



**6th International Symposium on  
Heavy Vehicle Weights and Dimensions**  
Saskatoon, Saskatchewan, Canada June 18 - 22, 2000

**Session - Effects of Vehicles on Pavements and Bridges  
Current road-vehicle interaction research in the UK**

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**Abstract**

Using the results of the OECD DIVINE project as a basis, the UK Highways Agency is managing a programme of research work on the possible implementation of those aspects of the results that are of particular relevance to the United Kingdom in providing a road network to meet the needs of current and future vehicles and traffic. The paper describes the research that should result in the economic and technical evaluation of measures to improve and control pavement variability and longitudinal profile, and an investigation of the relative importance of functional and structural condition.

The programme of work also includes the setting-up of a European Reference Group on Road-Vehicle Interaction, that will advise national and European organisations on various aspects of the vehicle infrastructure system. The membership, formation and current activities of this group will also be presented.

The Highways Agency is supporting European work on the economic balance between the use of different tyre types. This project aims to provide the means by which the economic advantages to heavy vehicle operators of using particular tyre types can be set against the possible costs to road authorities of the damage caused by those tyre types. The paper describes the results of accelerated experimental work to establish the relative damaging effects of different tyre sizes, the use of vehicle operating cost models to establish the economic effects of those tyre sizes, and the arrangement for case studies to be carried out in several European countries. Finally, the possible consequences of the research for the formulation of policy in European countries are discussed.

The work described represents a significant contribution to the consideration of the road pavement and the heavy vehicles that use the road as a system, rather than as discrete components.

## 1.0 INTRODUCTION

The research requirement identified by the UK Highways Agency (HA) principally arose from the OECD Dynamic Interaction between Vehicle and Infrastructure Experiment (DIVINE) project (OECD, 1998), a large-scale international experiment having a number of objectives in the field of dynamic vehicle-infrastructure interaction. Other projects carried out for the HA, and further work undertaken in the UK and elsewhere, have all pointed to the need to consider the heavy goods vehicle and the road pavement (or other elements of the infrastructure) as a system: changes to one component of the system affects other components.

The DIVINE project investigated a number of the more significant parameters in the system, and the HA requirement now is to examine how the conclusions of that experiment affect the particular characteristics of the UK trunk road network. This will include pavement and bridge design and maintenance, and the operating conditions of the HGV fleet using the network. Furthermore, because the DIVINE project provided strong evidence of interaction between dynamic HGV loadings and the functional condition of the road pavement, there is a need to examine the effect this conclusion has on the UK reliance on conventional indicators of structural performance, and the implications of any recommended changes to these indicators.

Over the past ten years, economic pressures on operators have increased, and the adoption of wide base single tyres as fitments to heavy goods vehicles has become more widespread in the UK. Recent surveys in Europe suggest that about 80% of 5- and 6-axle (2+3 and 3+3) truck-semitrailers in the UK are now fitted with wide single tyres on the trailer. Elsewhere in Europe, the proportion of this type of vehicle fitted with wide single tyres is smaller, but rising. The advantages of these tyres to the operator are significant; their lower assembly weight allows payloads to increase, and their decreased rolling resistance reduces fuel consumption.

However, while bringing advantages to truck operators, many studies suggest that such tyres can increase the structural wear in road pavements. This gives rise to concerns that wear caused by wide base single tyres, at least those of particular sizes, does not adequately comply with the principle of cost recovery which applies in the UK to construction and maintenance costs for the primary road network.

Tyre technology is advancing rapidly, and new tyre sizes and materials are being introduced frequently. As a result of commercial pressures, tyre manufacturers respond to the wishes of their clients by the introduction of lower weight, smaller diameter, or increased carrying capacity tyres and these may have adverse consequences for road infrastructure. In a complex commercial and regulatory environment, the economic balance between the advantages to operators of the use of different tyre types, and their possible disadvantages to road authorities in respect of possible increased pavement wear, needs close examination in order to inform policy development in this area. The

HA is also currently supporting research in this area, both at national and European level.

Finally, the HA is conscious that a great deal of attention has been paid to the road-friendly vehicle. However, the road freight sector is a significant component of the UK economy, as is the case with a number of other economies in Europe. The concept of the vehicle-friendly road must therefore also be considered, but in the context of the vehicle-infrastructure system, it is the "mutually-friendly" aspect that is perhaps most important. Thus, a deterioration in the longitudinal profile of the road can cause an increase in fuel consumption of the vehicle. Similarly, the use of certain types of tyre on trucks can increase the damage caused to the road, even without changes in the total load carried.

