Science of the Total Environment xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Adaptive traffic management in cities — Comparing decision-making methods

Sef van den Elshout *, Rinkje Molenaar, Bart Wester

DCMR Environmental Protection Agency Rijnmond, PO Box 843, 3100AV Schiedam, The Netherlands

HIGHLIGHTS

• Analysis of practical aspects of decision making on adaptive traffic management for environmental purposes.
• Real-time traffic management using air quality measurements has few advantages over more generic management strategies.
• Measures aimed at peak concentrations only have a small impact on the overall exposure to traffic related air pollution.

ARTICLE INFO

Article history:
Received 21 August 2013
Received in revised form 12 November 2013
Accepted 18 December 2013
Available online xxxx

Keywords:
Adaptive traffic management
Real-time decision making
Urban air quality
Black Carbon

ABSTRACT

Traffic is the dominant source of air pollution in cities. We simulated 'adaptive traffic management' (temporary traffic interventions that are invoked based on preset conditions such as high ambient concentrations) aimed at reducing traffic related air pollution. We compared these results with the effect of permanent temporary traffic interventions (measures that are always invoked for a few hours, irrespective of other criteria). The potential impact of the traffic interventions was assessed using Black Carbon and NO_x-concentration observations in a busy urban street in Rotterdam, The Netherlands. Results show that generic traffic information (counts, speed, composition) in combination with general knowledge about the atmospheric conditions, provide sufficient information for operational decision making. However, the results also show that the overall net benefits of temporary measures are very small. The impact of permanent measures such as lowering the traffic density during rush hours is higher than measures taken for short time periods when air pollution is high or expected to be high.

1. Introduction

Traffic is the dominant source of air pollution in cities. Restricting the amount of traffic in a city is of course the best way to reduce traffic emissions. This, however, is not easy and often politically sensitive. The question arises if the impact of traffic on air quality can be minimized by interventions, *given* a certain amount of traffic. This is the purpose of environmental adaptive traffic management (ATM) strategies. ATM or Intelligent Transport Systems (ITS) are not only operated for environmental reasons. To manage the flow of traffic through a city, adaptive systems are often already in place to assure that traffic moves as smooth as possible through a city under various conditions (traffic densities). We look at various aspects of the decision-making for environmental ATM.

The flow of traffic over a road network or through a city can be optimized for different objectives. If second order effects (smooth traffic with a minimum of interruptions might attract more traffic) are neglected, the technical network optimum – e.g. moving the maximum number of vehicles with the smallest possible delays (minimum idling times, avoiding stop and go traffic) – is also likely to be the most environmentally efficient way as well. However this can lead to unacceptable solutions where slow traffic or traffic on minor branches faces unacceptable waiting times at intersections (van Baalen et al., 2011; Koning et al., 2011 [Dutch version]). Generally a compromise optimization is chosen that is environmentally still quite good – assuming that most traffic still moves in the best possible way – but not the best solution. They propose to (temporarily) change the optimization criteria based on environmental conditions, e.g. when air pollution is high, the existing traffic management solution (compromise) is changed to a configuration that reduces overall traffic emissions. Similarly, Hodges et al. (2009) describe how the Leicester city ATM system is enhanced with air quality sensors to include this information in decision-making.

Interventions can be *temporary*, manipulating traffic for relatively short (hours) periods with the aim to reduce the traffic emissions when air pollution is high. Alternately they could be *permanent* short duration optimization measures, e.g. tweaks that always occur on weekdays during rush-hours (thus avoiding a lot of real-time decision-making). Temporary traffic measures are needed when: air pollution is high and traffic is the (main) cause. Episodes of for example high

* Corresponding author. Tel.: +31 102468368.
E-mail address: Sef.vandenelshout@dcmr.nl (S. van den Elshout).

0048-9697/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.scitotenv.2013.12.084

particulate matter (PM_{10}) concentrations also occur when secondary aerosol is formed or when polluted air masses are transported to a city from surrounding areas. Taking traffic measures on such occasions is not helpful in reducing air pollution levels.

Typically traffic related air pollutants are needed as indicator. The two pollutants (regulated by the EU) that pose problems in many cities are nitrogen dioxide (NO_2) and PM_{10}. NO_2 is typical for traffic (though other sources exist as well) but being a largely secondary pollutant its relation with the emissions is less direct than NO_x, the mixture of nitrogen oxides that is actually emitted but not regulated. Black Carbon (BC) is a typically traffic related pollutant and a very health relevant pollutant like PM_{10}. When it comes to traffic related air pollution BC is even the preferred health relevant indicator (Janssen et al., 2011; Keuken et al., 2011).

There is no practical absolute limit value for pollutant concentrations with short (hourly) averaging times that could guide short-term decision making. It is mainly the longer averaging time criteria that are hard to meet: daily averages for PM_{10} year average for NO_2. Therefore it was decided to not only look at high concentrations as such. As environmental indicator we looked at the road increment (e.g. ΔBC or ΔNO_x). When this Δ is high it is sure that there is a) a problem and b) it is traffic related and a traffic intervention makes sense. Going one step further, the road increment is high when there is a lot of traffic but also when the dispersion conditions are poor. Trying to minimize emissions at these unfavorable conditions for example by shifting them to more favorable times might be an ATM option.

