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Evaluation Results of the Amsterdam, Netherlands, Practical Trial with In-Car Travel and Route Advice

Isabel Wilmink, Eline Jonkers, Maaike Snelder, and Gerdien Klunder

Travel and route guidance services are widely available. Social navigation services that provide travelers with advice aimed at minimizing driver travel time, while also taking into account the effect on travel times of other travelers, are relatively new. Theoretically, social navigation has been shown to reduce total travel time by 10% to 30%. This paper presents the evaluation results of a large-scale field trial for pretrip and on-trip route advice with load balancing, in which about 20,000 participants were active. The evaluation provided insight into the potential effects of in-car information services, such as effects on user behavior, traffic flow effects, and technical aspects. Participants used mostly the pretrip advisories. Compliance with the on-trip route advice was 50%, which was considered high (compared with compliance with route advice on variable message signs). An effect on traffic flow could not be measured, as penetration rates were (despite thousands of users) still too low. An offline study using measured travel times combined with a traffic model, however, showed that substantial delay reductions can be achieved for the Amsterdam, Netherlands, region. Participants' appreciation of the service resulted in a mixed picture with positive and negative ratings. The main practical contribution of this paper is that the results can be used to develop social navigation services. Empirical insights about route advice compliance can be seen as the main scientific contribution.

Travel and route guidance services are widely available. Generally, they try to minimize individual travel times without considering the effect on the travel times of others. This type of guidance results in a user optimum. Various researchers have shown that route guidance toward a system optimum can reduce the total travel time of all users by 10% to 30% (*1*–*5*). System optimal route guidance is related to the concept of social navigation and provides the traveler with advice aimed at minimizing driver travel time, while also taking into account the effect on other travelers' travel times (*6*). Traditionally, there are two ways of influencing drivers' compliance level: either by charging drivers for the marginal cost they cause society or by rewarding them for the marginal benefit they bring to society.

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The concept of social navigation was first introduced by van den Bosch et al. (*7*). As shown above, the effect on total travel time can be high in theory. However, it might be difficult to achieve that effect in practice because the effect also depends on the penetration rate, the level of altruism, and the compliance rate. The first empirical study of the effect of social navigation was done by Djavadian et al. (*6*). They developed a social navigation app that they used in a pilot multiuser laboratory experiment in which 25 participants were asked to make route choices in a virtual travel environment under various information and incentive scenarios. The results indicate that drivers are willing to navigate socially (when the travel time on the social route is not significantly higher than the travel time on their current route), but that compliance with the route advice depends on the driver's level of altruism and willingness to change the route, which varies with the drivers' familiarity with the current route, uncertainty associated with the social route, bounded rationality, gender, driving experience, and other factors. Drivers are more willing to comply with the social advice when they are well informed and well rewarded. Drivers familiar with the network tended to use their normal route and indicated that they would change routes only if their current route was heavily congested.

As far as the authors know, there are few (on-trip) social navigation services available on the market. There is also not much information in the literature on the effects in practice of travel and route guidance apps, especially in instances in which compliance is concerned. Arentze et al. reported the results of a field test conducted to test a new navigation system for trucks that takes into account which roads trucks can drive on comfortably and safely and also considers negative externalities, such as instances in which a route runs through a built-up area (*8*). A sample of 100 truck drivers participated in the experiment. They used the new system first in a tracking mode only and, then, in full navigation mode. Diary data and GPS data logged by the system were analyzed to evaluate whether users drove the route recommended by the navigation system; their original intent was unknown. Results indicate that the navigation system changed the route choice, showing a shift of routes from smaller roads to higher-level roads, with benefits for traffic efficiency (travel distance and travel time) and the environment. Drivers did deviate from the proposed route relatively frequently (on average 2.55 times a day), stating travel time on the chosen route and the accessibility of the route as the main reasons.

In the Amsterdam, Netherlands, Practical Trial, the first (as far as the authors know) navigation app was developed that is available on the market and that contains elements of social navigation (*9*). This paper aims to present a selection of the evaluation results of this app with respect to app usage, compliance, participants' feedback, and

effect on traffic flow and travel times. It is likely that social navigation will be deployed internationally in the coming years and decades at many other locations in the world. The main contribution of this paper is a practical one; the results presented in this paper can be used in the development of future social navigation services. The empirical insights with respect to route advice compliance can be seen as the main scientific contribution.

