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Factors affecting the exposure of passengers, service staff and train drivers inside trains to airborne particles

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ABSTRACT

This study investigated train air conditioning filters, interior ventilation systems, tunnel environments and platform air quality as factors affecting the concentrations of airborne particles inside trains and provides information on the exposure of passengers, train drivers and service staff to particles. Particle sampling was done inside the passenger cabin, the driver cabin and the service staff cabin during on-board measurement campaigns in 2016 and 2017. The results show that interior ventilation plays a key role in maintaining cleaner in-train air. Noticeable increases in PM_{10} and $PM_{2.5}$ levels were observed for all of the measured cabins when the train was running in the newly opened tunnel. The increases occurred when the doors of the passenger cabin and the service staff cabin were open at underground stations. The door to the driver cabin, which remained closed for the entire measurement period, acted as a filter for coarse particles ($PM_{2.5-10}$). The highest particle exposure occurred in the passenger cabin, followed by the service staff cabin, while the driver had the lowest exposure. The highest deposition dose occurs for the service staff and the lowest for commuters.

1. Introduction

Exposure to particle pollutants has become a major public concern due to its potential health effects. Toxicological, epidemiological and clinical studies have established that particulate matter (PM) is associated with a wide variety of respiratory, pulmonary and cardiovascular health effects (Campbell, 2004; Delfino et al., 2005; Dominici et al., 2006; Pope et al., 2004). Evidence of the association between PM and lung cancer has led the International Agency for Research on Cancer to classify outdoor PM as carcinogenic to humans (IARC, 2013). These negative health effects are commonly determined based on PM exposure analysis, for the dose, that is, the fractions that are inhaled and subsequently deposited in the body, is thought to play a key role (Löndahl et al., 2007; Russell and Brunekreef, 2009). The exposure-dose response in the respiratory system can serve as a proxy parameter for interpreting the health effects of PM (Jaques and Kim, 2000). However, lungs are complicated, and the deposition dose of inhaled PM in lungs differs in different respiratory regions depending on deposition fractions and particle properties (Löndahl et al., 2007).

Railway particles are no exception when it comes to their potential impact on human health. On the contrary, their metal-enriched nature and wide size range from ultrafine to fine and coarse fractions have made them an important public health issue. Railway PM, particularly in underground sections, has commonly been reported as at higher levels than outdoors (Braniš, M, 2006; Johansson and Johansson, 2003; Kim et al., 2012; Mugica-Álvarez et al., 2012; Querol et al., 2012). Although it has not yet been determined whether railway particles are more genotoxic than outdoor PM (Janssen et al., 2014; Karlsson et al., 2005; Moreno et al., 2017a; Spagnolo et al., 2015), it is important to study the quality of railway air to promote a healthy railway environment for both commuters and railway staff. Even though the short-term effects of railway particles may be insignificant, they could become significant to highly exposed railway employees (Bigert et al., 2008).

Tunnels have several advantages over roadway transport and have thus become a common feature of local railway or subway systems. However, tunnel microenvironments have been found to provide substantially higher exposure to airborne particles than above-ground environments (Strak et al., 2011; Wang and Oliver Gao, 2011). Tunnels turn the railway environment into a confined space, resulting in higher PM concentrations generated internally by the movement of trains and passengers or transferred from outdoors. One effective approach to improving underground platform air quality is the installation of tunnel ventilation systems (Lee et al., 2015; Moreno et al., 2017b). Platform screen doors (PSDs) are also recommended to reduce particle concentrations on underground platforms (Kim et al., 2012; Martins et al., 2016).

