Title: The future of urban sound environments: Impacting mobility trends and insights for noise assessment and mitigation

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Highlights

An interdisciplinary team reviews the potential impact of ongoing mobility changes on sound environments

Insights emerge for urban noise impact and innovative noise mitigation solutions

The fluidification of the society is likely to favor noise at sensible periods of the day

The amount of collected data as part of the smart city favors new modes of governance

Keywords

noise mitigation; future of urban sound environments; mobility trends; interdisciplinary discussion;

Abstract

The degradation of the sound environment contributes significantly to the external costs of mobility and is an obstacle to the development of cities. Action plans aiming at fighting traffic noise often take a long time to reach mature implementation. Therefore, it is advantageous to envisage how societal and urban changes and associated changes in mobility practices will modify the urban sound environment of tomorrow. In this article, an interdisciplinary team of seven researchers, whose work focuses on different fields of acoustics and mobility, reviews the potential impact of ongoing mobility and society changes on sound environments. First, the team identified the trends dealing with urban renewal, societal changes and new mobility drivers that have the greatest influence on sound environments, and analyzed in detail. From this analysis, insights emerged for urban noise impact and innovative noise mitigation solutions in the light of improved assessment of the links between mobility and urban sound environments.

1. Introduction

Awareness of the health effects of noise progressively increased in the second half of the 20th century (Rueb, 2013). Noise refers to any acoustic phenomenon producing a generally unpleasant or disturbing sensation (ISO, 1996). The high noise levels, combined with the growing aspiration of city dwellers for a pleasant and environmentally friendly city, have quickly made noise a first-rate nuisance, to characterize and mitigate (WHO, 2011). Metropolitan urban areas, since they are both the place with highest noise levels and the highest population densities, concentrate the highest exposures and therefore most of the current efforts to contain noise.

City dwellers aspire for both calm sound environments and lively neighborhoods. These aspirations are in contrast with the increasing urbanization observed, which is inseparable from movement and therefore sound environments dominated by road traffic noise. The concentrated demand for mobility inherent in the development of cities is a potential vector for the degradation of sound environments. In practice, the urban planning decisions – including *laissez-faire* policies – of the second half of the 20th century left a significant place for the automobile in the city (Buchanan, 1963; Mumford, 1968; Kenworthy and Laube, 1999), and road traffic is as a result now regularly cited as the most annoying source of noise (Science for Environment Policy, 2017).

The urban and societal changes observed can also have a significant impact on sound environments. The fluidification of living rhythms (Bauman, 2000), the urban development, sprawl and intensification, or the changes in individual mobility practices modify the intensity and temporality of sound sources, and thus shape sound environments. Studying the impact on the sound environments of these urban and societal changes is crucial because they will make the urban sound environments of tomorrow. Anticipating and adapting noise mitigation methods and modeling approaches to this evolution is also essential.

This article intends to highlight the key factors in the on-going changes in mobility practices that will shape the urban sound environments of tomorrow. More specifically, a prospective analysis aims to target factors that are a threat to urban sound environments, and to deduce from it the likely evolution of urban sound environments. Insights are then provided for the mitigation of noise environments in terms of actions to be taken, models to develop, and modes of governance to encourage. The article is based on an interdisciplinary discussion, at the interface between several disciplinary fields dealing with mobility and acoustics, and a review of the emerging noise abatement solutions. The discussion aims to stress the levers for improved future sound environments. The paper is intended for researchers in both disciplinary fields, and recalls some basic knowledge to promote their rapprochement.

Section 2 describes the followed methodology and the framework of this work. Section 3 reviews several on-going mobility and society changes and highlights their potential impact on sound environments. Section 4 underlines the methodological shortcomings in current methodologies for assessing the impacts of mobility on sound environments, and points out new insights for noise assessment and mitigation. Section 5 concludes on the findings from this discussion, and identifies the most promising current avenues of research for improving future sound environments.