The HA consider, therefore, that one of the main objectives of future research in the area of vehicle-infrastructure interaction should be to develop a multi-factorial equation describing the operation of the system. Once developed, the equation may then be carefully optimised in order to ensure that road freight operations are carried out at minimum economic and environmental cost, while ensuring that damage to the road infrastructure (and consequential costs to public budgets) is also kept to a minimum.

This paper describes the approach adopted by the UK Highways Agency in these particular areas of concern and the research which is currently going on at the Transport Research Laboratory (TRL).

## **2. DIVINE DEVELOPMENT IN THE UK**

The DIVINE project investigated a number of the more significant parameters in the vehicle-infrastructure system, and research was commissioned in the UK to examine how the conclusions of that experiment affected the particular characteristics of the UK trunk road network. Because the DIVINE project also provided strong evidence of interaction between dynamic HGV loadings and the functional condition of the road pavement, an examination of the effects of this conclusion on conventional UK indicators of structural performance was also necessary.

The project was set up to study a number of topics relevant to the vehicle – infrastructure system and to evaluate the technological advances and the likely significant developments in the fields of both pavements and vehicles. The principal objectives of the work relevant to this paper were:

- Implementation of DIVINE results in UK
- Implementation of DIVINE results in Europe
- Investigation of functional versus structural condition

## 2.1 Implementation of DIVINE results in UK

The report on the DIVINE project emphasised the need to consider roads and vehicular traffic as a transport system where changes in one or other of the system's components can have a significant impact on the system's overall performance. For example, changes in vehicle axle loading and/or modifications to vehicle suspension design can directly influence the service life and maintenance requirements of road pavements while road surface profile and friction can affect the rate of wear of vehicle components as well as the safety of road users. Adverse wear on both roads and vehicles was shown by the DIVINE study to be strongly influenced by the level of unevenness of road surfaces over the range of longitudinal profile wavelengths that excites dynamic responses from vehicles; this wavelength range depends on the mechanical properties of vehicle suspensions as well as vehicle operating speeds.

Because the conclusions of the DIVINE report were based on limited trials under controlled conditions, their implications for the UK 'transport system' are being assessed in this research. DIVINE indicated, for example, that there might be benefits available from the introduction of road-friendly suspension. Such benefits need to be assessed against the existing benefits that should have arisen from the provision of air suspension on UK trucks but also against the possible disadvantages from such suspensions. The results indicated that in some circumstances, air suspension could produce unwanted frequency matching in short-span bridges, and this could be potentially costly. The results from these assessments together with information from other ongoing studies, for example relating to technologies to improve surface evenness, provide a basis for the evaluation of the costs and benefits to the UK of implementing the results from the DIVINE investigations. The implications of other developments in pavement construction, such as the increasing use of thin surfacings and heavy-duty roadbases, will also be considered in this evaluation.

Environmental aspects, for example noise and exhaust pollution, may be affected by any deceleration and acceleration associated with significant levels of pavement unevenness and the study will take note of any observed effects in this area.

Whole life costing analysis techniques will be used to examine the costs and benefits associated with the following possible improvements to the UK road-vehicle transport system:

- (i) improve road surface evenness so as to reduce dynamic loading of vehicles and thereby extend the service life of pavements and reduce vehicle-operating costs.
- (ii) improve the evenness of approach surfaces to bridges so as to reduce the vehicular loading on bridge structures.
- (iii) improve tyre/suspension technology to reduce dynamic loading effects and achieve further increases in the benefits (i) and (ii) described above.



To carry out these analyses, use will be made of the whole life cost modelling software developed for the HA by TRL. Outputs from these analyses will provide benefit to cost ratios for each of the road-vehicle transport elements examined together with measures indicating the sensitivity of these ratios to variations in the input parameters.

In addition to the results on flexible road pavements, DIVINE provided a number of results on the effects of suspension type on bridge performance. In some circumstances, as noted earlier, these effects can be significant, and it will be necessary to ascertain which of the results are applicable to UK conditions. In particular, an attempt will be made to identify those types of bridges that may be vulnerable to these effects.