The next section of this paper presents a description of the Amsterdam Practical Trial and the two apps that were developed in the trial. The evaluation approach is then briefly described, followed by a discussion of the effects found in the trial. Conclusions and recommendations complete the paper.

AMSTERDAM PRACTICAL TRIAL SERVICE

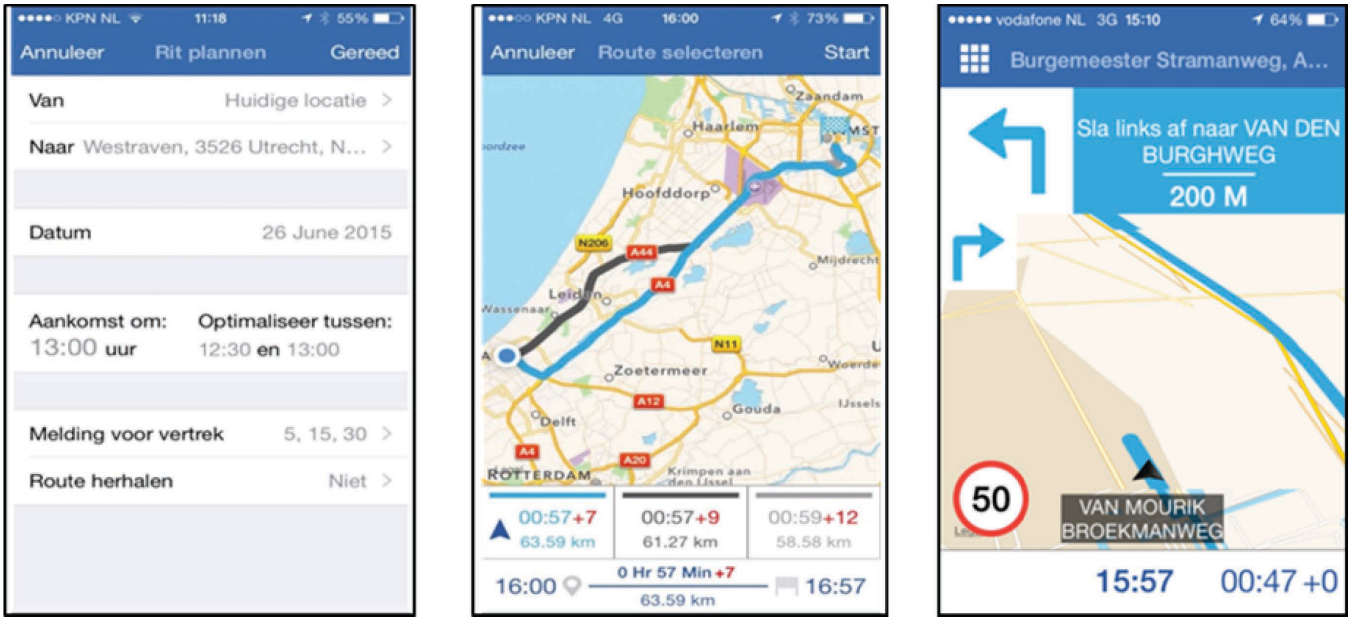
The Amsterdam Practical Trial is a large-scale field operational test in which innovative technologies are applied with the aim of reducing the amount of congestion in the Amsterdam area. In Phase 1 of the trial, roadside systems and in-car systems were tested separately. This paper concerns the in-car trial in Phase 1, in which an in-vehicle service giving travel and route advice was developed and tested by two consortia. The authors' consortium, Amsterdam onderweg, developed two smartphone apps for this trial: Superroute for everyday traffic and Super P-route for event traffic. The trial period lasted a full year (2015).

The main goal of the trial was to investigate how effective in-car information services are in reducing delays and improving travel time reliability. Another goal was to learn as much as possible from the field trials, especially about the collaboration between government and industry partners in the trial and the behavior of the service users. This paper focuses on the first goal.