2. Methods and materials

2.1. Methods

The prospective exercise on urban sound environments presented here required an interdisciplinary discussion at the interface of the fields of mobility and acoustics. The diversity of the experts' disciplinary fields of research, whose works focus on physical acoustics, soundscapes, noise and health, mobility, air pollution, indicators and urban planning, allowed a perspective to approach this question from various angles. The study partners met physically on 27/02/2019 for a discussion on the impact of changes in mobility practice on noise environments. The methodology was as follows:

- Two weeks prior to the meeting each expert received a short description of the scope of this prospective study and was asked to prepare a 10 minute presentation on their view on emerging trends and methodologies;

- During the meeting, each participant highlighted his or her viewpoint followed by a generative discussion that resulted in an accumulation of ideas;
- At the end of the meeting a discussion was started that aimed at reaching consensus between the experts;
- After the meeting, a first draft of the consensus document circulated. This document was further amended and discussed over several months.

The selection of trends in societal change and mobility practices was based on literature, notably on the deliverable D2.1 of the MOBILITY4EU project (L'Hostis et al., 2016). The selection of innovative noise mitigation solutions resulted both from literature and the expertise of the participants. The confrontation of sound and mobility knowledge highlighted the most impactful trends, which are those presented here. In section 3, the impacting trends are analyzed in the light of current knowledge in acoustics, in order to deduce the likely changes in urban noise environments in the coming years. These trends point to insights in terms of modelling and noise mitigation policies, which are discussed in section 4.

The empirical part is largely drawn from European countries, thus it directly applies to cities whose mobility trends are part of this context. However, the disparities between cities are such that applying the results of the general analysis proposed here for a given city requires that local specificities be taken into account, as each city's needs, context and aspirations are different (Anderton et al., 2015).

2.2. Material: foreground on urban sound environments

This section provides some background knowledge on urban acoustics and traffic noise, which is necessary for assessing in a prospective angle the links between mobility and urban sound environments. Most of the examples will be drawn from road traffic noise, which is generally declared as the most annoying source of noise in urban areas (Science for Environment Policy, 2017).

The noise impact of changes in mobility can be approximated on a macroscopic scale on the simple basis of the estimated increase or decrease in the number of vehicles (cars, airplanes, etc.) on a territory. Due to the decibel scale used in acoustics, emissions related to a traffic flow are proportional to the logarithm of the vehicle flow. It is for instance common to state that doubling the vehicle flow increases sound levels by 3 dB. This simple relation gives some insight into the links between the number of vehicles and the average sound level:

- Reducing the number of vehicles by 10% will only reduce noise levels by up to 0.5 dB, which is hardly noticeable to listeners;

- A strong reduction in the number of vehicles, for instance by 90% (for example in the context of a strong modal shift towards bicycles in traffic free city centers), will make average noise levels decrease by 10 dB.

The spatial distribution of noise is of great importance when assessing noise impacts. The spatial variability of noise levels is indeed very high (Aumond *et al*., 2018), and closely linked to both urban spatial characteristics (Liu *et al*., 2013) and the road network (Barrigon Morrillas *et al.*, 2005). In addition, links between sound levels and large scale urban spatial attributes can be found in the literature. Salomons and Berghauser Pont (2012) showed that road traffic noise increases with the road network density and the travelled distances by car per surface unit, but decreases as the building density increases, resulting in a sound level decrease with increasing population density. A negative correlation between sound levels and building densities is also found in Ryu *et al.* (2017).
The temporal evolution of noise is also a key element in the assessment of the impacts. The aggregated indicator promoted by the Directive 2002/49/EC, the L_{den}, underlines the specificity of noise exposure over evening and night periods by introducing respectively a 5 dB and 10 dB penalty for these periods. This specificity must thus be taken into account when assessing the impact of increased traffic flows during these periods.

3. On-going society and mobility changes and their impact on sound environments

The close links between society and mobility are widely accepted in the scientific literature (Urry, 2007). The observed trend of increased mobility is likely to continue: by 2050 passenger mobility should increase by 200-300 % and freight activity by as much as 150-250 % (Wilson 2011). In parallel with this increase, the forms of mobility are changing. L'Hostis *et al*. (2016) addressed the societal needs and requirements for future transportation and mobility, and listed the societal drivers that have an impact on mobility and logistics. Four identified trends in mobility are discussed in this section from a sound environments point of view.

