. Furthermore, the capacity gains increased with an increasing equipment rate of ACC. In contrast to the commonly used constant time gap of ACC systems, Wang & Rajamani [4] proposed a variable time gap policy which analytically led to a more stable traffic flow and a higher highway capacity.

Compared to ACC with a limited speed range (e.g. above 40 km/h), more is expected from Stop & Go, which particularly assists the driver in congested traffic situations. One of the ACC systems tested by Minderhoud [3] was especially designed for supporting the driver in stop-and-go conditions with a speed range of 0-60 km/h. However, this system showed negative impacts on road capacity, most likely because of the relatively large time gap of 1.2 s. Within the German research initiative INVENT, Benz et al. [5] focused on raising the congestion outflow by examining different time gap settings of a Stop & Go. Microscopic simulation results showed an increased traffic flow with a time gap of 1.0 s, because this setting is smaller than the average time gap applied by unsupported drivers when leaving the traffic jam.

The functionality of driver support systems can be enhanced when vehicles exchange information with each other. For example, the Cooperative Following system uses automated longitudinal control combined with vehicle-vehicle communication to anticipate severe braking maneuvers in emerging shock waves with the aim of smoothening traffic flow and enhancing traffic safety [6]. The results of a small-scale simulation showed that vehicles equipped with this system quickly responded to downstream braking maneuvers, which led to safer headways at a platoon level. Kesting et al. [7] proposed a ‘jam-avoiding’ ACC strategy that adapts the ACC driving style dynamically to the traffic situations determined by vehicle-vehicle or vehicle-infrastructure communication. When approaching a traffic jam, the comfortable deceleration level of the ACC system decreases to increase the traffic safety by earlier braking. When arriving at the bottleneck section and when leaving the traffic jam, the maximum acceleration increases while the time gap decreases, both to increase the capacity. Microscopic simulation results showed that already a small amount of ‘traffic-adaptive’ ACC vehicles improved the traffic stability and performance and led to a reduction of traffic congestion.

The results above point out that driver support systems have the potential to reduce the sometimes unwanted driving behavior to mitigate congestion. Particularly systems that stimulate early braking when approaching a jam, such as the Cooperative Following system, showed positive effects on traffic safety,

while traffic efficiency was especially improved by ACC and Stop & Go systems that operate with a relatively small time gap. Following from these findings, it is expected that the Congestion Assistant can contribute to the dissipation of congestion. This in-vehicle system supports the driver during congested traffic situations on highways and consists of: (a) an Active pedal that produces a counterforce of the gas pedal when the driver is approaching a traffic jam at too high speed and (b) a Stop & Go that takes over the longitudinal driving task from the driver in a traffic jam. The Congestion Assistant is developed based on user needs and evaluated with respect to its impacts on driving behavior in a driving simulator [8]. The results from the driving simulator experiment showed indications of an improved traffic safety and efficiency when approaching and driving in a jam. This paper presents the results from a microscopic traffic simulation study that investigated the extent to which these impacts prevail when focusing on a whole traffic flow instead of only one driver.

This paper is structured as follows. The next section describes the ITS Modeler, which is the simulation environment that was used to study the traffic flow impacts of the Congestion Assistant. The next section discusses the implementation of the Congestion Assistant in the ITS Modeler. The two sections after that present the impacts of the Congestion Assistant on traffic efficiency respectively traffic safety. Subsequently, the observed findings and used methodology are discussed. The paper ends with conclusions and an outlook.

SIMULATION ENVIRONMENT: ITS MODELER

To study the impacts of the Congestion Assistant on highway traffic, the modeling approach should be able to: (a) simulate the traffic flow by distinguishing individual driver-vehicle combinations that represent the interactions between vehicles and between driver and vehicle, (b) simulate changes in driving behavior induced by the Congestion Assistant to describe the behavior of vehicles equipped with or without this system, (c) simulate highway environments, including bottlenecks, such as on-ramps and lane drops that can cause congestion and (d) realistically represent traffic flow dynamics, particularly with respect to the congested regime and the transitions between free flow and congestion.

These basic requirements are met by the ITS Modeler [9, 10]. The ITS Modeler is a modeling environment in which intelligent cooperative vehicle-infrastructure systems can be modeled, tested and evaluated for their impacts on traffic efficiency, traffic safety and the environment. It has to be connected to a commercially available traffic simulation tool for the road network and the generation of vehicles. In this study, the ITS Modeler was coupled with Paramics [11]. The ITS Modeler has a modular and transparent set-up, so that new models and algorithms can be easily added. Each time step of 0.1 s, the ITS Modeler calculates new vehicle positions and states by a driver model and a vehicle model. Next to these models, it has an ITS model that describes the working of the Congestion Assistant. The different components of the ITS Modeler are discussed below. Most focus is put onto the longitudinal driver model, because this model forms the basis of the functional definition of the Congestion Assistant and it has a large impact on the formation of traffic jams.

The driver model consists of a lateral and a longitudinal component. The lateral driver model describes the driver's actions with respect to lateral vehicle control. This model distinguishes free lane-changing and mandatory lane-changing. The free lane-change model represents overtaking when a slower predecessor is forcing the driver to reduce his speed below his desired speed. It primarily considers lane-changes to the left to gain speed advantage. However, the model was adapted to introduce lane-changes to the right in congested traffic conditions to also gain speed advantage (i.e. when the lane to the right moves faster than the current lane). This adaptation is applicable as soon as the current vehicle speed is below a threshold, set at 70 km/h. The mandatory lane-change model is applied if a driver is aware that the lane he is driving on does not lead to his destination, does not continue on the next link, or is not accessible for him. Generally, the free lane-change model is applied, unless a driver has to make a mandatory lane-change.