The Superroute app (for everyday traffic) and Super P-route app (for event traffic) bring dynamic and personalized traffic information into the vehicle. First, they give pretrip advice about the best departure time and route. Multiple route options based on the personal preferences of the user are presented. Users are classified into four types. The user types have different route choice preferences, which implies that criteria, such as total estimated travel time, travel time on motorways, route length, level of congestion, and level of adherence to previously given route advisories, are weighted differently. During a trip the so-called smart routing algorithm continuously monitors whether a better route based on the most recent traffic data is available. When that is the case, the app again offers multiple routes from which to choose; this is the dynamic (on-trip) part of the app. A limited form of social navigation (distributing vehicles over the network, moving from user to system optimum) takes place by not guiding all users via the same fastest route. For each route, the amount of spare capacity and advisories given to other users are considered. As a consequence, travelers are not always guided to the fastest routes if the capacity of that route is anticipated to be reached given the earlier route advisories provided to others. Small amounts of extra travel time, up to 3 min, are accepted. This approach is possible because of the differences in preferences; some users prefer a reliable or comfortable route over the fastest route. The route advisories use so-called via points, which indicate route choice locations. There is generally only one logical road or series of roads to take between two via points, at least for through traffic. These via points play an important role in determining whether a user was compliant with the route advice or not, as will be shown later. More information about the smart routing algorithm can be found in Wilmink et al. (*10*).

An extra functionality of the Super P-route app (compared with the Superroute app) is parking advice, the possibility of booking a parking space in advance, and advice on the walking route from the parking place to the event (and back). At the end of the trial, the Super P-route app functionalities were added to the Superroute app, so that there was one app—integrating all functionalities—that people could use (multimodal travel advice was also added then).

Figure 1 shows some screenshots of the Superroute app interface (the Super P-route app is very similar). The screen on the left



(a) (b) (c)

FIGURE 1 Screenshots of Superroute app.

shows how a trip can be planned. The user can fill in the origin and destination addresses and the date and time the trip is expected to take place. The user can indicate whether the departure or arrival time is flexible and whether an alert is desired. The screen in the middle shows how the user is presented with up to three routes to choose from at the start of the trip. The user can select the preferred route and start the (turn-by-turn) navigation (screen on the right). Every 3 min, or whenever a user deviates from the route, new route advice is generated. Special attention has been paid to incorporating the users' preferences. The design of the interface was updated according to feedback from users, and there were incentives for the users such as a free smartphone holder and a loyalty program. These additions should make the app attractive for drivers.

The Superroute app and Super P-route app work on smartphones and tablets with operating systems iOS and Android, using a 3G (or 4G) connection and a network location fix. The technical solution of Amsterdam onderweg combines existing systems and has interfaces with several sources of data, such as loop detector data from the National Data Warehouse for Traffic Information, Bluetooth sensors and number plate recognition cameras, trial participants' floating car data, weather information, and parking information. In addition, there are interfaces with traffic control centers. A more detailed description of the data used can be found in Calvert et al. (*11*).

EVALUATION APPROACH

This section presents a brief description of the evaluation approach with respect to the method, use of data, computation of compliance, trial area, setup, and participants. A more detailed description can be found in the evaluation plans in Wilmink et al. (*12, 13*).

Method

In the evaluation of the Superroute app and Super P-route app, a number of steps can be distinguished. To be able to observe an effect on traffic flow, many trial participants are needed as well as enough circumstances—with delays—in which the apps have added value. Participants have to use the app on a regular basis and comply with the advice. When app usage is high, an analysis can be done on whether the effects on traffic (travel times and delays) can be observed and what the effects are for individual users. For all aspects mentioned above, research questions and hypotheses have been formulated. This paper focuses on the results on usage, compliance, and other behavioral aspects. It does not discuss costs, benefits, and scaling up.

Evaluating a service that provides departure time and route advice to a large number of participants during a long period of time and for which a large amount of data is logged has a number of challenges. The following are the most important:

- Participants' intentions cannot be measured (e.g., what route or departure time do they normally choose? or why do they or don't they follow the advice?).
- Whether the advice fits with the participants' trip (maybe participants have to pick up someone else along the route) is not known.
- It is very difficult to relate the traffic flow as measured with infrastructure-based sensors to the use of the app and compliance with the advisories.

The first and second challenges were partly covered by questionnaires.

Data

For the evaluation of this field trial, data from several data sources were combined:

- Data from the app (such as GPS data),
- Data from the National Data Warehouse for Traffic Information,
- Survey data (at the start of the trial, halfway through, and at the end of the trial),
- Interviews with road authorities involved, and
- Various websites and publications for data on situational variables. The situational variables used were incidents, events, weather circumstances, road work, other trials, calamities, time of day, and other special circumstances having a large effect.

The data communicated between the app and back office (route requests from app to back office and route advice from back office to app) produced the largest amount of information about the use of the app and compliance with advisories—very valuable data for the evaluation.