3.1. Distribution of wealth and labour market developments

Direct consequence of the global economic growth will be an increase in flows, particularly freight. At the individual level, economic growth usually converts into more mobility, as illustrated by the growth of tourism (Dubois *et al*., 2011). The number of air passengers carried worldwide grew for instance by 6.3% in 2016, and this trend is likely to continue as this increase has been during the past 40 years continuous and resilient to oil-price shocks or recessions (EC, 2017). This increase in flows is likely to result in an increase in noise emissions, whose the Advisory Council for Aeronautics Research in Europe

(ACARE) is aware as it fixes the goal of reducing by 65% the perceived noise per passenger kilometer by 2050 relative to the year 2000 (ACARE, 2015). This objective is however vague since the selected indicators are not mentioned in the report.

In addition, the working arrangements are being restructured. Observations show that average daily travel-time expenditures are stable over time (Stopher *et al*., 2017), giving credit to the idea of travel time budget (Zahavi, 1976). It appears that increases in transport modes speed or new improvements in mobility are spent into more kilometers travelled and hence more mobility. Telework and part-time work are the two major foreseeable trends already happening that are expected to grow further in the future. This trend leads to a drop in the number of trips to work and thus to a decrease in the peak hour travel. On the other hand, these new working arrangements favorize urban sprawl, or even commuting from one city to another, with a probable associated increase in the number of trains operating and the related noise. This trend is therefore a potential vector for a modification of the temporal and spatial structure of urban sound environments.

3.2. Inclusive society, personalization, accessibility

Life rhythms are changing. There is an emerging consensus among social scientists (Clegg and Baumeler, 2010) around the idea of *liquid modernity* introduced by Z. Bauman (Bauman, 2000), but also on the acceleration of the social life (Rosa, 2003). Acceleration and flexibility provide an explanation to the increase of leisure time and its associated mobility pattern, which tends to desynchronizing the existing rhythm of mobility at the risk of exceeded noise annoyance over evening and night periods. The flexibility in rhythms can also modify diurnal noise temporal patterns, with longer rush hours and less breaks. For example, the average daily travel time for non-work or studies activities increased from 40 min in 2001 to 52 min in 2010 in Île de France region, Paris (Courel & Gloagen, 2016). The evolution towards instant delivery also affects logistics. For example, by 2025, 20% of retail sales are expected to be online, which will imply an increase in the demand for urban parcel deliveries and smaller but more frequent shipments (Vidyasekar and Frost & Sullivan, 2013). This might favor noise at sensible periods of the day. However, this depends on the modes of transport chosen, which were at first mainly operated with bicycles (Dablanc *et al*., 2017). The example of individual meal delivery companies, initially provided by cyclists but increasingly turning to motorized deliveries and longer delivery distances, illustrates the potential danger to urban sound environments of this trend (Aguilera et al., 2018). The arrival of drones for delivery, which might deteriorate sound environments, is also subject to caution.

In addition, the move of city dwellers towards more active and healthy lifestyles implies a shift to soft modes of transport (Davis *et al.*, 2012) that are also known to be quieter. However, mobility trends vary greatly from one segment of the population to another. Young generations are likely to use the car less, but active mobility may be less plausible for all people within the older segments of society, which may result in more public services close to where people live (Anderton *et al.*, 2015). Finally, car ownership has been a status symbol since the introduction of mass production of private vehicles. But in large cities, and among younger generations (Deloitte et al., 2015; McKinsey et al., 2012), mobility is increasingly seen as a service that not necessarily includes private car ownership (Kamargianni et al., 2018).