The longitudinal driver model describes the driver's actions with respect to longitudinal vehicle control. This model distinguishes free driving and car-following. Each time step, a desired acceleration is calculated for both situations. The most restricted one is used as the resulting desired acceleration and is

limited within the boundaries for comfortable acceleration and deceleration, set at +3 m/s^2 and -5 m/s^2 respectively. In the free driving situation, the driver attempts to reach or maintain his desired speed within certain boundaries. The desired speed indicates the speed that would be maintained in the absence of other traffic and is drawn from a normal distribution. The mean and standard deviation (SD) of the free driving speed have been determined from loop detector measurements [12]. For passenger car drivers the mean desired speed is set at 121 km/h (SD = 12 km/h) and for truck drivers at 86 km/h (SD = 6 km/h). The desired acceleration for free driving a_{ref_v} is based on the difference between the current speed v and the desired speed v_{ref}:

$$a_{ref\_v} = r \cdot \left(v_{ref} - v\right) \tag{1}$$

with r a constant relaxation factor, set at 0.4/s. In the car-following situation, the driver has to adjust his speed and/or following distance with respect to traffic ahead. The desired acceleration for car-following a_{ref_d} is a linear function of the difference between the current distance headway $d(t-t_r)$ and the desired distance headway d_{ref}, the speed difference between the current speed and the speed of the predecessor $v_{rel\_p}(t-t_r)$ and the speed difference between the current speed and the speed of the pre-predecessor $v_{rel\_pp}(t-t_r)$:

$$a_{ref\_d} = c_d \cdot \left(d\left(t-t_r\right) - d_{ref}\right) + c_{v\_p} \cdot v_{rel\_p}\left(t-t_r\right) + c_{v\_pp} \cdot v_{rel\_pp}\left(t-t_r\right) \tag{2}$$

with t_r the reaction time of the driver and c_d, c_{v_p} and c_{v_pp} constant factors, default set at 0.3, 1.5 and 0.2 respectively. Like the desired speed, the reaction time is drawn from a normal distribution. For car drivers a mean value of 0.3 s is used (SD = 0.05 s) and for truck drivers 1.0 s (SD = 0.3 s) [12]. Note that these values are exclusive of aspects like delays for moving the foot between the gas and brake pedals and perception thresholds, as these aspects are modeled separately. The desired distance headway d_{ref} is assumed to be a second order polynomial of the current speed v:

$$d_{ref} = c_1 + c_2 \cdot v + c_3 \cdot v^2 \tag{3}$$

with c_1, c_2 and c_3 constant factors, default set at 3, 0.25 and 0.02 respectively.

The vehicle model describes the dynamic behavior as a result of the interaction with the driver and the road, taking into account the ambient conditions. The input variables from the driver model are the positions of the gas and brake pedals. Together with these input variables, the vehicle model uses information about the characteristics of the vehicle, the road geometry, the condition of the road and the wind. The output of the model is an updated vehicle acceleration, which is used to calculate the new speed and position of the vehicle.

IMPLEMENTATION OF CONGESTION ASSISTANT

Both the Active pedal and the Stop & Go of the Congestion Assistant were implemented in the ITS Modeler as a new ITS model that describes the behavior of the system and the interaction between the driver and the system. The Active pedal slows down the driver when approaching a traffic jam at too high speed by providing a counterforce of the gas pedal. It is assumed that the driver will obey the Active pedal, so when this function is switched on, it controls the behavior of the vehicle. The Active pedal computes a desired acceleration a_{ac} that represents the necessary deceleration for safely approaching the traffic jam. It is calculated based on the distance to the tail of the traffic jam x, the current speed v and the speed of the last vehicle in the tail of the traffic jam v_j:

$$a_{ac} = \frac{v_j^2 - v^2}{2 \cdot x} \tag{4}$$

The desired acceleration by the Active pedal represents the deceleration needed to obtain the same speed as the last vehicle in the tail of the traffic jam. However, the Active pedal only helps with slowing down and thus gives a counterforce of the gas pedal if the desired acceleration is smaller than a threshold of -0.5 m/s^2. When the desired acceleration is larger than this threshold, it is assumed that the driver maintains an appropriate speed himself, so that no counterforce of the gas pedal is needed. Furthermore, the Active pedal is only working when the driver is less than a certain distance removed from the jam. In this research, two variants of the Active pedal were investigated: one operating from 1500 m before the jam and the other operating from 500 m before the jam. The desired acceleration by the Active pedal is bounded by -1 m/s^2 which resembles deceleration by releasing the gas pedal. The Active pedal becomes inactive when the tail of the traffic jam is reached or when the Stop & Go overrules the Active pedal. Besides the desired acceleration by the Active pedal, the ITS Modeler also calculates desired accelerations related to free driving and car-following. The vehicle model will use the most restrictive one.