The results of the entire assessment process will form the basis of a structure for possible changes to requirements, and will provide the HA with robust evidence on which to judge whether, or not, to implement the results from the DIVINE and TRL studies. The criterion for the assessment of whether or not a measure is recommended for implementation will be based on the cost-benefit analyses which will include some parameter values which cannot be determined precisely. Sensitivity analyses will be helpful at this stage to increase the confidence in the benefits from each measure. If the potential benefits are significant, then a priority list of implementation actions will be drawn up together with estimates of time schedules and resources needed for the full implementation of the results by the HA on their trunk road network.

## 2.2 Implementation of DIVINE results In Europe

Given the harmonisation of standards at the European level, HA participation in the process of implementation of the DIVINE results in Europe provides an opportunity to maintain awareness of future developments on the vehicle-infrastructure system, and allows the promotion of dialogue and information exchange between vehicle, suspension and tyre manufacturers, pavement engineers and vehicle operators. This is an important objective for the UK, which will lead to improved mutual understanding and exploitation of technical developments in the sector.

To maximise consideration of the results from DIVINE in Europe, it was felt necessary to bring the results to the attention of a suitably qualified and experienced group who could establish and continue an inter-disciplinary dialogue. Such a group would then be able to make appropriate recommendations on implementation to the European Commission.

Following the successful use of a DIVINE Reference Group in Australasia, a similar Group has now been established in Europe. The most relevant aspects of its Terms of Reference are:

1. *To provide to policy-makers with a source of expertise on the technical and economic implications of the results of the DIVINE experiment in respect of road pavements, bridges and vehicles, to enable appropriate reviews of national and EU regulations on vehicle weights and dimensions and their effect on infrastructure.*
2. *To provide advice to national and European authorities on which of the results of DIVINE can or should be implemented, and whether further research work is necessary.*
3. *To provide a source of expertise on current and future developments in the vehicle-infrastructure system including pavement engineering and pavement performance, bridge design and response to loading, vehicle suspension systems, tyres, etc.. In carrying out this main task, to take account of all relevant environmental, technical, safety and economic factors that might influence a decision on implementation, and to identify supporting research needs.*
4. *To show how the existing results should be applied to lower-volume roads (rural roads) in Europe;*
5. *To identify problems and problem owners in the field of vehicle-infrastructure interaction, and to encourage a common understanding and language among the various stakeholders.*

### 2.3 Functional versus structural condition

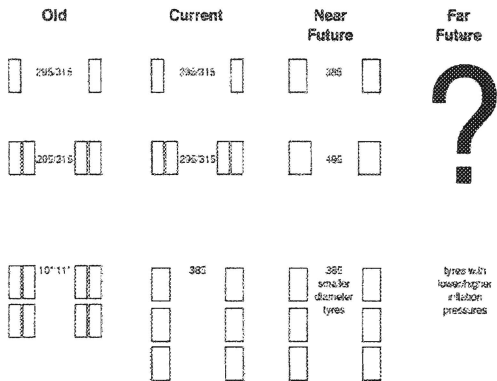
Results from the DIVINE project showed that the functional condition of a road had a large impact on the dynamic load response generated in a vehicle. The research currently in progress at TRL aims to examine this in more detail for UK roads. Sections of road will be monitored over a period of time. The condition of the road will be measured in terms of longitudinal profile and will be analysed against the dynamic response generated by a TRL instrumented vehicle. The vehicle will also be calibrated in association with WIM data. As the road deteriorates over time, the changes can be related to the changes in dynamic response in the vehicle. With further work in this area, a relationship that links the various parameters should be established so that criteria for the most beneficial vehicle-pavement system become clear.

## **3. UK AND EUROPEAN RESEARCH ON THE EFFECTS OF TYRE SIZE ON PAVEMENTS**

Figure 1 illustrates the progression of tyre development and use in Europe over recent years. The main objective of current UK and European research on this topic is to establish the relative effects of wide base single tyres and dual tyre assemblies in respect of road pavement damage, vehicle operating costs, vehicle safety and comfort, and

environment, particularly noise. Quantified and reliable information will enable national governments and the EU to consider any policies that might need to be applied in respect of the use of wide base single tyres, the recovery or distribution

Fig 1 Tyre development in Europe



of any additional costs or benefits arising from their use, and any necessary harmonisation of safety or environmental standards.

