Dr. Malin Löfsjögård
Swedish Cement and Concrete Research Institute, Stockholm, Schweden

MSc (Civil Eng) Robert Larsson and Tech. Lic. Ronny Andersson, Cementa AB, Malmö, Sweden

Benefit of reduced fuel consumption from economic and environmental perspectives

Introduction

This presentation and summary is based on [1]. For a full list of references, please refer to [1].

Road traffic now represents one of the major sources of environmentally and hygienically harmful emissions. A reduction of the total quantity of traffic-related emissions would therefore yield great environmental benefits. A number of independent studies have demonstrated that the properties of the road, such as surface texture and rigidity, affect the fuel consumption of vehicles.

The economic and environmental benefits of vehicles travelling on roads that have fuel consumption reducing properties are calculated in this study. A model has been developed for quantifying the benefits from the national economy aspect, and life cycle analysis (LCA) is used for calculating the reduced environmental impact.

Earlier studies of the influence of the road on fuel consumption

The texture of the road is of significance to the rolling resistance of the vehicle. Several studies have examined the relationship in more detail and have demonstrated that effects exist, but the magnitude varies between the studies, principally because there is no standardized method of measurement for this purpose. It is the wavelength of the texture that affects properties such as friction, noise, wear and also rolling resistance as shown in Fig. 1.

Experiments and field measurements performed in Belgium, France and South Africa show that the evenness and rolling resistance of the road surface effect the fuel consumption of the vehicles, [3-5]. Depending of vehicle type, the results show that a more uneven surface increases the fuel consumption with approximately 5-9 %.

Studies performed in America during the 1980s show that the rigidity of the road structure is of significance to the fuel consumption of heavy vehicles [6, 7]. The results showed that heavy trucks travelling in a very warm climate on a flexible road structure consumed up to 20 % more fuel than equivalent trucks running on a rigid road structure. A similar, but more comprehensive, experiment was performed later in Canada with the aim of studying the relationship in more detail [8]. The Canadian study revealed a maximum effect of 11% in favour of the more rigid road structure. A new study has been performed in Canada, but the results have not been presented yet, [9]. The most probable explanation for the results is that heavy vehicles caused greater deformations in soft pavements than in more rigid pavements. As a result of the higher deformations, more energy must be supplied to the vehicle in order to maintain its speed. Asphalt is a viscous material, which means that the material has a delayed response to an external load. Fig. 2 gives an example of a delayed response in a bitumen-bonded material. The strain in response to an external moving load reaches a maximum after the load has passed the measurement point.

Bitumen-bonded materials are thus temperature sensitive, which means that the rigidity declines with increasing temperature. The impaired rigi-

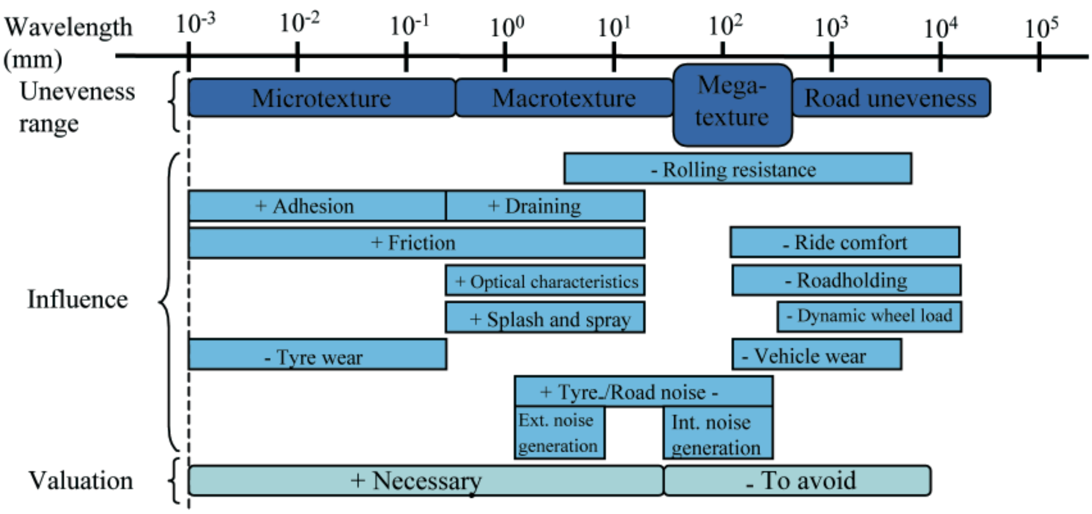

Fig1: Influence of the texture on tyres or the vehicle [2]. Negative influence is shown with minus sign and positive with plus sign in the figure.

