Applying Intelligent Transport Systems to manage noise impacts

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Summary
This contribution discusses how traffic management, and many other measures that can be categorised as Intelligent Transport Systems (ITS, i.e. all traffic and transport measures that use ICT) can help reduce noise levels by influencing mobility choices and driving behaviour. Several examples of such measures and how they impact noise levels will be given, ranging from giving travel, route or departure time advice to automated driving ("self-driving vehicles").

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1. Introduction

Cities are growing and this means that urban road and public transport networks are going to be more heavily used as well. Motorway networks also show increased usage. Although the accessibility of many regions and cities is still improving, there are also drawbacks to increased mobility: liveability and environmental problems (and traffic safety, as well, but that is out of scope for this paper).
In the field of traffic and transport, attention has shifted from measures aimed at motorway traffic to measures aimed at urban areas. This also means that there is a shift in what those measures aim to achieve: from a focus on travel times (and perhaps traffic safety, depending on local traffic safety statistics) to finding a balance between those objectives and objectives regarding liveability and pollution. The question addressed in this paper is: how can road traffic and transport measures help reduce noise levels / noise annoyance? This contribution discusses how innovative traffic management, and many other measures that can be categorised as Intelligent Transport Systems (ITS, i.e. all traffic and transport measures that use ICT) can help reduce noise levels by influencing mobility choices and driving behaviour. Several examples of such measures and how they impact noise levels will be given, ranging from giving travel, route or departure time advice to automated driving ("self-driving vehicles").

2. Choices of travellers

From the research reported in [1], it follows that to reduce noise levels along a specific road, traffic and transport measures should be mainly aimed at achieving changes in:

1. vehicle speeds – optimizing both the average speed and the highest speeds (especially at night time);
2. traffic volumes and composition – specifically so that the noisiest vehicles are banned or given an incentive to take an alternative route;
3. acceleration/deceleration – avoiding extreme accelerations (and sometimes even decelerations, e.g. on slopes)

Road users tend not to think in these terms though – they make travel and driving behaviour choices as described below, and those choices can be the starting point for the design of measures to reduce noise production.
Figure 1 gives an overview of all the choices that travellers can make (and the figure also shows that there are interactions between these choices – a choice on one level influences choices on other levels). The choices range from long-term choices such as where to work and where to live to very short term driving behaviour choices such as how aggressively one accelerates at an intersection. Most of the choices are made pre-trip, i.e. at home or at the office, but some choices are made on-trip and can, with many drivers having navigation

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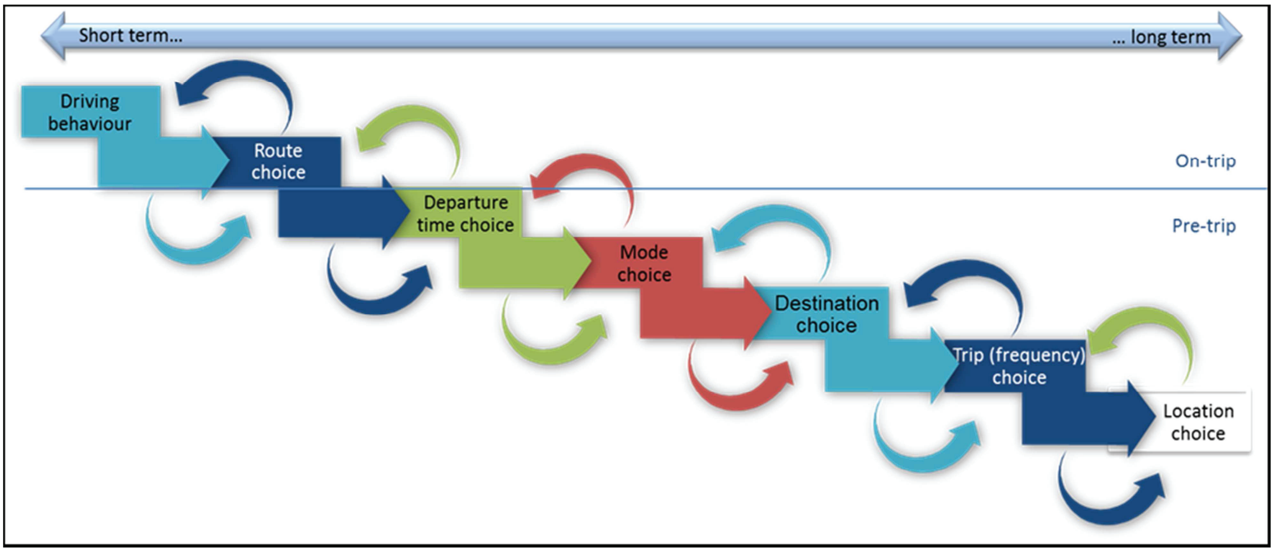

Figure 1. The traveller's pre-trip and on-trip choices.

devices or smartphones in their vehicles, be influenced real-time.