3.3. Urbanization and new city management forms

Cities and city-regions are increasingly becoming the dominant forms of human habitat. They are densifying and spatially extending. Growing cities lead to more intense and longer urban flows, both for passengers and goods (Sena e Silva *et al*. 2013). Densification and urban sprawl are two processes in progress and most likely to continue, which are factors of mobility and therefore potential noise pollution. Density is generally associated with a decrease in road traffic noise levels, while urban sprawl, by increasing the kilometers travelled, contributes to an increase in noise pollution. These processes can also exacerbate environmental inequalities in noise, with: (i) gentrified city center populations exposed to relatively low noise levels, as city centrums are marked by more and more efficient public transport networks, traffic calming policies, and the development of active transport modes, (ii) car-dependent populations on the inner periphery living in areas with high traffic density and high noise levels exposure, (iii) external suburbs, despite being inhabited by heavy contributors to traffic noise, remain relatively quieter than urban environments because of their lower density. Social tensions could be exacerbated between these three urban configurations, that somewhat superposes with the *three speeds city* model introduced by Donzelot: gentrification, periurbanisation and marginalisation (Donzelot, 2006).

Regarding urban logistics, freight is an important component of traffic in cities (10 to 15 % of vehicle equivalent miles), and this proportion is increasing due to the current spatial deconcentration of logistics facilities (Dablanc *et al.*, 2016). The number of commercial vehicles increased by 32% from 2006 to 2014, and their contribution to both air and noise pollution is high. For instance, 10% of the vehicles in London are commercial vehicles, and they contribute to 30% of the NO_x emissions (McKinsey & Company, 2017). Night delivery is one of the targeted solutions, which would mean degraded night sound environments, since an increase in flow rates inevitably entails an increase in noise emissions. This effect could nevertheless be mitigated by using hybrid or electric mid-size delivery vehicles.

In parallel, forms of city management are also changing. The development of the smart city aims at articulating human and social development with information and communication technologies in cities. These include actions for smart governance, economy, mobility, environment, people, and living (Giffinger et al. 2007). As regarding mobility, Intelligent Transportation Systems and its related services are a key lever to converge towards mobility efficiency. Environment-friendly solutions, including noise mitigation, is also a targeted objective of the smart city.

3.4. Environmental protection: climate change, pollution resource and energy efficiency “sustainable consumption”

Policies targeting the environmental impacts of transport are increasingly enacted, as an indirect evidence of the rising awareness in society of environmental issues. Increased awareness of the impact of local air quality (particulate matter) and the strengthening of EU emission regulations have urged both regional and local initiatives to ban diesel vehicles and favor hybrid and electric cars. In addition, climate change forces countries to act in favor of renewable energy, which will have a direct impact on the choice of propulsion for private vehicles, public transport, and finally goods transport. Electric vehicles are often seen as a solution to mitigate consumption issues. However, the resulting noise reduction might be disappointing. Following the simple rules recalled in section 2.2, the effects of introducing 10% of electric vehicles would be about 0.5 dB. The real effects might be even less since they mainly reduce engine noise whereas rolling noise is the main source of vehicles at speeds above 30 km/h (Pallas et al., 2016). However, optimistic scenarios estimate that electric vehicles could account for 48% to 76% of the car fleet by 2030 (Mc Kinsey & Company, 2014). This share becomes significant from the point of view of noise emissions. This trend also modifies consumption and logistics, with for instance the development of short supply chains aiming at reducing traffic flows and thus noise.

Policies targeting the environmental impacts of transport also include speed reduction, which led to a decrease in noise emission per vehicle. This measure, combined to the increase in the number of vehicle kilometers travelled, led to a significant change in the ratio of peak levels to the constant hum (Van Renterghem et al., 2012).

4. Insights in noise impact assessment and mitigation

4.1. Insights in noise impact assessment

4.1.1. New noise assessment trends

Noise impacts are first estimated in terms of exposure. Exposure calculations are often based on static approaches, which cross-reference population density data with calculated noise maps to estimate the number of people exposed to threshold levels. However, a recent work has shown the interest of taking into account activity patterns to refine the calculation of exposures, showing that noise exposures largely depend on the individual's within-day dynamics (Kaddoura *et al.*, 2017). The context of exposure also plays an important role, in particular calm sound environments at the residence place is a strong demand of city dwellers. Geography, particularly renewed by time geography (Hagerstrand, 1970), has been much more interested in movement than in its necessary counterpoint, rest (Seamon, 1979). The affirmation of the restorative character of the use of the home in social practices and its corollary need for calm would deserve to be investigated in the light of new knowledge in the human sciences.