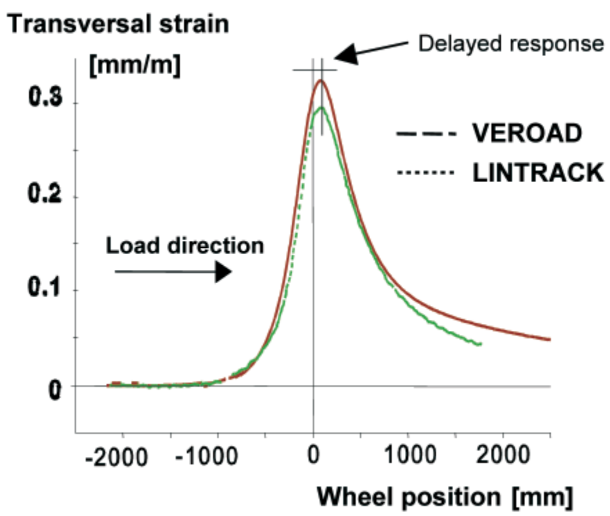

Fig. 2: Comparison between measured and calculated transversal strain [10]. The figure is based on processed data.

dity gives rise to visco-elastic effects that result in part of the kinetic energy of the vehicle being transferred to the road structure. The amount of energy transferred can be quantified by integrating, for an element of road structure volume, the stress and strain change as a function of time [11]. Visco-elastic effects are merely one of several effects involving energy being transferred to the road structure due to the properties of the bitumen-bonded material. Other effects or mechanisms are dynamic effects, hysteresis and mass moment of inertia.

Material such as polymer-modified bitumen and concrete do not display the same sensitivity to temperature variations, and thus have a much higher rigidity at high temperatures.

The influence of temperature, load and speed in particular affects the magnitude of the deformations and thus the energy consumption of the vehicle. However, it should bear in mind that there are other factors that also contribute to the rolling resistance of a vehicle. Unless the measurements have taken this into account, these factors can be reflected in the measurement results.

The results reported earlier apply to motorways with high or very high traffic intensity. The effects are naturally lower for motorways with more normal traffic intensity.

Benefit of reduced fuel consumption

The economic and environmental benefits of vehicles travelling on roads that have fuel consumption reducing properties are calculated in this study. A model has been developed for quantifying the benefits from the national economy aspect, and life cycle analysis (LCA) is used for calculating the reduced environmental impact.

The calculation examples below concerns a 1 km long concrete road that is located in southern Sweden and carries a traffic volume of around 12 700 vehicles per 24 hours. The proportion of heavy vehicles is around 17%. The base case of assumed fuel saving is 1 %. The calculation example concerns a period of 40 years, with an assumed annual traffic increase of 2 %.

Economic valuation

The purpose of the study was to make a valuation from the national economy viewpoint of potentially reduced fuel consumption as a result of a more rigid road construction being employed. It is thus not a complete valuation from the national economy aspect, since factors such as accidents, delays and noise have not been taken into account.

The national economy calculation model is based on the SIKA, EPS and ExternE valuation methods of environmental effects. The model takes into account both the direct economic benefits to the user and the economic benefits to the environment. The economic benefits to the user are related to a saving in fuel costs to road users as a consequence of lower fuel consumption when the vehicles travel on a more rigid road structure. In addition, lower fuel consumption also lowers the emissions from road user vehicles and also those occurring in conjunction with the production and distribution of the fuel itself.

The study shows that relatively simple calculations can reveal that substantial national economy benefits can be achieved by constructing rigid road structures. For the case of 1 % reduction in fuel consumption, the national economy benefit is SEK 2.3 – 6.2 million (EURO 260-690 thousand) per km of motorway, depending on the valuation method used.

Environmental valuation

Earlier studies have compared different road structures and studied the environmental impact viewed over the entire life cycle of the road. It emerged that the traffic during the life cycle of the road is entirely dominating from the environmental loading aspect, and major environmental benefits are gained by reducing the total fuel consumption.