The Stop & Go (see [13] for more detail) takes over the longitudinal driving task in the traffic jam. It is assumed that the driver cannot overrule the Stop & Go, so when this function is switched on, it controls the behavior of the vehicle. The Stop & Go is assumed to be autonomous with respect to its (de)activation. This means that it does not use vehicle-vehicle communication to turn on or off. Instead, the Stop & Go will be active based on the current speed. If the vehicle drives at a speed of at most 50 km/h for a period of at least 3 seconds, the Stop & Go will become active. It will become inactive if the vehicle drives again at a speed of 70 km/h or more for at least 3 seconds. In this research, two variants of the Stop & Go were investigated: one with a desired time gap t_{st} of 1.0 s and the other with 0.8 s. The Stop & Go tries to maintain the desired following distance d_{st} according to:

$$d_{st} = d_0 + t_{st} \cdot v \tag{5}$$

with v the current speed and d_0 the safety margin, set at 3 m. Next, the Stop & Go computes a desired acceleration that represents the necessary acceleration for safely driving in the traffic jam. It can be computed on the basis of the deviation from the intended speed or on the basis of the distance difference and speed difference between the own vehicle and the predecessor. The resulting desired acceleration is given by the most restrictive one and is limited between the maximum comfortable acceleration and deceleration, which are set at +3 m/s^2 and -5 m/s^2 respectively. The desired acceleration by the Stop & Go based on the speed deviation a_{st_v} is related to the difference between the current speed v and the intended speed of the Stop & Go v_{int}:

$$a_{st\_v} = r_{st} \cdot \left(v_{\text{int}} - v\right) \tag{6}$$

with r_{st} a constant relaxation factor, set at 0.4/s and v_{int} set at 22.2 m/s (~ 80 km/h). The desired acceleration by the Stop & Go based on the distance difference and speed difference with respect to the predecessor a_{st_d} is a linear function of the difference between the current distance headway d and the desired distance headway d_{st} and the speed difference between the current speed and the speed of the predecessor v_{rel_p}:

$$a_{st\_d} = k_a \cdot \left(k_d \cdot \left(d - d_{st}\right) + k_v \cdot v_{rel\_p}\right) \quad (7)$$

with k_a, k_d and k_v gain factors of the Stop & Go controller.

It is assumed that the Congestion Assistant knows about the state of the traffic flow by means of vehicle-vehicle communication. The system knows from each downstream vehicle whether it is located in a traffic jam or not. The Active pedal uses this information in its algorithm to slow down the driver if necessary. The frequency band for vehicle-vehicle communication will presumably be allocated in 2010, after which such cooperative applications can become reality [14]. In this simulation study all vehicles can communicate with each other. Accordingly, the ITS Modeler checks the current speed and location of each vehicle in the network. This is done for each traffic lane individually and for each time step of 0.1 s. The traffic state on a lane is said to be congested when more than 3 vehicles follow each other at a speed of at most 50 km/h for a period of at least 3 seconds. The last vehicle in the queue is used to determine the distance that a vehicle equipped with the Congestion Assistant is away from the traffic jam.

SIMULATION SET-UP

Different variants of the Congestion Assistant were investigated, since it was expected that variation in system design might result in different traffic flow impacts. Each variant of the Congestion Assistant consisted of either the Active pedal or the Stop & Go, or a combination of both functions (see Table 1).

TABLE 1 Variants of Congestion Assistant Consisting of Active Pedal and/or Stop & Go

Variant	Active pedal	Stop & Go	Notation
1.	Active from 1500 m before jam	-	1500 m
2.	Active from 500 m before jam	-	500 m
3.	-	Time gap of 1.0 s	1.0 s
4.	-	Time gap of 0.8 s	0.8 s
5.	Active from 1500 m before jam	Time gap of 1.0 s	1500 m & 1.0 s
6.	Active from 500 m before jam	Time gap of 0.8 s	500 m & 0.8 s

The magnitude of the traffic flow effects was expected to depend on the equipment rate of the Congestion Assistant in the vehicle fleet. Therefore, the impacts were studied at 10% and 50% equipment rate. The six variants of the Congestion Assistant were studied at the two equipment rates, resulting in twelve experimental scenarios. In each experimental scenario three user classes were distinguished: (a) passenger cars not equipped with the Congestion Assistant, (b) passenger cars equipped with the system and (c) trucks not equipped with the system. The reference situation is the situation in which no vehicles were equipped with the Congestion Assistant.

Being interested in the impacts of a Congestion Assistant, a highway segment with a lane drop was simulated to create congested traffic conditions. The road geometry of the Dutch A12 highway served as input for the simulated road, because loop detector data measured on this highway were used for the calibration of the reference situation (see below). The simulated road consisted of a 4-lane highway segment with a 120 km/h speed limit. The total length of the segment was about 6 km with a left lane drop from 4 to 3 lanes after about 4 km. Except for the start link and the end link, each link was 500 m and contained a loop detector in the middle. Two detectors were added at 700 m before and 1000 m after the lane drop to simulate the detectors on the A12 highway used for the calibration and validation process.

In total 13 scenarios were studied in the ITS Modeler. The simulation duration of each scenario was set at 2.5 hours. After about one hour, congestion set in upstream of the lane drop. The first and last 15 minutes of the simulation runs were not taken into account in the analyses. To simulate the randomness of traffic behavior, ten replications per scenario with different random seeds were applied. Besides the release of vehicles onto the network, the stochastic elements of the ITS Modeler (e.g. desired speed) are connected to these random seeds. The evaluation modules of the ITS Modeler were used to examine the traffic flow impacts of the Congestion Assistant. These modules provide a range of indicators for throughput and safety that can be retrieved per time interval (e.g. 1 minute) for cross-sections (i.e. detectors), links, routes and the whole network.