In addition, environmental acoustics is increasingly turning away from approaches based solely on quantitative approaches. Raymond Murray Schafer's work in the 1970s led to the notion of "soundscape" (Murray Schafer, 1979), now widely used, which can be defined as "the sound environment as perceived, experienced or understood by one or more persons, in its context" (ISO 12913-1:2014; Aletta *et al.*, 2016). Research in soundscape concentrates an increasing effort, as underlined in Kang *et al.* (2016). In particular, research in sounds classification within urban sound environments often highlights a distinction between mechanical, natural and human sounds. The questions then arises as to the competition between the sources of these classes and their suitability for a given environment. Interactions between road traffic noise, water and bird sounds have been extensively investigated in the literature, the latter two being perceived positively and the former negatively (Jeon *et al.*, 2010). As an example of the practical result in terms of urban planning, fountains are sometimes advocated to improve sound environments dominated by road traffic noise, although recent research shows the limitation of such practice (De Coensel *et al.*, 2011). In terms of modeling, soundscape approaches target qualitative indicators, such as the sound pleasantness, which better characterize the perceptual effects than the aggregated energetic indicators (Aletta, 2015; Aumond, 2017), or the tranquility rating, which associates visual attributes such as the percentage of natural features visible in the scene (Pheasant *et al.*, 2008).

Soundscape approaches also emphasize the importance of preserving quiet urban neighborhoods, with modalities for their identification and preservation described in (EEA, 2004). The interest in preserving places with high quality acoustic environments, referred to as restorative places, has been demonstrated; they are proved to positively affect well-being and therefore require special attention (Van Kamp et al., 2016). In that perspective, metrics have been proposed, such as the perceived restorativeness soundscape scale (PRSS) introduced in Payne (2013) that is based on criteria such as the appealing, attention, notion of refuge, etc. Such metrics help rating the restorativeness of different soundscapes, which makes it possible to differentiate for example the soundscape of different urban parks.

Finally, noise is increasingly taking part of global assessment, as long with other environmental externalities, within integrated approaches. In particular, noise emissions are increasingly taking part of Life Cycle Assessment (LCA), whose methods of consideration are still debated (Cucurachi *et al.*, 2012). Meyer *et al.* (2019) showed for instance that integrating the impact of noise into LCA can double the estimated impact of road transport on human health.

4.1.2. Assessing the noise impact of urban renewal

Urban renewal, including densification and urban sprawl processes, requires revisiting noise modeling. Urban-scale prediction and assessment of noise impacts faces several obstacles:

- First of all, estimating the road traffic demand in view of potentially disruptive modal shifts for passengers and new distribution models for goods is a huge challenge. Not only, the L_{den} levels may be affected, but also the number of noise peaks and quiet intervals. Today, we already witness changes in exposure-annoyance relationships for railway noise and aircraft noise (WHO, 2018) that may be caused by such modal shifts and increased traffic intensities in air and rail traffic. Therefore, developing integrated modelling chains that combine mobility and noise and include a modelling of transportation modal shifts is a crucial research challenge for the coming years;

- Secondly, assignment of traffic to the road network has some uncertainty. The deterioration of traffic conditions induced by an increase in travel demands on the main arteries can load residential areas, which is very difficult to model. Since noise is a very local phenomenon (propagation distances are short in a densely built network), this can result in breaking up quiet areas and thus have significant consequences on the number of people exposed to traffic noise. Moreover, reducing traffic in city centers, e.g. via low emission zones and traffic free areas may result in increased traffic in the periphery rather than inducing the modal shift that planners hope for. Urban planners need models able to highlight this spatial modification in sound environments. More generally, the digital twin technology applied to the city environment is increasingly seen as a potential way to facilitate decision making (Mohammadi & Taylor, 2017), which could also apply to the context of sound environments;