A life cycle analysis was made in this study in order to show the environmental effect of reduced fuel consumption. As mentioned earlier, several different valuation methods have been developed. The valuation method used in this study is the effect category method (short). The analysis is based on an inventory in which all sub-processes in the life cycle of the road are studied.

The results of the life cycle analysis clearly demonstrate the environmental effect of reduced fuel consumption. The traffic accounts for by far the highest loading. This environmental loading can be related directly to the fuel consumption of the vehicles, and a percentage reduction in this consumption produces a substantial environmental benefit. This is illustrated in Fig. 3 in which the effect of 1 % reduction in fuel consumption (negative value) is related to the environmental loading during the construction, operation and maintenance phases.

A 1 % reduction in fuel consumption results in a reduction in environmental loading that is twice as high as the total environmental loading from the construction, operation and maintenance phases.

Discussion and further research

On the basis of earlier experiments involving measurement of the influence of the road surface on the fuel consumption of the vehicle, the conclusion is that the texture characteristics of the road surface affect the fuel consumption by an amount of the order of 5 to 9 %. At the same time, it should be noted that the characteristics of the surface texture do not depend on the choice of materials as such, but are due to factors such as proportioning, aggregate content, etc. In other words, a texture that is beneficial from the fuel consumption viewpoint can be obtained with both bitumen-bonded and cement-bonded materials.

As regards the rigidity of the road structure and its significance to the fuel consumption of the vehicle, there are thus both theoretical reasoning and measurements that suggest a relationship. On the other hand, it is more difficult to draw conclusions concerning the magnitude of the effects. The measurements carried out are comprehensive and, particularly those obtained in Canada, have been obtained at a high metrological standard. There are naturally doubtful elements in the measurements, and these ought to be studied further. External circumstances may also have affected the magnitude of the measurement results. However, the measurements are considered to be comprehensive and they indicate that the rigidity of the road structure is of importance in this context. An in-depth study using calculation models and field measurements would determine, once and for all, the bearing that the rigidity of the road has on the fuel consumption of the vehicle. Mechanisms that are particularly of interest for further research are visco-elastic effects, dynamic effects, hysteresis and mass moment of inertia. The last mechanism is shown to have an effect according to studies in railway design.

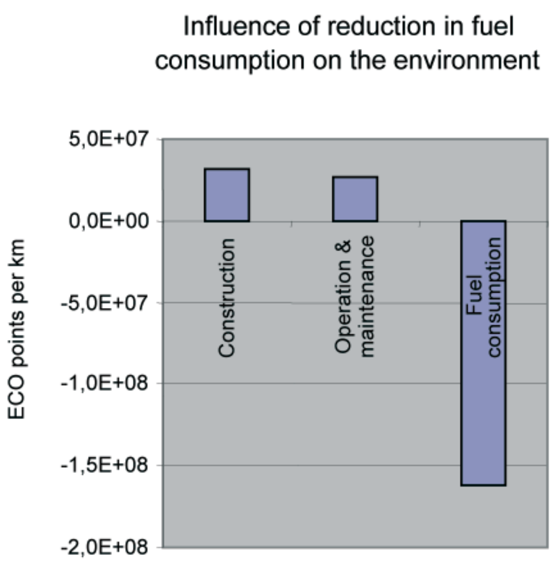

Fig. 3: Effect of 1 % reduction in fuel consumption compared to the environmental loading from construction, operation and maintenance phases (period of 40 years).

Conclusions

The study presented shows that more rigid road structures, such as polymer-modified asphalt or concrete, contribute to efficiency improvements in national economy, while also reducing the environmental loading. The initial additional cost of a more rigid road structure can easily be justified by taking into account the lower fuel consumption in national economy calculations. In addition, if efforts are to be made to arouse environmental awareness in the planning and design of the infrastructure, the added value effect of more rigid structures should be taken into account in studies and environmental analyses.

The results from the performed study demonstrate that a seemingly small reduction in the fuel consumption of the vehicle leads to major national economy and environmental benefits. A reduction of 1 % yields a national economy benefit corresponding to SEK 2.3–6.2 million (EURO 260-690 thousands) per km of motorway over a period of 40 years depending of valuation method.

To gain credit for the benefits of reduced fuel consumption at the calculation stage, it is necessary to determine on scientific grounds the amount by which a more rigid road structure contributes to reduced fuel consumption. This could be achieved, for example, by a project in which theoretical models are validated against field measurements in which two different road structures are built in parallel with one another, with comparable surface properties and the same topographic design.

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