Optimization of design speed in highway engineering networks

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Abstract

Transport is essential for the functioning of modern societies. A well-developed transport system should enable the free movement of goods, services and people and promote inter and intra-regional communication. It also allows businesses and people a greater choice of location for work, trade, living, shopping, learning and leisure.

Keywords: air emissions, vehicle speed, level of service.

1 Introduction

Transport is essential for the functioning of modern societies. A well-developed transport system should enable the free movement of goods, services and people. Nevertheless, the drastic increase in transport demand and in particular the great need for road transport has resulted in major environmental degradation in the form of air pollution, global warming, noise and safety. Among them, the fast growing consumption of energy and production of greenhouse gases possess a significant position.

In highway and environmental engineering direct relationships have been developed to correlate vehicle emissions and speed, referring separately to every type of emission. From the aspect of innovation in highway engineering networks, a consistent high speed is a key element for road operating quality. A high level of service can be achieved by constructing high-speed motorways and reducing travel time. High speed, nevertheless, results in more gas emissions and environmental distress. In this present paper, the research performed on the appropriate vehicle speed which balances these contradictory factors, namely emissions and level of service, is outlined.

Keywords: air emissions, vehicle speed, level of service.
Given the significant impact that highway transportation has to the economic development, it is important for highway engineers to strive towards two goals: (1) providing a high level of service (seek to minimize travel times and delays) and (2) providing a high level of safety. These two goals are often contradictory and must be achieved in the context of constraints. Such constraints can be broadly classified as economic, political and environmental.

The drastic increase in transport demand and in particular the great need for road transport, has resulted in major environmental degradation in the form of air pollution, global warming, noise and land take. Among them, the fast growing consumption of energy and production of greenhouse gases possess significant position. A balance must be struck between the mobility and access needs of people on the one hand, and environmental and natural resource needs on the other.

In the present paper, the research performed on the appropriate vehicle speed which balances these contradictory factors, namely emissions and level of service, is outlined.

The rest of the paper is organised as follows: Section 2 describes the level of service and its relationship to vehicle speed. Section 3 describes the air emissions due to road transport and their relationship to vehicle speed. In Section 4, an attempt is made to present aggregate sorts of environmental pressure and to identify an Air Environmental Pressure Index, following a multicriteria aggregation approach. It is given also, a short outline of the developed method. In Section 5 the optimum speed is identified, and Section 6 are the conclusions.

2 The level of service

The level of service (LOS) is a qualitative measure describing traffic operational conditions and a measure of drivers’ perception of these conditions, such as speed, travel time, freedom to manoeuvre and safety. Levels of different operating conditions are assigned to different levels of service, ranging from A to F, with level of service A representing the best operating conditions and level of service F the worst. The traffic volume, the geometric features of road and the type of terrain (i.e. level, rolling or mountainous) play a critical role in level of service.

In our paper, we consider stable the traffic volume, and the only factor influencing the level of service depends on the vehicle speed. At Fig.1, the relationship between the level of service and speed is represented, resulting in the combined effects of different terrain types (level, rolling or mountainous), where on the y-axis, number 6 represents level A and number 1 represents level F [4]. These relationships are referred to two-lane, undivided highways, which are a key element in the road network of a country. Efficient mobility is their principal function and the average speed reflects their mobility.
Figure 1: The Level of service of different terrain types.

3 Air emissions

3.1 Description of air emissions

Road transport is a significant source of discharge of a number of air pollutants into the environment. The combustion of fossil fuels are responsible for the release into the atmosphere of air pollutants as sulphur oxides (SOx), nitrogen
oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOC), heavy metals and particulate matter (PM).

Greenhouse gas emissions from the road transport sector are entirely dependent on the amount of energy used. The increase in greenhouse gas emissions has resulted in a significant climate change, that is expected over this century. In the EU, these emissions from transport increased by 19% between 1990-2000, contributing a fifth of total greenhouse gas emissions in 2000. Road transport is in turn the largest contributor to these CO2 emissions.

The regulations on vehicle technology (e.g. the use of catalysts in new petrol-powered cars from 1st October 1990) has led to a reduction of emissions of these substances. Nevertheless, there is a considerable amount of emissions of carbon dioxide (CO2).

3.2 The relationship between vehicle speed and emissions

The environment benefits of vehicle technological improvements are being offset by growth in road transport and the continually need for higher level of service that means decrease of travel time and increase of speed.

Vehicle speed has a major influence on the emissions of the vehicles. For the determination of the relationship between speed and the emissions, the methodology COPERT II it was used. The basic principle in these calculations is that the kilometres driven are multiplied on the basis of certain driving conditions by the emissions of pollutants during these driving conditions. It is calculated the annual emissions of all pollutants, for all road traffic source categories and road classes, taking into account several parameters as total fuel consumption, vehicle park, driving conditions, emission factors.

At Figure 2, the presented curves were calculated based on the relation of speed dependency of CO, VOC, NOx and CO2 emission factors, for gasoline passengers cars, complying with the Directive 91/441/EEC [2].