The research is being carried out in a co-operative project, the principal output from which will be an assessment of the total financial consequences of the use of wide base single tyres on heavy goods vehicles. In addition the work will lead to the development of guidelines for the minimisation of road wear, and optimisation of the safety, comfort, environmental effects, and vehicle related costs and benefits associated with the use of wide base single and dual tyres in Europe.

### 3.1 Co-ordinated experimental work.

On the basis of a state-of-the-art review, and consideration of possible future developments in tyre technology, it has been possible to define a programme of experimental work on various types and sizes of tyre, to enable a more complete description of their possible effects.

The advice of tyre manufacturers in respect of likely future developments is that:

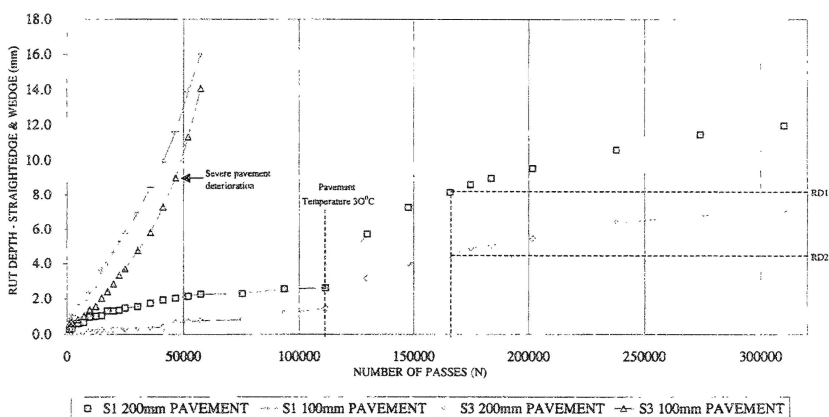
- The range of tyre sizes that can be classified as wide base single tyres could increase over the next few years.

- The range of application could increase from their present use on towed axles to their use on steering axles, and possibly on driven axles.
- The characteristics of these tyres, such as inflation pressures and diameters, could be significantly different from previous generations.

The experimental programme was therefore designed, as far as possible, to take into account these possible new developments.

At present, work on the experimental programme is in hand in the UK, the Netherlands, Portugal, and Finland. Selected results of this testing programme are given in Figures 2 and 3.

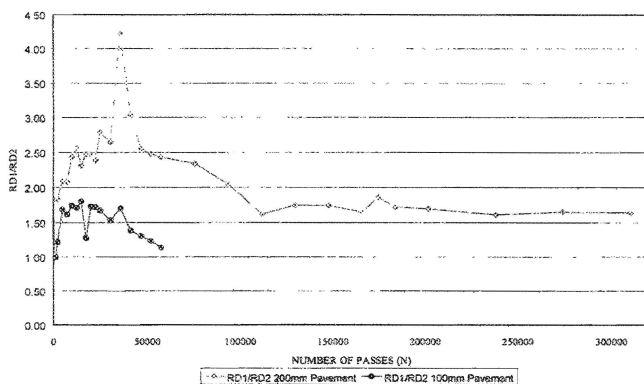
Figure 2. LONG TERM PAVEMENT TEST  
Section 1 - 385/65R22.5 Tyre Section 3 - 495/45R22.5 Tyre



These show the comparative effects of two sizes of wide single tyre: the 385/65R22.5 commonly used in Europe, and the prototype tyre size 495/45R22.5. The latter tyre is clearly less damaging to the pavement, in terms of the measured rut depth, as is shown in Figure 2. Both tyres were loaded at the equivalent of a 9 tonne axle load. The influence of test pavement temperature is also clearly seen, as the temperature is raised from 20 to 30 degrees centigrade after about 11000 applications of the wheel load.

If a comparison is made between measured rut depths at particular numbers of applications of the wheel load, then it is seen from Figure 3 that the ratio stabilises at a value of about 1.6, after the early-life loading of the pavement.

Figure 3. LONG TERM PAVEMENT TEST  
(Rut Depth 385/65 / Rut Depth 495/45) v Number of passes (N)  
Initial readings amended to 1mm



### 3.2 Application of Vehicle Operating Cost models

Work in this area is designed to identify or provide modelling tools that will help in the assessment of the overall effects of the use of different tyre types. Many different factors contribute to the costs of vehicle operation, of which tyre size and characteristics is one. The requirement, therefore, is for a model that is sufficiently sensitive to the changes likely to be brought about by the use of different tyres, and that is applicable to Europe in terms of the in-service operating conditions for the vehicle, payload types and sizes, etc.