When using a microscopic traffic simulation tool such as the ITS Modeler, it is important to check the model against reality. This was done by calibrating and validating the reference situation (i.e. unsupported driving) using loop detector data measured during the afternoon peak on a segment of the Dutch A12 highway near the left lane drop at Woerden. The first test runs with the default parameter settings of the ITS Modeler showed that the model could be improved, because no satisfactory congestion occurred due to the lane drop. The calibration particularly focused on the car-following parameters of the ITS Modeler, since the lane-changing parameters were not found to significantly influence the results. First, the constant factors *c2* and *c3* in the equation of the desired distance headway (see Equation 3) were estimated. Therefore, 1-minute speeds and densities (approximated by the ratio of flow to speed) about 700 m upstream of the lane drop on the A12 were used. A distinction was made between the desired distance headway of cars and trucks. The data on the two middle lanes were used to estimate the factors for cars, while the data on the right lane was used for trucks. This calibration step resulted in the following equations for the desired distance headway:

$$d_{ref} = 3 + 0.8 \cdot v + 0.03 \cdot v^2 \text{ (car)} \quad (8)$$

$$d_{ref} = 3 + 1.0 \cdot v + 0.04 \cdot v^2 \text{ (truck)} \quad (9)$$

Compared to the default settings, the driver now tries to maintain a larger distance headway. This particularly agrees with congested traffic conditions in which drivers tend to keep much larger distance headways than in non-congested conditions [15]. As expected, test runs in the ITS Modeler with the new equations resulted in congestion upstream of the lane drop. However, this congestion dissipated much earlier than on the A12. Moreover, the traffic flow did not fully recover downstream of the lane drop according to the rather low observed speeds. Therefore, the calibration further concentrated on the constant factor for the distance deviation c_d in the equation that describes the desired acceleration for car-following (see Equation 2). A higher value of this factor would increase the upstream congestion build-up and the downstream recovery from this congestion, because it represents a more fierce reaction of drivers towards deviations from their desired distance headway. Based on test runs with several different values and by minimizing the mean squared error for speed and flow data, the most appropriate value of c_d appeared to be 0.5 instead of the default value 0.3. The traffic demand in the simulation runs was based on 5-minute flow data collected about 1200 m upstream of the lane drop on the A12. The vehicle fleet in the simulation runs consisted of 93% passenger cars and 7% trucks, similar to the percentages on the A12. The validation of the reference situation was based on the same type of data as the calibration, but then measured on another day. On both days, congestion set in after a while, the weather was good, there were no accidents, events or holidays and the detectors were available and working well. Figure 1 shows the calibration results by speed-time and speed-flow plots based on data from the A12 and the ITS Modeler. The figure of the validation results is very similar to this one.

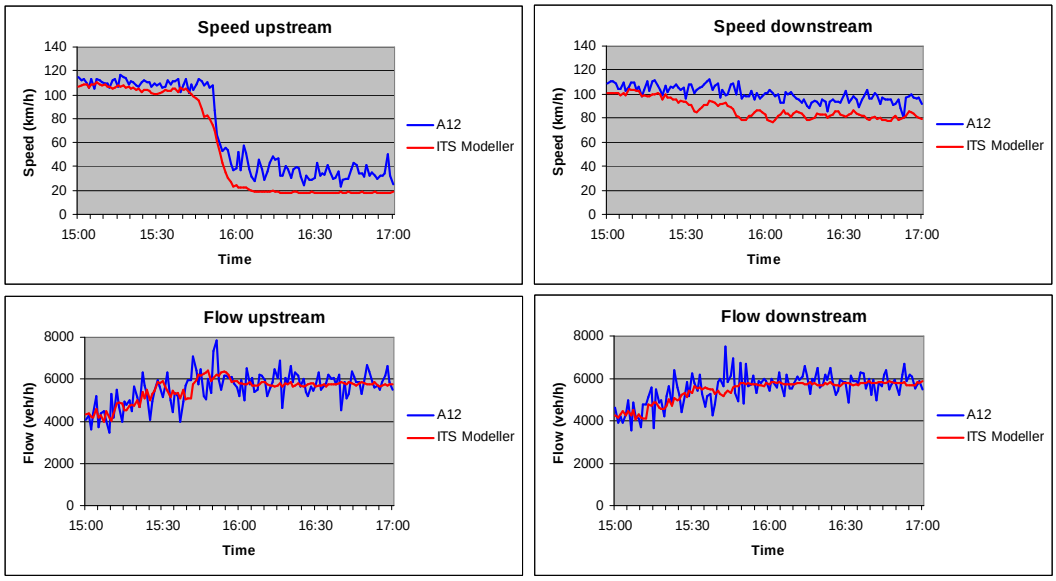
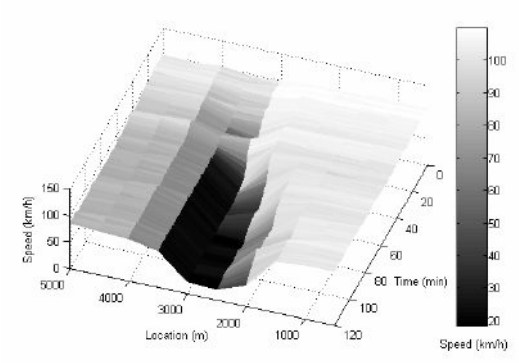


FIGURE 1 Speed-time and flow-time relations based on data from A12 and ITS Modeler.