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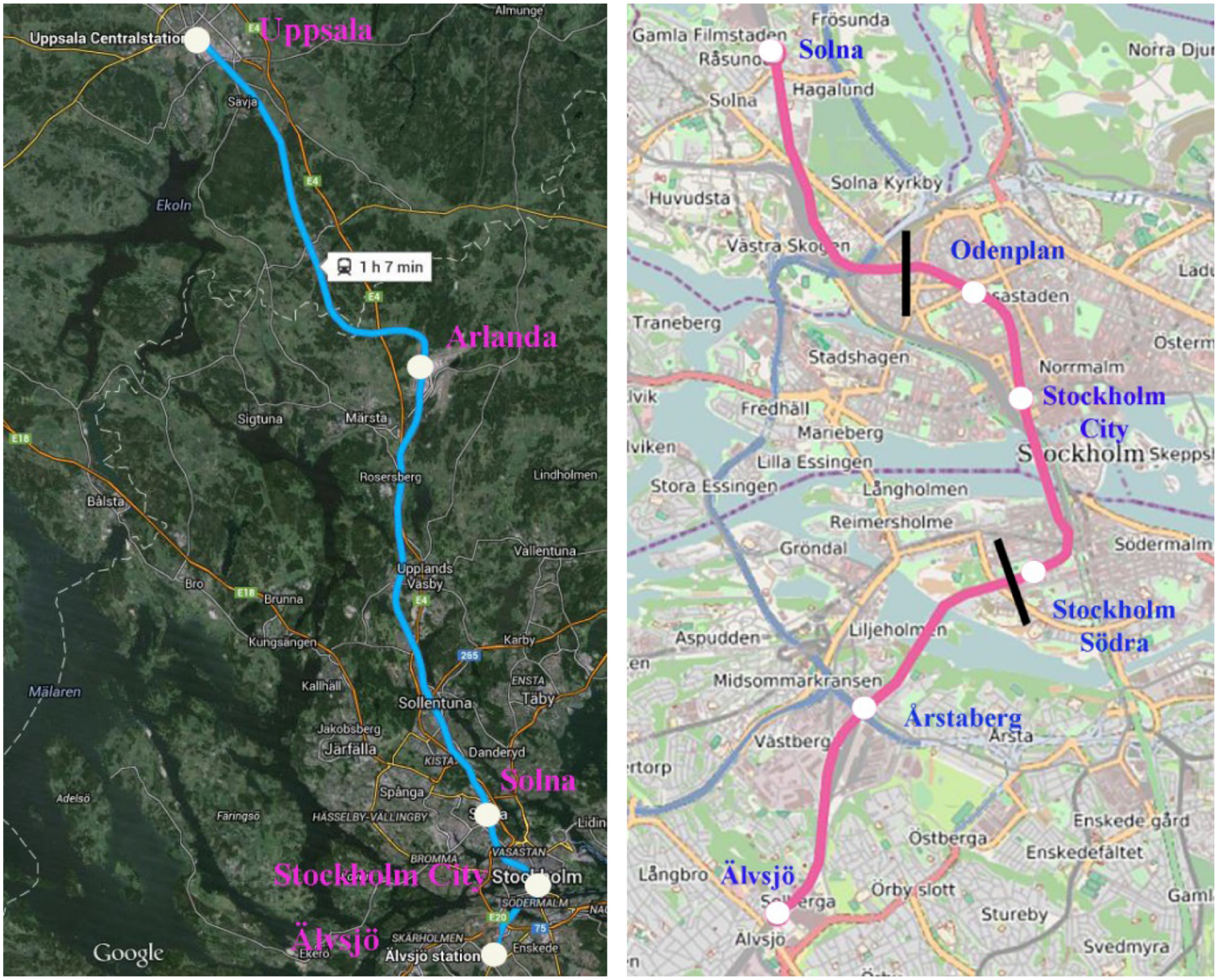

Fig. 1. Map of the routes for the commuter trains studied. *Left*: the route between Uppsala and Stockholm City station used in the 2016 measurements. *Right*: The route between Solna and Älvsjö used for the 2017measurements. The endpoints of the new tunnel are marked by broad black lines.

Considering that most people spend more time inside train compartments than on platforms (Kam et al., 2011), the indoor air quality of a train is also of concern, particularly for railway employees such as train drivers and service staff who work inside trains. However, there are fewer published studies of the air quality inside trains than there are of the air quality on platforms (Amato, 2018). Although PM concentrations inside train cabins are usually lower than those measured on underground platforms, the levels are still reported to be higher than urban background or street levels (Aarnio et al., 2005; Cartenì et al., 2015; Kam et al., 2011; Querol et al., 2012). In some studies, the PM levels inside trains was found to be even higher than on platforms if the compartments lacked proper ventilation systems (Branǐ, M, 2006; Park and Ha, 2008).

It has been suggested that particles inside trains can be traced back to outdoor aerosols, particles at station platforms, and train movement-induced particles (e.g. mechanical wear particles and resuspension fractions) (Cha et al., 2018; Cheng et al., 2012; Kam et al., 2011; Querol et al., 2012). Moreover, tunnel environments have been found to have strong effects on the indoor particle levels when a train is running there (Aarnio et al., 2005; Cha et al., 2018). The high concentration of particles in tunnels increases the PM levels inside train cabins, either by penetrating through gaps or by transferring through doors when they open at stations. With the increasingly use of technology to improve the air quality on underground platforms (e.g., advanced ventilation systems and PSDs), it is of interest to investigate the collateral impacts of these technologies on the air quality inside trains. It has been noted that the application of PSDs on a subway platform in Seoul resulted in a 30% increase in PM_{10} concentrations inside trains due to reduced air mixing between the platform and the tunnel, leading to particle concentrations accumulating in the tunnel (Son et al., 2014). A total of 22 studies (articles published in scientific journals), carried out in 14 different cities, have been covered for the literature review regarding the studies of air quality inside trains, as summarised in Table S1. It can be seen, that the key parameters that have been commonly investigated, are the levels of PM10 and PM2.5, with only 3 studies measured the smaller fraction PM1 in Barcelona and Beijing subway systems. Although, it has been discussed in some studies, in terms of the influence of factors (such as air ventilation and filtration), on the air quality inside trains, very few studies evaluated those factors based on direct experimental tests (Martins et al., 2015). In addition, the air quality inside train cabins is of interest for passengers, but also in particular for railway employees (such as service staff and train drivers), while the evaluation of particle exposure to those persons is much less common than passengers with only 3 studies measured the driver cabin.