- Finally, the assessment of environmental injustices in noise exposure is an exercise that requires knowledge of both the spatial distribution of noise levels and the populations affected, in terms of social conditions, age, etc. This necessarily entails the reinforcement, already at work, of research groups involving environmental economists, epidemiologists, geographers and acousticians. First findings on how noise influences urban landscape show that the spatial noise distribution has a significant impact on the property market. Kim *et al*. (2007) showed that a 1% highway traffic noise increase is associated with a 1.3 % decline in land price. Such numbers are however hardly transferred to urban context, where a very low association between price market and noise exposure is found in Brandt & Maennig (2011) due to confounding factors. The spatial noise distribution also correlates with living spaces and thus social groups, so that strong social inequalities in environmental noise exposure are observed. Its processes are reviewed in Dreger *et al*. (2019): groups with lower socioeconomic position suffer from a higher noise exposure, combined with an inability to afford more effective noise insulation and an increased vulnerability to the effects of exposure (EC, 2016).

At the microscopic scale, the urban planning efforts in city centers are moving towards a more global reflection on health and quality of life that is in line with the on-going research on soundscape, which promotes holistic approaches (see section 4.1.1). The integration of soundscapes approaches into modeling frameworks shared by architects and acousticians is an important challenge to progress towards the design of high quality sound environments.

4.1.3. Assessing the noise impact of societal changes

The societal changes described by sociologists, which are a move towards more flexibility and an acceleration in life rhythms, have begun to disrupt relationships with mobility, with predictable consequences for urban sound environments. The individualization of living patterns, and the increasing instantaneous nature of deliveries, increase the number of trips during evening or even night periods, which are traditionally conducive to calm. These new noise nuisances question the indicators and models to evaluate them.

The acoustic indicators commonly used to describe night annoyance are criticized for not taking into account the impulsive nature of the noise associated with awakenings (Basner, 2018). In addition, evidences show the interest of taking into account the number of noise events when assessing perceptual effects of noise, in terms of the sound pleasantness of a scene (Gille et al., 2016; Ricciardi et al., 2015). As a result, noise indicators to assess the impacts of noise, both in terms of annoyance and health effects, are still under discussion (Lercher, 2018), with the aim to include the temporal structure of sound environments. Indicators have recently been proposed to summarize the temporal variations of noise, such as the Harmonica index which accounts for the sound levels amplitude (Harmonica, 2013), or the Intermittency Ratio (Wunderli et al., 2015), which highlights the proportion of the sound energy contained in noise peaks.

However, the estimation of noise event indicators remains difficult because the usual modelling frameworks for road traffic noise prediction do not adapt well enough to the dynamics of noise induced by road traffic, and even less so to the random nature of noise events. Recent modeling approaches, which rely on microscopic road traffic models, seem promising for estimating acoustic indicators characterizing noise peaks or calm periods (Can *et al.*, 2007; De Coensel *et al*., 2016; Estevez-Mauriz & Forssen (2018).

4.1.4. Assessing the noise impact of new mobility drivers

Mobility is also changing in terms of nature. The development of smart cities and new transportation devices can have a very beneficial effect on sound environments. The deployment of electric vehicles contributes to a reduction in noise levels since they attenuate propulsion noise. However, their impact on urban sound environments will remain limited, until a massive spread. The probable future emergence of autonomous vehicles can also be a lever for reducing noise levels, with the implementation of driving modes that are economical in terms of the noise pollution generated (reduction of high accelerations and congestion). However, some rebound effects are under study, these vehicles can for instance induce empty trips and even congestion (Millard-Ball, 2019).

On the other hand, the development of new modes of transport, in particular drones, person-carrying drones or urban helicopter transport, can lead to a significant deterioration in sound environments. Initial researches have focused on the characterization of drones' emissions (Kloet *et al.*, 2017), or in showing their increased annoyance compared with cars or trucks (Christian & Cabell, 2017 ; Torija et al., 2020). It seems crucial to intensify the efforts on researching the potential noise impact of new modes of transport, including beyond noise levels a research on the additional cognitive load induced by these new vehicles.