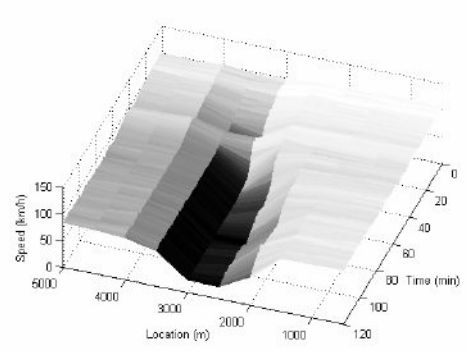
It can be seen that the speed and flow data from the ITS Modeler resemble those from the A12. In both situations, the congestion due to the lane drop sets in at a similar time (i.e. around 15:50 h) and in a similar way (i.e. 'sudden' speed drop). The flow recovers less after the lane drop in the simulation runs, reflected by lower downstream speeds compared to those observed on the A12. Both the empirical and modeled flows follow the same patterns in time, upstream as well as downstream of the lane drop. However, a difference is that the A12 data shows more variation than the ITS Modeler data. This is partly due to the underlying driving behavior models of the ITS Modeler and it is also caused by averaging the modeling results of 10 replications. It was concluded that the calibration of the ITS Modeler resulted in satisfactory outcomes with respect to the onset of congestion.

IMPACTS OF CONGESTION ASSISTANT ON TRAFFIC EFFICIENCY

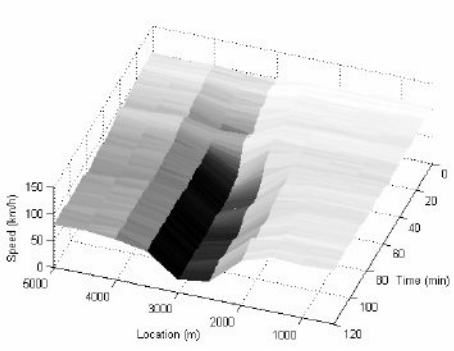
This section presents the impacts of the Congestion Assistant on traffic efficiency. The results are based on speed and travel time. The speed was measured at each detector of the network and aggregated into 1-minute intervals. For travel time an average was calculated by the ratio of total travel time to the number of vehicles arrived at the end of the simulation. Figure 2 shows the average speed as function of time and location to study the onset and course of congestion on the whole network. The plots concern the reference situation, the 'single' variants of the Congestion Assistant consisting of either an Active pedal working from 500 m before the jam or a Stop & Go with a time gap of 0.8 s and the 'combined' variant consisting of both functions. The plots of the other variants look similar to these ones. The lane drop from 4 to 3 lanes is situated around 3250 m.



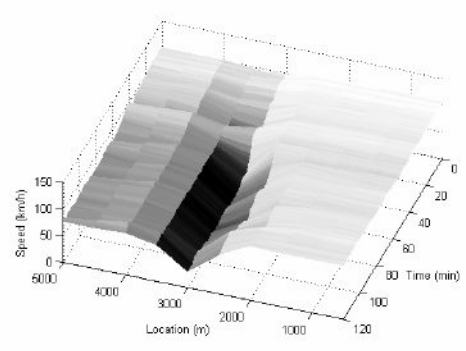
a) Reference



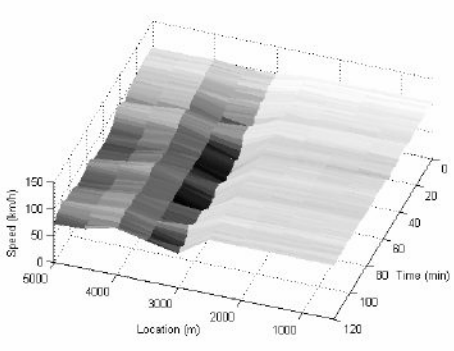
b) 500 m (10%)



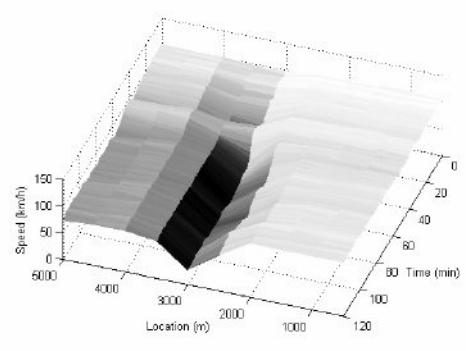
c) 500 m (50%)



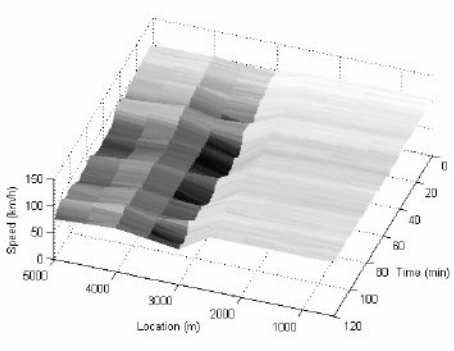
d) 0.8 s (10%)



e) 0.8 s (50%)



f) 500 m & 0.8 s (10%)



g) 500 m & 0.8 s (50%)

FIGURE 2 Speed in time and location: reference versus two single and one combined variants of the Congestion Assistant (10% and 50%).