Determining Compliance with Route Advice

The challenges in determining compliance with route advice and how compliance was ultimately determined are explained in detail in Djukic et al. (*14*). In summary, compliance can be determined only on trips for which the navigation function is used. For about 88% of all trips, however, only pretrip functionalities were used. If the navigation function was used, the way the participants interacted with the app (e.g., not ending a trip when arriving at the destination, not entering a precise destination, and ending a trip before arriving at the destination) sometimes caused problems in interpreting the logged data. To overcome the various data problems, different filtering, enriching, cleaning, correcting, and postprocessing steps were applied to the app data.

Compliance with route advisories was measured on the basis of the route via points. All major decision points in the network (points from which multiple routes can be chosen) were marked as via points. The navigation function of the service translated a set of via points that were generated by smart routing into turn-by-turn navigation advice. When there were no deviations from the route, the trip was classified as fully compliant. When the participant deviated from the route, but that action did not result in a change in the set of via points, the trip was classified as substantially compliant. When a new set of via points was generated, the trip was classified as noncompliant.

Trial Area

The trial area consisted of the city and suburbs of Amsterdam and Schiphol airport. The analyses cover trips in the trial area and trips to or from the event locations (Arenapoort and RAI areas). The area

is large enough to enable analysis of the effects of departure time advice and route advice. There are enough alternative routes available for participants traveling to or from Amsterdam or crossing the area while on their way to a destination outside the trial area. Large incidents and road work just outside the trial area that could have a large influence on traffic in the trial area were taken into account as a confounding variable.

Trial Setup

For everyday traffic, evaluation of the service covered the period from January 15 through October 15, 2015. The evaluation of the service for event traffic was carried out for a number of specific events in 2015: one fair in the RAI convention center, eight concerts in the Arenapoort area, and the SAIL Amsterdam 2015 event (a nautical event with 2.3 million visitors in 5 days, all over the city).

Trial Participants

All who were willing to participate in the trial could register and download the apps from the App store or Google Play store and thereby agreed to share their data. Specific recruitment actions were undertaken. Participants in the trial for everyday traffic were recruited from those users who regularly use the roads in the trial area. Participants in the trial for event traffic were recruited via the events (e.g., direct mailing to people who bought a ticket and promotion on the event websites). Ultimately, more than 28,000 people registered on the website for the trial with the Superroute app. Of this group, 21,428 installed the Superroute app on their phones, and at least one trip was registered from 19,865 participants. Fifteen percent of the participants used the app at least once a week, and almost 30% used the app at least once every 2 weeks. The other 55% used the app sporadically.

RESULTS

This section presents the evaluation results with respect to app usage, compliance, participant feedback, effect on travel behavior, and effect on traffic flow.

App Usage

Almost 20,000 people used the Superroute app at least once; they are considered the participants. Many participants used the Superroute app to plan trips (pretrip) and to receive departure time advice and route advice. The app was used to navigate and receive updated route advice during a trip for only a small part of the trips. For about 60% of trips for which navigation was used, almost 16,000 trips, it was possible to determine the compliance level. Figure 2 shows the number of evaluated trips over time. At the start of the trial, the number of evaluated trips was the highest. In May (a holiday period in the Netherlands), the number of trips was lower, but in June it increased. During the summer holidays (July and August), the app was used less, but after the holidays it increased again, in August partly because of the use of the app for SAIL Amsterdam. In the months afterward, the use of the app increased further. A few hundred participants used the app almost the entire trial period.

For events, the participants used the Super P-route app. The number of trips for which compliance could be evaluated varied considerably over the events. During SAIL, 11,000 trips were made in a 5-day period. For the other events, the number of trips made with the app varied between 100 and 1,400, with an average of more than 700. For events later in the trial period, the app was used more than for events in the beginning of the trial period.

The service has been running with high stability and reliability for a long period. However, the smartphone app experienced some problems. The app sometimes crashed (mainly on Android devices), and the positioning based on the smartphone's GPS was sometimes difficult in relation to latency, frequency, and completeness. This aspect had consequences for the evaluation. Data for many of the trips were missing or difficult to interpret. Much effort was needed to process the data, and a fairly large share of the trips could not be included in the evaluation.

During the trial the apps were improved and new functionalities were added. Before the SAIL event extra promotional activities were carried out, and at the end of the trial several loyalty concepts were tested, giving participants small rewards when they used the app in the right way.