In view of the diversity of these new sources, estimating effects based on traditional subdivision on transport modes (air, rail, road) can no longer be defended. The development of new impact indicators that can lead to a unified theory for noise annoyance, sleep disturbance, and restoration is called for.

4.2. Insights in noise mitigation

4.2.1. Insights in road traffic management

The proximity between sources and exposed people in urban areas calls for a reduction of traffic noise at source. The decibel scale recalled in section 2.2 draws direct conclusion in terms of road traffic management. Indeed, a small proportion of noisy vehicles (for example logistic vans, motorcycles or old vehicles), for instance 1% of vehicles that emit 20 dB more than the rest of the vehicle fleet, make average sound levels increase by 3 dB. This result is a brake to legislating on vehicles noise limits to reduce noise levels, as a small proportion of noisy vehicles, added to the inertia in the renewal of the vehicle fleet, can contribute significantly to high ambient levels. But the opposite is true, a policy targeting the 1% noisiest vehicles may reduce noise levels significantly. Acoustics radars are therefore under testing and being deployed in some cities. They aim to identify noisy vehicles, pinpoint their location and automatically ticket them. The sensor “Méduse” patented by BruitParif relies for instance on an acoustic antenna composed of four microphones arranged in a regular tetrahedron (Mietlicki, 2018). Finally, the reduction of the engine component of vehicle noise, and the arrival of electric vehicles on the market, bring out new opportunities for flanking noise control via quiet-tire policies and road pavement choice and maintenance increase.

Acting on road traffic to mitigate noise requires the development of dedicated modeling chains. The links between vehicle flows and sound power levels are indeed not trivial, since kinematics of single vehicles is extremely important for noise emission. Thus, the effect of modifying the vehicle flow has an effect on the vehicles kinematics and, consequently, on noise emissions. For example, reducing the number of vehicles can be acoustically compensated by an increase in speeds that increases sound levels. Recent advanced modelling approaches have been developed that rely on microscopic traffic models, with the aim to capture the vehicle reassignments and the changes in traffic conditions, such as traffic congestion, that may occur with acting on traffic management. These models work as follows: the traffic model, originally designed for traffic management purposes, outputs vehicle trajectories on an instantaneous basis, which feed noise emission models (De Coensel *et al*., 2005; Can *et al*., 2009). The other advantage of this modelling approach is to enable the evaluation of sound level time series and then the calculation of specific indicators that better describe sound environments (Can *et al.*, 2008). These models have been used to evaluate the impact of speed reduction or specific intersection designs on the sound levels distribution. For example, the sound environments associated with roundabouts are improved compared with traffic light intersections, as they smooth traffic and reduce the number of acceleration phases (Chevallier *et al.*, 2009; Luo *et al.*, 2012). De Coensel *et al.* (2010) demonstrated the interest of low speed green waves for reducing noise levels. Finally, integrated approaches have combined noise and air pollution assessment within multi-criteria evaluations that showed that the effects can vary from one externality to the other (Fernandes *et al.*, 2019; Sampaio *et al.*, 2019). For example, De Coensel *et al.* (2012) proposed a case study in which a reduction in speeds is slightly beneficial from an acoustic point of view, while NO_x emissions strongly decrease but the number of particles emitted increases because vehicles operate in sub-regime speed.

4.2.2. New modes of governance

The emergence of new modes of governance and the growing diversity of stakeholders are changing the way in which noise is being addressed. For instance, GPS applications available on the market, whose objective is to optimize individual travel, shift traffic to residential streets, which can significantly increase noise levels in initially quiet areas (Foderaro, 2017). This raises questions of governance regarding sound environments in the smart-city context with private and public actors (Courmont & Le Galès, 2019; Meijer & Bolivar, 2016). Decrease in private car ownership could also be al lever to mitigate noise. Indeed, as soon as vehicles (cars, busses, trams, trains) are owned by a limited number of operators, noise emission policy could take on new forms including stakeholder negotiations and long-term planning.