Examples of how these choice can work out are:

- Location choice: Land use choices (and regulation) can help reduce commuting distance, can influence what routes are used by what types of vehicles (e.g. no noisy vehicles in residential areas), and could influence whether or not one can drive a silent electric vehicle (including ones with limited ranges).
- Trip (frequency) choice: To make the trip or not. If employers allow or even encourage employees to work from home, this could lead to fewer early morning commutes.
- Destination choice: where to travel. And that can be anywhere now, with many destinations presenting themselves on the internet and navigation systems making it easy to find them.
- Mode choice: Obviously some modes are noisier than others. Travellers can be encouraged to use less noisy modes, if the benefits for them are clear. (This does not include the choice to purchase a silent vehicle, e.g. an electric scooter, bicycle or car, but incentives to do that can certainly help, because once a silent vehicle is available it can be used.)
- Departure time choice: From a traffic demand management point of view, one would like to influence departure times such that they are during the most favourable time periods, noise-wise. Here, there might be a clash with the aim of many traffic measures currently in place to influence departure time, as they are generally aimed at having car (and truck!) drivers avoid driving during the peak periods, and that often leads to a shift of departures to earlier in the morning, which means more traffic in the "night time" (before 7 in the morning). There is also a link with encouraging employees to work from home – in this case, perhaps, only for a few hours in the morning.
- Route choice: Some routes cause more problems, in terms of noise annoyance, than others. With more and more travellers using traffic information and navigation devices, and governments opening up their data about traffic conditions (real-time), there are also more and more possibilities to influence route choice. From a noise perspective, it could be worthwhile to get in touch with service providers to ensure that noise levels are a criterion in their route advices ('social navigation').
- Driving behaviour: This is an area that is starting to get interesting, as functionalities are becoming available that can significantly influence driving behaviour, including choices regarding speed and lane use, following behaviour, acceleration/deceleration behaviour and

gear choice. Vehicle automation is a hot

topic and the driving strategies of automated vehicles ("driverless cars") could be designed to minimise noise production (taking into account information about the areas along roads). Automated vehicles could drive even smarter by using information communicated to them from other vehicles or road-side and back office applications. This could be used to achieve a better distribution of traffic over the network, or even over the lanes of a specific road section.

The next paragraph discusses some innovative measures that could be used to combat noise annoyance, in their present form or in an adapted form, with knowledge about how the measure could help reduce noise levels incorporated.

3. Innovative traffic measures

Traffic and transport measures used to be mostly physical measures, but these days there is not much room, or budget, to add or enhance physical infrastructure. Thus, the emphasis is on better use of the existing infrastructure through many different ITS measures – fitting with the idea of Smart Cities. Information about what are the most promising ITS measures is becoming available, using results from field tests and widespread implementations of some more mature measures. If we can inform travellers of the alternatives they have for their trips (pre-trip and on-trip), they can make better choices (or their in-veihcle systems can do that for them). Impacts on noise will need to be compared to impacts related to other policy goals cities have (e.g. accessibility/travel times, traffic safety, air quality). Decision support models that enable multi-criteria optimisation can be deployed to make it easier for road authorities, traffic operators and service providers (e.g. of travel advice apps) to decide how and when a measure should be applied.
In this section, the following innovative traffic measures are discussed:

- Real-time route advice
- Incentives to avoid driving in peak periods
- Network-wide traffic management
- Traffic control
- Automation of the driving task
- Improving bicycle facilities

3.1. Real-time route advice

There have been many advancements in data collection and processing over the past years, which means that there is more information about how and where people travel than ever. Also, a large share of travellers is connected to the internet, through their smartphone, navigation device or in-car systems. That means that there are many ways to for travellers to get advice on what is the best way to travel for them.
In traffic management, a distinction is made between pre-trip and on-trip information. Pre-trip, travellers research their destination and the way to get there (mode and route choice, departure time, parking or P+R advice). Websites and apps combine historic and real-time data to estimate the travel time via various routes so that they can advise on the best route at that time. The advice can be updated on-trip as well these days, which makes travellers more flexible.
It is not likely that noise annoyance is a factor in the advices generated by websites, navigation systems and smartphone apps. Mostly, the advice given is the fastest route at the time that the travellers has indicated he/she wants to travel. There are some systems that offer the possibility to choose the most fuel efficient route. The 'most liveable' route could be added as well – the information needed to generate such route is available, though probably not used for this purpose yet. And travellers may be willing to choose a more liveable route if the difference in travel time is small. Such 'social navigation' has been researched (see e.g. [2]) and can be quite effective, depending on the level of altruism that travellers display. Adding an incentive like a reward for choosing a liveable route could be considered – see section 3.2 for a discussion of how financial incentives have been shown to substantially influence drivers' choices. In addition, there are large scale field trials with apps that give route advice and much can be learnt from these trials about the user acceptance and compliance with advices from these trials. For instance, in the Amsterdam Practical Trial [3], apps are currently being tested that give different route advices to different types of travellers. The app takes into account the state of the network, with the aim to distribute traffic more efficiently over the network (in this case, seeking to reduce