4 Identification of Air Environmental Pressure Index (AEPI)

For a thorough assessment of environmental burden caused by vehicle speed, it is needed to derive an aggregate Air Environmental Pressure Index (AEPI). To this purpose, a multicriteria aggregation approach has been followed (identification a model allowing inter criteria comparisons). The basic steps as defined in relevant literature (Belton and Steward, 2002) of such a multicriteria approach are the following: [1].

- **Definition of criteria:** “Criterion” is a means or standard of judging. In the decision-making context, this would imply some sort of standard by which one particular choice could be judged to be more desirable than another. The criteria, that will be identified, must be measurable on a quantitative scale. For the purpose of this paper, the criteria represent value, expressed through indicators of air emissions relative to speed.
- **Eliciting scores**: (intra-criterion information). Each criterion is associated with a numerical scale on which the corresponding indicator is measured. In order to make the aggregation possible, it is necessary to construct comparable scales. The value of each criterion, expressed through different speed, has been divided by the minimum value of each criterion. So, for every value of speed, we introduce a non-dimensional indicator, that denotes how much higher is the value of the criterion from the minimum value.

- **Assigning weights**: (inter-criterion information). Weights denote how many times more important is criterion i, compared to criterion j. They capture the psychological concept of “importance”. Thus, it is often difficult to derive such weights because the decision maker is not able or not willing to articulate his preferences. This is especially true in our case, where the criteria do not stand for human preferences but for aspects of environmental problems that are all to be avoided. In our case, CO2 emissions are considered to be of equal importance to NOx, CO and VOC emissions together. The corresponding weights for each criterion are presented in Table 1.

![Figure 2: Emissions of air pollutants dependent on speed.](image)

<table>
<thead>
<tr>
<th>emission (j)</th>
<th>(w_j)</th>
<th>emission (j)</th>
<th>(w_j)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2</td>
<td>0.500</td>
<td>NOx</td>
<td>0.167</td>
</tr>
<tr>
<td>CO</td>
<td>0.167</td>
<td>VOC</td>
<td>0.167</td>
</tr>
</tbody>
</table>

Table 1: The weights of emissions.
Deriving aggregate value: In the last step of the analytical procedure the scores defined on each particular indicator should be synthesised in order to provide a unique measure of environmental pressure. The most commonly used aggregation method relies on additive functions that assume that the overall performance index is the weighted sum of its lower-level components. In our case, an air environmental pressure index AEPI(Vi) is defined as follows:

\[
AEPI (V_i) = \sum_{j=1}^{4} w_j \cdot sv_{ij} (V_i)
\]

where:

\(V_i\) = vehicle speed, \(i = 1\div13\)
\(sv_{ij}\) = score of emissions j related to vehicle speed \(V_i\)
\(w_j\) = weight of air emission j

The relationship between air environmental pressure index and vehicle speed \(V_i\) is expressed in Figure 3.

Figure 3: The air environmental pressure index.

5 Optimization of speed

The rapid growth of road transport and the technological innovation of car manufacture have led to an increase of vehicle speed. Most literature, on causes of speeding, points to speeding as a feature of risky driving behaviour. There are many factors affecting drivers’ speed choice, as the road environment (road location, road type, time of day, week, year), the characteristics of vehicle (model, type, safety standards, maximum speed) and the driver characteristics.
Nevertheless the driver is interested in increasing the speed and reducing the travel time. So, the provided high level of service of the type of road has significant importance for the driver. These travel trends go hand in hand with rapid and improvement of highway systems.

On the other hand, this continuing growth in vehicle travel results in more air pollution and degradation of adjacent ecosystems. From the curves of Figure 2, the influence of speed on air pollutants is significant. The speed of 70 km/h causes the less environmental charge. The type of terrain of road determines the corresponding level of service that is provided. So, in level terrain, speed of 70 km/h corresponds to level of service E, while in mountainous terrain, this same speed, corresponds to level of service D.

It is noticeable (Figure 3) that vehicle speed influences strongly these unfriendly gas emissions and, more than that, the relationship is of a parabolic form. An increase, in vehicle speed, from 100 to 120 km/h results in double discharge of gas emissions.

The air pollutants and level of service are two contradictory factors, where only the implementation of an optimum vehicle speed (70-80 km/h) would be struck a balance between them. The general problem that we face is that the feasible speeds in terms of the characteristics of engine of the car and the road features allow much higher speeds than those the perspective of the negative effects of road transport would accept.

It is obvious, that the optimum speed contributes to a more general framework of policy decision. The identification of external cost of air pollution, namely the costs that road users inflict on society, must be taken into account to the trades-off of benefit cost analyses of road network.

6 Conclusions

The continuing increase in road travel tends to offset technological improvements in vehicular emissions, energy efficiency and safety. Roads are the source for many air pollutants which has major implications from human health to global climate change.

A broad policy initiatives are demanded. A shift to cleaner, more efficient vehicles, reduction in number of vehicles with development of alternative transport modes, more environmental friendly modes and implementation of speed limit and speed policies, would help to mitigate these impacts.

At the beginning of the 21st century, it is obvious that an integrated, holistic and multi-disciplinary approach on highway network planning and design for a sustainable future is absolute necessary.

References