In parallel, the rise of the soundscape approach, the deployment of urban sensor networks, and the general trend towards greater participation of the various stakeholders in decision-making argue for new modes of governance to mitigate urban sound environments. The association of different stakeholders and methods in sound planning have been discussed in (Alves et al., 2015) or (Gauvreau et al., 2016). The promoted holistic approach calls for instance for an active participation of city-dwellers in the decision-making process, involving as well noise experts and city's players in focus groups.

4.2.3. Insights as concerning the smart city

The smart city is already very present in the acoustics context, particularly via the development of connected sensor networks (Sevillano et al., 2016; Picaut et al., 2017; Mydlarz et al., 2019), which help to monitor sound levels, but must be set to guarantee the privacy of city dwellers in response to national laws. City-of-things distributed monitoring technology may be used directly in noise control by adapting speed limits or variable access charging or tolling based on noise emission. However, the smart governance dimension of smart cities, which could be defined as an hybrid governance associating citizens to decisions made by pubic authorities, did not fully reached yet the acoustics community. Sensor networks of the new generation might eventually participate in moving towards an association of citizens in the decision-making process, and towards greater transparency in governance models. Open data, such as the service offered by the New-York City that references and shares on-line noise complaints (NYC, 2019), or smartphone noise applications that allow users to measure and share the noise environment, such as Noisecapture (Picaut et al., 2019), can help to move in this direction. This will in addition require the development of data visualization platforms that can be easily interpreted, in order to test the impact of temporary policies.

Finally, the current development of intelligent measurement networks can be used to: (i) implement noise reduction solutions (such as speed reduction) adapted to the noise levels measured, (ii) detect noisy vehicles and decide on action concerning them, (iii) assess the benefits of local noise reduction policies, by measuring their effects.

5. Conclusions

The degradation of sound environments is mainly attributed to the mobility demand and an obstacle to the qualitative and quantitative development of cities. Societal and urban changes and the current changes in mobility practices make it difficult to anticipate the sound environments of tomorrow. However, this prospective analysis is essential to propose appropriate noise mitigation solutions.

The interdisciplinary discussion proposed in this article highlights the most influencing trends within ongoing mobility and society changes on sound environments, and defines the consequences in terms of noise assessment and mitigation. The selected trends that are likely to tend towards a deterioration of sound environments are the global economic growth, the acceleration and fluidification of life rhythms, the increase of freight traffic, the appearance of new aerial sound sources, and the spatial growth of cities. The selected trends that are moving towards an improvement of sound environments are the development of active mobility, the development of short supply chains, the emerging electric vehicles and new forms of mobility. The article sets however limits in terms of anticipation, so the most studied trends have been favored. Trends in urban sound environments may differ from those predicted here if unanticipated external factors, such as technological disruptions or a collapse in mobility, significantly alter mobility practices in the coming years (Urry, 2016; Scheel et al., 2015).

Finally, the paper builds on this discussion to propose and comment on insights for the assessment and the mitigation of the noise impacts of mobility:

- The development of integrated modelling chains combining urban morphology, mobility and noise is called for to assess the impact of the urban renewal on noise. In addition, interdisciplinary researches involving environmental economics and geographers are required to better retroactively describe the impact on society of the evolution of urban sound environments;

- The proposal of unified noise indicators that can handle a variety of noise sources and specific demands such as tranquility, restoration, and undisturbed sleep is required to better assess the impacts;
- Research efforts on the potential impact of new modes of transport are crucial to anticipate the acceptability of the evolution of future noise environments;
- The rise of new modes of governance associating all the stakeholders involved in the design of urban sound environments is encouraged to mitigate noise. It could benefit from the increasing amount of collected data as part of the smart city as long as decision-making methods are developed in parallel.

These research insights and their further continuation is crucial to make the development of cities and mobility compatible with sound environments of quality.

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