delays). The travellers' trips are logged so their compliance with the route advices can be analysed, and travellers are asked to fill in questionnaires, which gives insight into the motivations of thousands of travellers in the Amsterdam area for using such apps.

3.2. Incentives to avoid driving in peak periods

There are several ways to influence the departure time choices of travellers. In several countries pricing measures have been implemented, like tolls or a congestion charge. The technology to collect tolls has, in many countries, advanced to a point where it is possible to charge variably, with higher rates during peak hours. In theory, the rates charged could also be made to depend on the impact of trips on the liveability in an area. In practice, there might be an adverse effect of pricing measures that are implemented to discourage travelling in peak periods – more trips in the very early morning, for instance, in very congested networks.
In the Netherlands, road pricing or congestion charges aren't popular measures. Instead, several measures have been implemented that reward travellers instead of charging them extra for the use of infrastructure. They are labelled as 'Peak traffic avoidance' measures ('Spitsmijden' in Dutch). An overview report of several Spitsmijden projects showed participants in the projects (ranging from a few hundred to over 10,000 per project) changed their behaviour such that they avoided 30-60% of their peak period trips [4] – with some participants continuing this behaviour even after the reward stopped (with the reward being a few euros per peak period avoided).
The original intent of measures rewarding travellers who avoid peak period traffic is to better spread traffic volumes over time, to prevent breakdown of traffic. Such measures are especially useful during road works or other temporary situations, where large numbers of travellers need to be persuaded to change their travel behaviour. License plate cameras or in-car devices are used to identify possible participants and determine whether vehicles have indeed stayed away from certain roads during peak periods. Such measures could also be considered for roads where noise levels need to be reduced – mostly as a temporary measure (until more permanent changes can be made). The measures would need to be explained very well to road users in order to get them to accept the measure (but a reward certainly helps). Also, along with the request to not use particular roads, advice could be given about alternatives: working from home for a few hours before going to the office, or using quiet and clean modes of transport such as electric scooters and bicycles.

3.3. Network-wide traffic management

Network-wide traffic management is based on the same objectives as real-time route advice, but looks at it from the network perspective (and thus often from the road authority's perspective) rather than the perspective of the individual traveller. Now that attention has shifted to urban traffic management, attention has also shifted from accessibility to liveability, or rather to finding a balance between multiple objectives.
Important instruments in urban traffic management are controlled intersections (traffic lights), variable

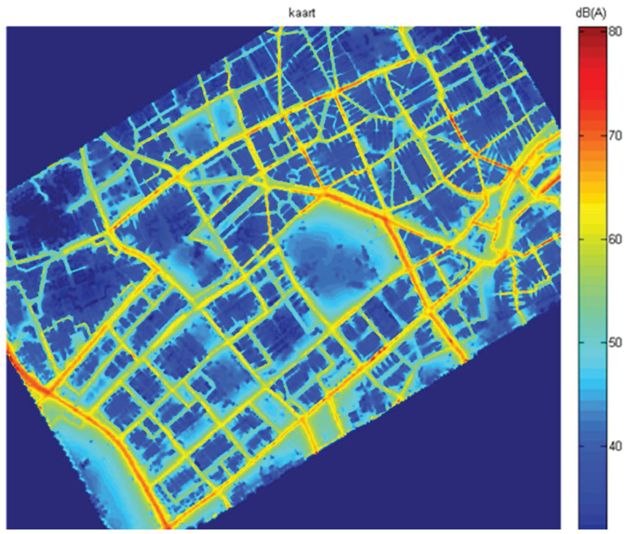

Figure 2. Noise map as used in the The Hague DSS.

message signs and parking guidance systems. All can be optimised for noise reduction. For parking guidance, it is even relatively easy to favour silent vehicles by reserving spaces for them or offering reduced rates.
Influencing traffic flows using traffic light control and variable message signs is more complex but has been tried out in The Hague. For a part of the road network of this city, a multi-criteria decision support system was built. In the Decision Support Tool (DSS) the situation in the network in terms of noise, pollutant emissions and traffic performance is presented with graphs, maps and a grade [5][6]. Also, the expected impact of measures can be

calculated. This is used to inform drivers of preferred routes and is supported by adaptation of the traffic signals, so that it becomes more attractive to use the preferred routes. Instead of just using travel times and queue lengths as triggers, now also air quality and noise levels can be triggers.