Actually making traffic interventions is not easy and many studies rely on modeling to assess the impact of a simulated traffic measure. We demonstrate how, under certain assumptions, the impact of simulated, and existing traffic measures can actually be determined using air quality measurements avoiding the use of emission and dispersion models, each with their inherent uncertainties. We do this for a busy inner urban road in the city of Rotterdam, The Netherlands.

2. Case description and research questions

There are four questions to be examined. Firstly does air pollution have to be measured for operational decision making on traffic management? If yes, a dense network of monitoring or sensor equipment is needed to make informed decisions (e.g. as in the MESSAGE project, North et al., 2009). Secondly, is it possible instead to use generic information such as traffic numbers and speed, meteorological data, etc. for management decisions and how does this affect the impact of the measures? In that case, using existing proxy information would be an efficient and cheap alternative. Thirdly, temporary measures (to be activated depending on environmental criteria) are compared to permanent measures that are always invoked at certain times. Lastly the beneficial potential of shifting emissions from unfavorable to more favorable dispersion conditions is examined.

In this study we use measured concentrations of BC and NO_x, in a busy urban street. In the morning the dominant traffic flow is towards the city center and in the afternoon in the opposite direction. The city employs an intelligent traffic management system (ITS) that manipulates the traffic lights in such a way that a minimum speed of 25 $km \cdot h^{-1}$ is maintained along a 1.2 km corridor. Seven weeks of traffic observations, evenly spread over the year 2011, resulting in a dataset of 1001 h were analyzed. The data on fleet composition (private cars and vans, medium duty and heavy duty trucks), traffic density and traffic velocity were obtained from the Rotterdam City Traffic Department. The average hourly traffic density was 1056, 62 and 8 vehicles for respectively private cars, medium duty and heavy duty vehicles. The street has two lanes in either direction. The street canyon (roads, parking places, pavement) is approximately 45 m wide. The street is tree-lined. Hourly concentrations of BC and NOx were obtained from a kerbside monitoring station and from a nearby (<500 m) background station. The meteorological information was obtained from the National Meteorological Institute from their site at Rotterdam Airport just north of the city.

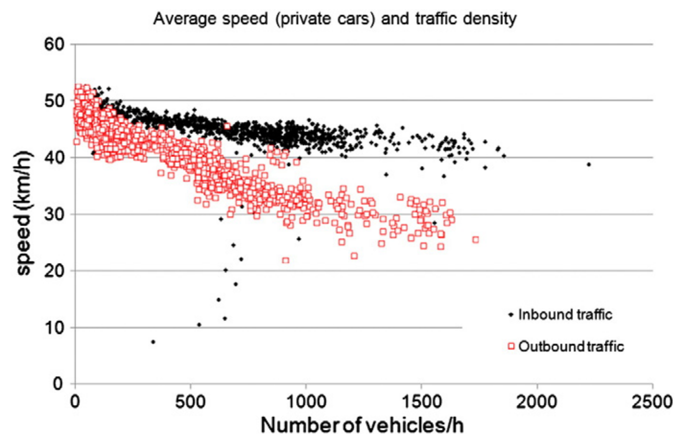

Fig. 1. The relation between traffic density and the average speed of the private vehicles.

2.1. Assumptions

- The increment between the concentrations measured at the roadside monitoring station and the background monitoring station (ΔBC or ΔNO_x) is due to traffic emissions. If the observed increment was <0 it was set to 0.
- Using traffic emission factors (Velders et al., 2012) weights were given to the number of medium and heavy duty trucks while analyzing BC and NO_x. Medium and heavy duty trucks are equivalent to 4.7 and 6.8 private vehicles respectively for BC and 19.0 and 29.4 for NO_x. Using these factors a weighted traffic density *Dw* (expressed as private vehicle equivalent/h — $pve \cdot h^{-1}$), is calculated. Note that at a given hour *Dw* is different while analyzing BC and NO_x.
- Vehicle emissions depend, to some extent, on the velocity and the velocity depends amongst others on the traffic density. Traffic interventions therefore tend to have multiple effects that each cause a change in emission per km. However in this case the Traffic Department succeeds in maintaining average speeds between 25 and 50 $km \cdot h^{-1}$ at all times (see Fig. 1). We therefore assume that there are no major changes of the emission/vehicle/km as a function of the traffic speed and density *Dw*. Hence we assume that the observed street increment normalized by traffic density ($\Delta BC/Dw$) at a given hour is mainly the result of the atmospheric dispersion conditions at that hour and rather independent of the traffic conditions.
- If the traffic numbers do not actually change the normalized street increment $\Delta BC/Dw$ (or $\Delta NO_x/Dw$), the impact of an intervention in the traffic density can be assessed by simply multiplying the change of the traffic density *Dw* with the street increment per unit of traffic $\Delta BC/Dw$ at the given hour. This seems to be the case: the increment per unit of traffic remains rather constant, independent of the traffic numbers. Fig. 1 shows that removing/adding 500 vehicles hardly affects the speed so it is a fair assumption that $\Delta BC/Dw$ and $\Delta NO_x/Dw$ remain constant upon changes in *Dw*. In this way we can use measured air quality data to estimate the impact of hypothetical interventions in *Dw*.

2.2. Traffic scenarios studied

Most of the ATM measures and ITS systems are used to minimize stop and go traffic and idling times by assuring that the traffic density doesn't exceed the road network capacity. This can be done by optimizing traffic light cycle times in real-time, by gating (Tate and Bell, 2000) e.g. if necessary creating congestion elsewhere where it is environmentally