It can be seen that the onset of congestion started at a similar time and location in all scenarios. However, the Congestion Assistant resulted in less congestion compared to the reference situation. The Active pedal caused a reduction in the amount of congestion by interfering in approaching a jam, this way reducing the congestion inflow. However, a much bigger reduction in the amount of congestion was obtained by the Stop & Go. This function interfered in driving in a jam and showed a more efficient car-following behavior, although combined with lower downstream speeds. Thus, both functions had positive effects on the dissipation of jams, but the effects due to the Stop & Go were much larger. Generally, the higher the equipment rate of the Congestion Assistant, the larger were the positive effects on traffic efficiency. The combined variants of the Congestion Assistant did not necessarily lead to better results than the single variants. In fact, the results of the combined variants were very similar to those of the Stop & Go variants. This means that the Active pedal has no added value with respect to traffic efficiency when it is combined with the Stop & Go.

The results on travel time show that the Congestion Assistant can significantly decrease the average travel time of a driver. For example, a 10% equipment rate of the system (variant 6, see Table 1) leads to an average travel time of 5.0 min and a 50% equipment rate to 4.3 min, whereas the average travel time in the reference situation is 5.7 min. Assuming an average travel time of 3.4 min in free flow conditions (i.e. speed is 110 km/h), the congestion due to the lane drop results in 2.3 min delay in the reference situation. When 10% of the vehicles are equipped with the Congestion Assistant, this can decrease the average delay with 30%. A decrease of up to 60% can be reached when 50% of the vehicles are equipped.

IMPACTS OF CONGESTION ASSISTANT ON TRAFFIC SAFETY

This section presents the impacts of the Congestion Assistant on traffic safety. The results are based on the percentage of hard braking and the percentage of small Time-To-Collision (TTC) values. The percentage of hard braking consisted of the percentage of vehicles that had a deceleration smaller than -3.5 m/s^2. Hard braking indicates disturbances in the traffic flow that might negatively affect traffic safety. The TTC is the time required for two vehicles to collide if they continue at their present speed and on the same path. The percentage of small TTCs was expressed by the percentage of vehicles that had a TTC value smaller than 4 s. These small values generally refer to a higher accident risk. Both indicators were based on the individual measurements on the whole network (collected at 0.1 s) and aggregated to a network value. Figure 3 shows the percentage of hard braking in all scenarios.

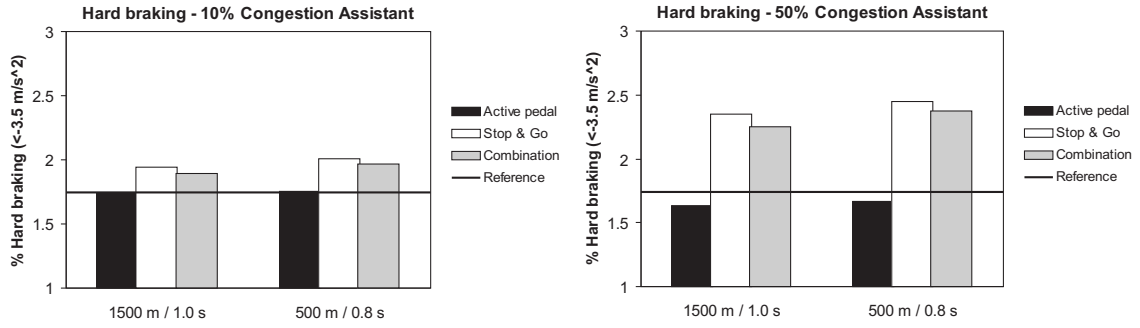


FIGURE 3 Percentage hard braking (<-3.5 m/s^2) on whole network: reference versus single and combined variants of the Congestion Assistant (10% and 50%).

It can be seen that the variants of the Congestion Assistant including a Stop & Go led to more hard braking actions compared to the reference situation and the Active pedal variants, although all percentages can be considered relatively low. In these scenarios, the percentages of hard braking with 10% equipment rate were lower than the ones with 50% equipment rate. Presumably, the Stop & Go causes the hard braking actions as a result of its small time gap in combination with the merging process.

It is expected that merging vehicles use smaller gaps (created by the Stop & Go vehicles) than desired, so that they will brake after the cut-in maneuver to increase their headway again. Adding an Active pedal to the Stop & Go decreased the percentage of hard braking, particularly at a 50% equipment rate. However, it did not lead to larger positive effects compared to a Congestion Assistant consisting of only an Active pedal. The Active pedal variants resulted in a similar level of hard braking as the reference situation, except when 50% of the vehicles were equipped with the function, regardless of its setting. These scenarios led to the lowest percentages of hard braking.