Participants were also consulted about use of the app. Twenty-three percent of respondents indicated that they used the app most of the time: as much as possible, and more than 30% of respondents indicated

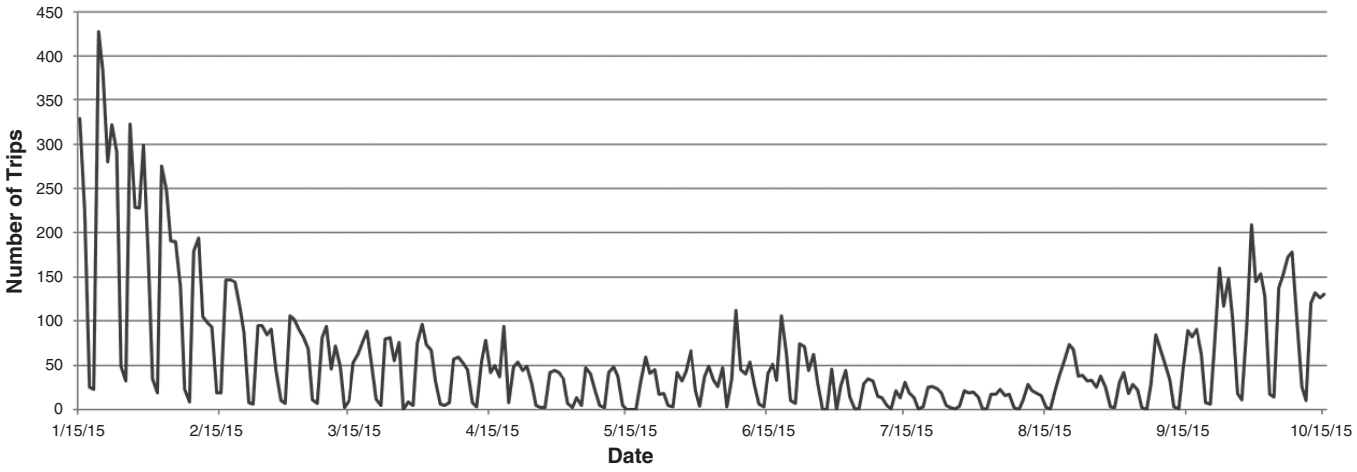


FIGURE 2 Number of evaluated trips per day for entire evaluation period.

that they used the app in special cases (incidents and bad weather). Many participants (25%) used the app specifically for events.

Compliance

Figure 3*a* shows compliance with the route advice over all evaluated trips in the trial, according to logged data. In about half of the trips, participants followed the route advice. In about one-fifth of the trips, participants were fully compliant. The results for events (not in the figure) are comparable: in 22% of the trips there was full compliance, in 25% there was substantial compliance, and in 53% of the trips there was noncompliance. Compliance varied slightly over time and was higher at the end than at the start of the trial. A reason for this finding could be that the app was improved during the trial and functionalities were added.

In the questionnaires, participants (in this case frequent users that used the app on more than 10 days) were asked how often they complied with the advice of the Superroute app (Figure 3*b*). To the question, "Do you mostly comply with the advice of the Superroute app?" most participants answered that they usually complied with the advice, although the majority of those reported that they complied partly. As participants used the app more often, they said they (partly) complied with the advice more often. For the Super P-route app, the results were much better: 61% of participants said they complied with the advice, 26% said they partly complied, and 13% said they did not. The reason for this finding could be that these participants used the Super P-route app for a very specific trip, to a specific area, at a specific time.

Participants were also asked whether it was possible for them to follow the advice. Almost 50% of frequent users said it was always possible to follow the advice. When participants answered that it was not always possible, reasons mentioned were incidents, road work, personal reasons (e.g., picking someone up), and difficulty using the app.

It is difficult to compare the subjective and objective data on compliance since the questionnaire did not distinguish between pretrip and on-trip advice, and departure time advice and route advice. In addition, what participants meant by "partly" is not unambiguous. But the results seem more or less in line with one another (fewer than one-half the participants indicated that they did not comply with the advice) and do not contradict each other.

A relationship between special circumstances (e.g., incidents and bad weather) and compliance with the advisories could not be found in the measured data. Thirty percent of respondents to the questionnaires did make that link, indicating that they used the app specifically in the case of events or bad weather.

Participant Feedback

Participants were asked to provide feedback on their experiences with using the app. In analyzing the answers for the Superroute app (everyday traffic), a distinction was made between frequent users of the app (use of the app on more than 10 days) and infrequent users. The analysis below takes only frequent users into account. See Figure 4 for an overview of the results. There were positive as well as negative ratings. Some aspects of the service were difficult for participants to rate, considering the high share of "I don't know" answers. When these answers were omitted, more participants usually gave a positive rather than a negative rating.