3.4. Traffic control

The previous section discussed network-wide traffic management, but management of single intersections or a string of intersections can also be beneficial.

Traffic control is becoming more flexible and better informed – in the sense that the algorithms used receive more and/or better information about what traffic is arriving at an intersection, which means that they can optimise which directions get green and for how long. In the future, communication between vehicles and traffic lights will make the information better still – the vehicle’s navigation systems can also inform traffic lights about the direction that the vehicle will take (turn left or right, or go straight ahead). And in turn, the traffic lights can inform vehicles about the best lane and speed to choose. This will result in fewer stops and less acceleration behaviour. If information about the vehicle type is included, priority can be given to noisy vehicles (for a short term effect: they produces less noise if they keep driving compared to stop-and-go behaviour. For the longer term, giving priority to the noisiest vehicles is less desirable, as this does not encourage a shift to less noisy vehicles).

3.5. Automation of the driving task

Automation of the driving task (resulting in ‘driverless cars’) is a hot topic and many benefits are expected from it. It will take a while before drivers are really not needed anymore, but vehicles are already taking over some driving tasks even in the average car of today (cruise control) and will start taking over more and more tasks. Vehicles are going to be programmed to drive safely and comfortably (right now, much like how humans drive). They could also be programmed to drive with as little noise as possible – much of the information needed for algorithms optimizing performance in terms of noise production is already available in digital maps, and more information that could be relevant can be added. This is not the focus of automotive engineers right now, but stakeholders with expertise in the area of noise mapping and noise abatement measures could get involved. There is link with other vehicle measures reducing noise, like quieter tires – when innovating one aspect of vehicles, other aspects could be innovated as well.

3.6. Improving bicycle facilities

Cycling is currently promoted in many cities, as it is a very sustainable and healthy mode of transport. The sales of electric bicycles are booming and this means that more and more travellers can ride longer distances than they would on a regular bike – making it possible to commute by bike, for instance. But even riding a regular bike can be encouraged by providing good facilities (such as supervised bicycle parking). Internet communities and bicycle navigation apps can be used to encourage travellers to make more sustainable mode choices. A good way to familiarise people with bicycles is by introducing smart bicycle renting systems in cities (e.g. Velib' in Paris, Villo! in brussels). Even bike-sharing has become possible with apps bringing bike owner and client together.

4. Monitoring and evaluation

Traffic monitoring is not a measure as such, but helps to provide input to measures, so that suitable strategies and advices can be generated. Also, monitoring is needed to generate data for evaluation of the effectiveness of measures.

Traffic monitoring anno 2015 uses various sources of information, and combines them using data fusion techniques [7]. The resulting information is increasingly shared as open data – between road authorities but also with service providers who can use the information to generate traffic information and travel advice. Sensors along or embedded in the road provide large amounts of mostly quite accurate data about traffic volumes and speeds, and sometimes traffic composition. Also, probe data from vehicles finds its way to more and more applications. Probe data can be collected everywhere in the network, and can give quite accurate (in space and time) data about speeds. Information about traffic volumes and/or traffic composition is less accurate, given the still low penetration rates (order of magnitude: 2-4% of vehicles on the road). However, the number of vehicles serving as probes will increase, and with that the data will become more useful over the coming years. Dedicated apps may be developed and used to also measure other useful data such as accelerations and other relevant events.

Before deploying a measure, traffic simulation models can be used, off-line or real-time, to evaluate what order of magnitude of traffic effects measures will have. Depending on the type of measure, and what travel choices are influenced, a microscopic (modelling individual vehicles and drivers) or macroscopic (model traffic flows at the link level) is used, see also [1]).

5. Conclusions

Intelligent Transport Systems (ITS) can be used to reduce road noise. At the moment, the focus of ITS measures is on improving accessibility and safety, and energy efficiency (fuel costs) is also a trigger for some measures. Noise does not seem to be on the agenda as much. But in designing ITS measures, noise can certainly play a role and expected noise impacts can be weighed against other impacts.

It has become easier to reach travellers (through smartphone apps and the internet, but also through roadside message signs). Influencing their travel behaviour has become easier too – if the travellers understand the reason or can be shown clearly how they benefit from it. Some measures implemented over the last decade have shown that behaviour can indeed be changed substantially. Including noise as a trigger for measures can mean that measures have to be designed differently. This requires a dialogue between different stakeholders, e.g. road authorities, environmental departments and service providers.

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