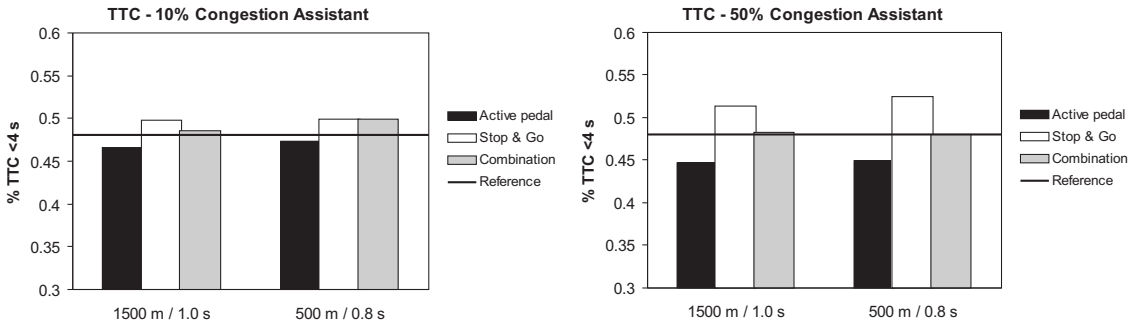


FIGURE 4 Percentage TTC <4 s on whole network: reference versus single and combined variants of the Congestion Assistant (10% and 50%).

Figure 4 shows the percentage of small TTCs in all scenarios. The variants of the Congestion Assistant including a Stop & Go led to higher percentages of small TTCs compared to the reference situation and the Active pedal variants. Adding an Active pedal to the Stop & Go decreased the percentage of TTC <4 s, particularly at a 50% equipment rate. However, it did not lead to larger positive effects compared to a Congestion Assistant consisting of only an Active pedal. The Active pedal variants resulted in significantly less unsafe following situations than the reference situation, especially when 50% of the vehicles were equipped with the function, regardless of its setting.

DISCUSSION

It was expected that the Congestion Assistant would lead to positive effects on traffic efficiency due to smooth behavior when approaching a jam by the Active pedal and efficient car-following behavior when driving in and leaving a jam by the Stop & Go. This statement could be confirmed, because both functions were found to reduce the amount of congestion compared to the reference situation. However, the effects of the Stop & Go were much larger than those of the Active pedal. This finding corresponds to the literature stating that particularly ACC systems, such as the Stop & Go, can outperform manual traffic and compensate for unfavorable human behavior [7, 16]. Combining the Active pedal and the Stop & Go did not lead to larger positive effects on traffic efficiency compared to the Stop & Go alone, which was in contrast to our expectations. The two variants of the Active pedal (i.e. working from 1500 m respectively 500 m before the jam) hardly showed any differences. However, the Stop & Go with a time gap of 0.8 s resulted in somewhat less congestion than the variant with a time gap of 1.0 s. This effect of time gap on traffic efficiency is in accordance with what is already known from earlier findings [3, 5]. The more vehicles equipped with the Congestion Assistant, the larger were the impacts on the dissipation of congestion. The travel time results confirmed the above results: the Congestion Assistant showed to significantly decrease the average travel time and delay.

It was also expected that the Active pedal and the Stop & Go would lead to positive effects on traffic safety due to a more stable and homogeneous flow. Generally, this statement can be confirmed, because both functions resulted in less congestion, particularly the Stop & Go. For the Active pedal, this statement can also be confirmed based on the hard braking data and the TTC data, which indicated safer approaching behavior towards the jam compared to unsupported driving. However, this is not true for the

Stop & Go. This function increased the amount of hard braking and the occurrence of small TTCs. This latter finding is not consistent with earlier research by TRG [17], which showed a decreased number of small TTCs due to a Stop & Go. However, it should be noted that small TTCs during automatic driving are less dangerous than small TTCs during manual driving, since the automatic system (e.g. the Stop & Go) can outperform the human driver, for example with respect to the reaction time. Adding the Active pedal to the Stop & Go decreased the percentages of hard braking and small TTCs, but it did not lead to larger positive effects on these percentages compared to the Active pedal alone.

This study showed that especially the Stop & Go positively influenced traffic efficiency. It would be interesting to further investigate the influence of other characteristics than the time gap on the results. For example, our Stop & Go supported the driver without deceleration and acceleration limitations. However, for the moment, it is expected that such systems will be restricted to a certain acceleration range (e.g. between -3 m/s^2 and +1.5 m/s^2), so that sometimes the driver needs to intervene. Another acceleration algorithm might also lead to safer braking and following behavior during the merging process, especially when this algorithm includes a "cooperative merging" application so that vehicles are able to communicate their lane change movements. Compared to the Stop & Go, the Active pedal showed smaller positive effects on traffic efficiency, although these variants increased traffic safety due to a smoother approach to the traffic jam. One reason for the small throughput effects might be the deceleration capacity of the Active pedal, which was restricted to -1 m/s^2. Further research could focus on versions with a less conservative deceleration capacity (and acting like an Active brake pedal rather than an Active gas pedal) which are expected to enhance traffic efficiency more.

The simulation environment ITS Modeler was used to assess the traffic flow impacts of the Congestion Assistant. As with any model, its value largely depends on the resemblance with the real-world. The calibration process resulted in a satisfactory resemblance between the empirical and the simulated traffic flow data, particularly with respect to the onset of congestion. Nonetheless, further model calibrations and adaptations are desired to improve the simulation outcomes in congested traffic conditions, for example by distinguishing different driving behavior in congested and non-congested situations.

CONCLUSION AND OUTLOOK

This paper presented the results from a microscopic traffic simulation study that was conducted to assess the impacts of a Congestion Assistant on the traffic flow in terms of traffic efficiency and traffic safety. These results are based on six variants of the system, consisting of an Active pedal and/or a Stop & Go, that were studied at two equipment rates and compared to the reference situation in which no vehicles were equipped with the system. The simulated road consisted of a 4-lane motorway segment with a left lane drop that caused congestion. The reference situation was calibrated and validated with data measured on the Dutch A12 motorway and showed a satisfactory resemblance with respect to the congestion build-up.