The feedback from participants on the Super P-route app (event traffic) was more positive. Considering the questionnaires filled in after the events (excluding SAIL, because there the app was integrated with the Superroute app), more than one-half of participants (56%) were satisfied with the app; one-third were not (this was the other way round for the Superroute app). Of the participants, 64% rated the information the app offered as useful and 18% as not useful. Fifty-eight percent found the information that the app offered to be clear, and 60% indicated they would use the app for other events as well.

Travel Behavior

In the questionnaires, participants were asked whether they changed their behavior because of the Superroute app (see Figure 5). Users said they usually did not choose a departure time different from what they had originally planned; only 14% indicated that they chose a different departure time for most or all of their trips. An important point to make is that a change in departure time for a relatively small share of traffic on a road section can have positive effects on traffic flow.

A large minority of participants (41%) said that they usually took a route that was different from their original plan because of the advice

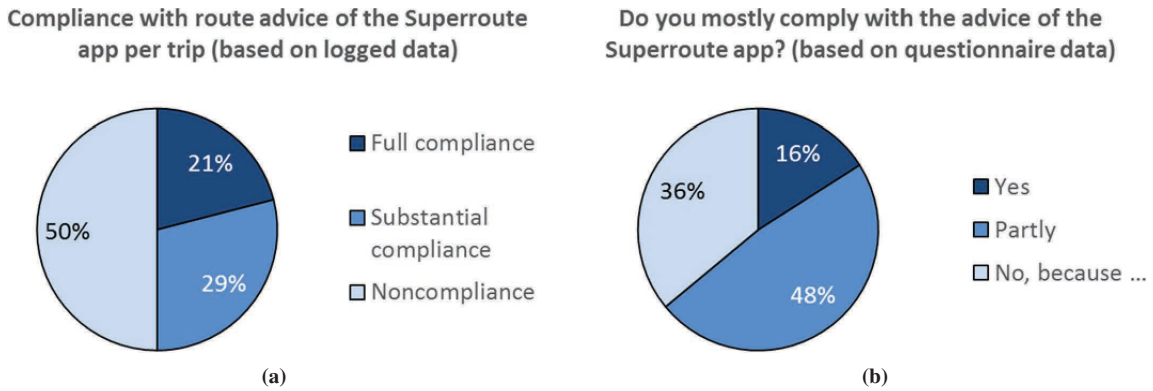


FIGURE 3 Compliance with (*a*) route advice of Superroute app (determined per trip), according to logged data (n = 15,577 trips) and (*b*) advisories as assessed by frequent users (more than 10 days), according to questionnaire data (n = 745 respondents).

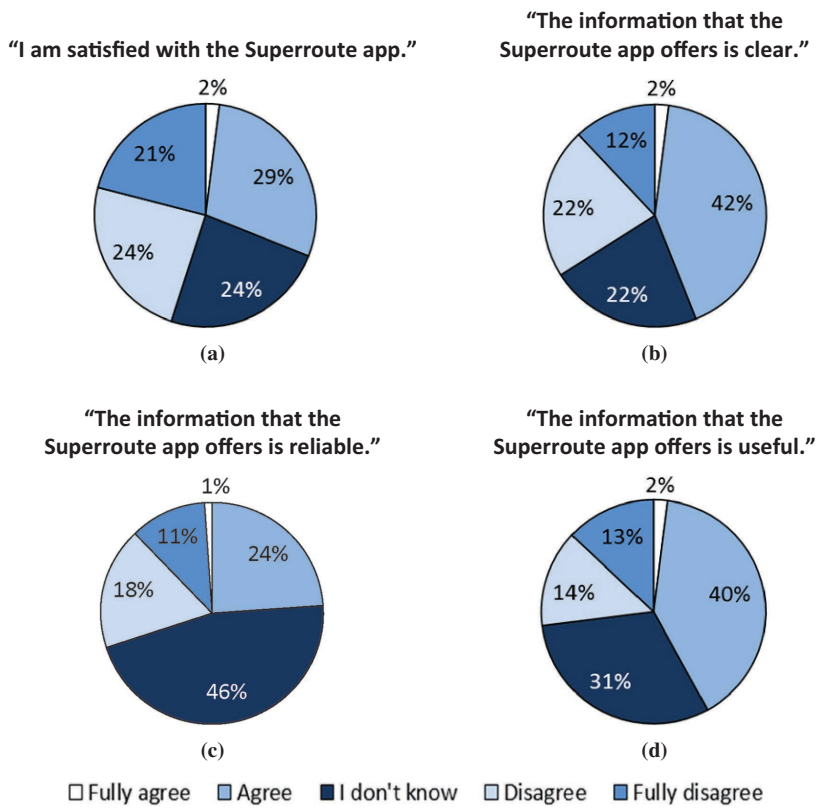


FIGURE 4 Satisfaction with app and participants' rating of clarity, reliability, and usefulness of information that app offers, according to data from questionnaire at end of trial (frequent users) (n = 741 respondents).

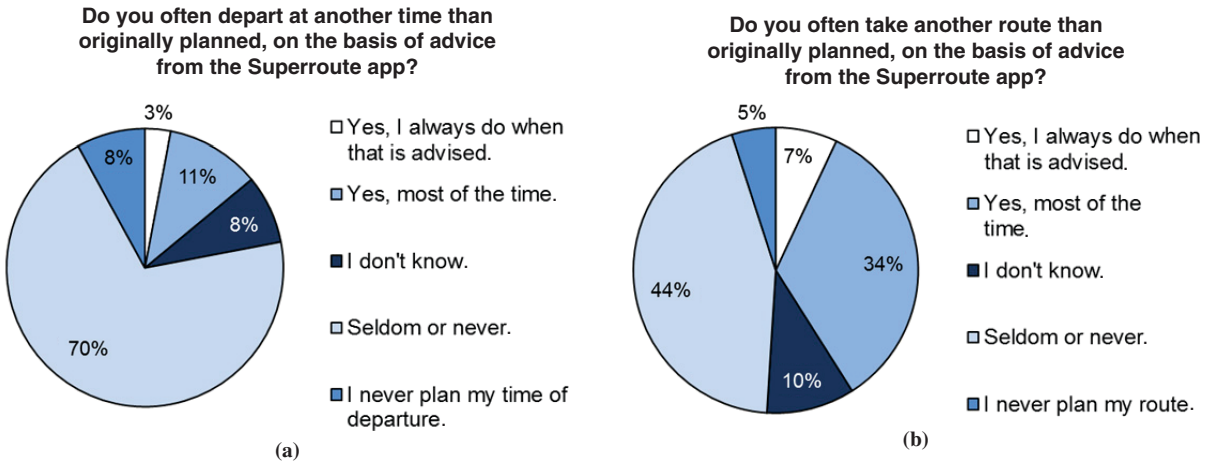


FIGURE 5 Participants (frequent users) responses to questions about changing their departure time and route on the basis of advice from Superroute app (n = 745 respondents).

of the Superroute app. This willingness to take another route increased to 50% with an increase in the amount of app use. These results are in line with the results on compliance given earlier in this section. A substantial number of participants were willing to change their routes, and did indeed change them.

Results for changes in departure time for events are comparable with those for everyday traffic: 13% of the Super P-route app users indicated that they chose another departure time because of the app advice. For changes in the route, results are a bit different from those for everyday traffic: 28% of participants said they chose another route because of the advice of the app, 49% indicated they did not choose another route, and 23% said they did not know. The Super P-route participants were also asked whether they had chosen a parking garage different from the one they would have chosen without the app. Fifty-two percent of participants confirmed that to be true, 34% said they did not choose another parking place, and 14% did not know.

Effects on Traffic Flow

Unfortunately, an effect of the service on traffic flow (throughput) could not be determined because (*a*) the effect of autonomous developments was substantial and (*b*) the number of evaluated trips was, ultimately, too small. The amount of congestion increased substantially in the area in the trial period (because of the recovering economy) as well as in the rest of the Netherlands. Even on days with a few thousand users receiving route advisories, penetration rates on specific routes in peak hours were still very low. The absolute number of users was always much lower than the considerable day-to-day variation in traffic volumes.