All variants of the Congestion Assistant resulted in less congestion in comparison with the reference situation. The system showed to compensate for the unfavorable human behavior that (also) causes congestion. The Active pedal smoothed the traffic flow when approaching a traffic jam by inducing better anticipation behavior of the driver compared to unsupported drivers. This had a small effect on the dissipation of congestion, rather it affected traffic safety by a safer approach to the jam. Vehicles equipped with the Stop & Go followed other vehicles more efficiently than non-equipped vehicles when driving in and leaving a jam by adapting smaller headways and eliminating the reaction time of drivers. This reduced the amount of congestion and significantly decreased the average travel time and delay.

The promising results above give rise to speeding up the further development of the Congestion Assistant. Current research and development efforts are mostly focused on cooperative systems that are able to communicate with each other and the infrastructure. These systems can, for example, provide detailed information about the traffic conditions ahead. The Active pedal of the Congestion Assistant is also assumed to have knowledge of what is happening further down the road. Such applications will

probably become available after 2010, when the frequency band for vehicle-vehicle communication is expected to be allocated [14]. Until then, the efforts should also be focused on promising autonomous applications, such as the Stop & Go of the Congestion Assistant. It is important to realize that the Stop & Go had significant impacts on the dissipation of traffic jams. In view of the severe congestion problems in many countries, it is recommended that in the short run a system will be developed and implemented that serves all interests best.

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REFERENCES

[1] European Commission. *Communication on the Intelligent Car Initiative "Raising awareness of ICT for smarter, safer and cleaner vehicles"*, COM(2006) 59 final, Brussels, Belgium, 2006.

[2] Treiber, M., A. Kesting and D. Helbing. Understanding widely scattered traffic flows, the capacity drop, platoons, and times-to-collision as effects of variance-driven time gaps, *Physical Review E*, Vol. 74, no. 016123, 2006.

[3] Minderhoud, M.M. *Supported driving: Impacts on motorway traffic flow*, PhD thesis, Delft University of Technology, Delft, The Netherlands, 1999.

[4] Wang, J. and R. Rajamani. The impact of adaptive cruise control systems on highway safety and traffic flow, *Journal of Automobile Engineering, Proceedings of the Institution of Mechanical Engineers, Part D*, Vol. 218, pp. 111-130, 2004.

[5] Benz, T., F. Christen, G. Lerner and D. Vollmer. Traffic effects of Driver Assistance Systems: The approach within INVENT, in: *Proceedings of the 10th World Congress on ITS*, Madrid, Spain, 2003.

[6] Van Arem, B., C.M.J. Tampère and K.M. Malone. Modelling traffic flows with intelligent cars and intelligent roads, in: *Proceedings of the IEEE Intelligent Vehicles (IV) Symposium*, Columbus, Ohio, pp. 456-461, 2003.

[7] Kesting, A., M. Treiber, M. Schönhof and D. Helbing. Extending adaptive cruise control (ACC) towards adaptive driving strategies, in: *Proceedings of the 86th TRB Annual Meeting*, Transportation Research Board, Washington, DC, 2007.

[8] Van Driel, C.J.G., M. Hoedemaeker and B. van Arem. Impacts of a Congestion Assistant on driving behaviour and acceptance using a driving simulator, *Transportation Research Part F*, Vol. 10, no. 2, pp. 139-152, 2007.

[9] Versteegt, E. and B. van Arem. Modelling cooperative roadside and in-vehicle intelligent transport systems using the ITS Modeller, in: *Proceedings of the 12th World Congress on ITS*, San Francisco, California, 2005.

[10] Versteegt, E., G. Klunder and B. van Arem. *ITS Modeller – IRVIN WP 1.1*, Report 2005-16, TNO Mobility and Logistics, Delft, The Netherlands, 2005.

[11] Quadstone. *Paramics Modeller V5.1.0 User Guide*, Quadstone Limited, Edinburgh, United Kingdom, 2005.

[12] Van Arem, B., A.P. de Vos and M.J.W.A. Vanderschuren. *The microscopic traffic simulation model MIXIC 1.3*, Report Inro-VVG 1997-02b, TNO Inro, Delft, The Netherlands, 1997.

[13] Van Arem, B. et al., Design and evaluation of an Integrated Full-Range Speed Assistant, TNO Report 2007-D-R0280/B, Delft, the Netherlands

[14] C2CCC: *Car 2 Car Communication Consortium*, http://www.car-to-car.org, consulted: May 2007.

[15] Dijker, T., P.H.L. Bovy and R.G.M.M. Vermijs. Car-following under non-congested and congested conditions, *Transportation Research Record 1644*, pp. 20-28, 1998.

[16] Zwaneveld, P.J. and B. van Arem. *Traffic effects of Automated Vehicle Guidance: A literature survey*, Report Inro-VVG 1997-17, TNO Inro, Delft, The Netherlands, 1997.

[17] TRG. STARDUST: Evaluation of scenarios to deployment of ADAS/AVG systems in urban contexts, Deliverable 10, Transportation Research Group, University of Southampton, Southampton, United Kingdom, 2004.