Although the effect on traffic flow could not be measured, the potential effect was estimated. A theoretical investigation using measured speeds and flows on the network explored the effects at higher penetration and compliance rates, using a simple traffic model for route assignment (with a multinomial logit model and an existing origin–destination matrix) (*15*). All drivers in the Amsterdam network were divided into two groups: those with and those without the routing app. Drivers without the app were considered to base their route choice on average travel times of the past 2 months. Those with the app were considered to receive a pretrip routing advisory comparable with that in the field trial, according to the real-time travel times, and to fully comply with the advice. The effect on total travel times and delays was investigated for 3 days in 2015: a day with average traffic patterns (January 28) and 2 days with more congestion than usual (February 3 and 5). If 10% of all drivers used the route advisory, the total decrease in delay over the whole day ranged from 2.4% on the average day to 3.4% on the most congested day. For a 90% penetration rate, 21% to 31% of the total delay in the network would be prevented. Adding on-trip routing advisories would increase this potential further.

Another indication for the potential of on-trip route advice is the fact that for some of the events that were included in the trial, traffic was distributed very well over several access routes to the arena event area (where normally some of these are barely used).

CONCLUSIONS

There was a great deal of interest in the field trial. Recruitment was successful with almost 20,000 participants, and on the days with the highest usage, more than 3,000 trips per day were logged in the trial area by participants.

The Amsterdam onderweg Consortium has offered a service that during the trial evolved from a service giving only route advice to a service that integrated several functions, such as pretrip advice (departure time advice and travel time and route information) and multimodal information. Some functions were added because participants had indicated their interest in them.

Participants often used the pretrip advisory function. Since this was not the focus of the trial, the evaluation did not go very deeply into that function. However, surveys showed that more than 40% of respondents indicated that they were flexible in their choice of departure time, and in the final questionnaire, 14% indicated that they did indeed change their departure time regularly in accordance with the app's advice.

The (on-trip) route advisory was used much less. In the first questionnaire, three-quarters of respondents indicated that they were flexible in their route choice, and in one-half the evaluated trips, participants complied fully or substantially with the route advisory. Of respondents to the final questionnaire, 41% indicated that they usually or always changed their routes according to the app's advice. That is a high share compared with other traffic management measures in the Netherlands, such as variable message signs or traffic information. Of the participants visiting events in the Arenapoort event area, 52% indicated that they changed their choice of parking garage according to the app's advice.

It was expected that the app would be used more often in special conditions, such as adverse weather, incidents, road work, and high demand. The data, however, did not show that this was the case for everyday traffic. This finding is in line with earlier research showing that the use of navigation apps on regular home–work trips is very low.

Usage of the on-trip function of the app was not concentrated enough in time and space to have much effect on traffic volumes on specific road sections and on travel times and delays. The amount of congestion in the trial area increased from 2014 to 2015 and varied considerably from day to day, which made it impossible to determine the effect of the service on traffic flow. Given the high compliance rate leading to the use of alternative routes in the network, it can be assumed that with much higher usage, there will be an effect on traffic flow, resulting in better utilization of the road network. An offline study showed that the effect on traffic delays could reach more than 30% for high penetration and compliance rates.

How participants judged the service varied; there were positive as well as negative ratings. Participants who used the Super P-route app for events in the arena area were more positive (when compared with the overall rating), and a majority would also use the app for other events.

RECOMMENDATIONS

The high level of interest in the field trial shows the potential of advanced, innovative travel information services. The field trial focused on on-trip route advisory, but there was more interest in the pretrip advisory. In many of the trips participants made, the navigation function was not used, even though travelers could benefit from it (and other road users would then also benefit). It is recommended that research focus on incentives that could be used that would lead to more road users making use of on-trip services, because then an impact on traffic flow could be realized. There are several ways to achieve that aim: (*a*) improve user friendliness and fulfill road users' desire for integrated mobility apps that combine several functions, (*b*) reward drivers who change their routes, and (*c*) improve in-car

services by supplying all service providers with information on where in the network spare capacity remains and how traffic can best be distributed over the network. High-quality open data on traffic conditions are crucial to determine where the spare capacity in the network is. A penetration rate of services higher than that deployed in the field trial is needed, but ultimately often only a small portion of the traffic needs to reroute or change departure times to considerably reduce congestion on a specific route.

Participants' behavior in how they used the app was quite unpredictable. Unexpected ways of using the app resulted in incomplete and difficult to interpret data. It is recommended that data processing be started much earlier during the trial, so that monitoring can be done to see whether the data collection is going according to plan or whether there are unexpected problems (and whether they can be tackled). This kind of "evaluation while doing" requires that evaluation efforts already be in effect during the design phase—not only of the evaluation team, but also of the app developers. Doing so will benefit the quality of the evaluation and, in some cases, also the quality of the app itself.

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