For a variety of reasons, it has been decided that models of the type used by truck manufacturers to forecast running costs may be helpful, and the Mercedes-Benz model is being used to produce early indications of the possible difference between operating costs when two different tyre types are used. As an example of the results obtained, the model indicates that the savings to UK vehicle operators of using 385/65R22.5 wide base single tyres on 5-axle truck-semitrailers is 3.5% when compared with the same vehicle using twin 11R22.5 tyres. This saving includes all the savings due to tyre costs, fuel consumption, and reduced tyre maintenance, but excludes further possible savings due to increased payload.

Similar calculations for the possible use of new generation wide base single tyres on the drive axle of such vehicles, show that a further saving of about 1.5% is possible. These

are significant savings for the vehicle operator, particularly in a highly competitive industry, and explain why the change to the use of such equipment has been so rapid in recent years. Elsewhere in Europe, the likely savings are smaller, mainly due to the reduced taxation on fuel in many other EU countries.

### 3.3 Associated effects of the use of wide single tyres

In order to assess the overall effects of the use of wide single and dual tyres, it is clearly necessary to take into account all those effects that do not directly concern the road pavement. These will include any vehicle handling and safety effects, consideration of tyre-road noise, and perhaps other environmental considerations.

### 3.4 Assessment of overall effects

With a knowledge of the most important parameters affected, it is possible to make an assessment of the overall effects of the use of wide single or dual tyres. There are, however, a number of important additional difficulties in doing so, the source of which lie mainly in the wide range of vehicle, tyre, and pavement types in use throughout Europe, and the variety of conditions under which they operate.

The detailed methodology for the assessment is still under consideration, but it is possible to set down its main principles, as follows.

- a) On the assumption that the tyre industry will continue to develop products beneficial to the truck operator, it is further assumed that the operator will respond by introducing those products where it is practical to do so.
- b) Assess the extent of this change in terms of the possible number and type of vehicles affected.
- c) Assess the benefits to operators and national economies that arise from the change.
- d) Assess costs to road authorities of a possible increase in damage to infrastructure as a result of the change.
- e) Compare the costs and benefits.

## **4. FURTHER RESEARCH ON THE VEHICLE-INFRASTRUCTURE SYSTEM IN THE UK**

Given that the results of the work described earlier result in:

- Improved longitudinal profiles on roads on the UK primary network, and

- A set of tools that will enable the optimised selection of tyre type on heavy goods vehicles

the UK Highways Agency would like to move towards the development of an optimised vehicle-infrastructure system. Such a system will not only take into account tyre sizes, but will also consider the costs and benefits of the provision of improved longitudinal road profiles as well as the environmental and other consequences of the selection of various parameters in the system.

Such optimisation of the system would make significant contributions to the improvement of socio-economic conditions in Europe. A correctly optimised system, for example, comprising an efficient vehicle and suitably constructed road, will lead to a reduction in fuel consumption, and thereby, reduced atmospheric emissions. This will be brought about by improving the longitudinal profile of roads used for freight transport, and by equipping the vehicle with improved tyre sizes and materials, both contributing to a reduction in rolling resistance of the vehicle.

In the same way, a contribution to a reduction in vehicle/road noise may be expected, this again being partially brought about by improved tyre-road contact and reduced rolling resistance.

In terms of an improved performance of the vehicle-infrastructure system, benefits would arise in two particular areas. First, by improving the efficiency of vehicle operation, costs will be minimised, and these reductions can be passed on to clients and end-users. Second, additional benefits will arise from the reduced need for maintenance of road pavements. Savings in this area are potentially greater than those attributable to greater vehicle efficiency because of the reduction in user delay costs. Such costs dominate the maintenance costs for roads, and any reduction in the frequency or duration of road works represents significant savings.

## 5. SUMMARY AND CONCLUSIONS

The HA identified the need for research to establish the relationship of the main findings of the OECD DIVINE project to the UK trunk road network

Particular aspects from the DIVINE work are the centre of a research project now under way at TRL. Investigation of many aspects of DIVINE are included but in particular whole life costing techniques will be used to examine the costs and benefits associated with the possible improvements in road-vehicle systems. Operating cost modelling will also be used for additional information. Besides the examination of the effects of DIVINE in the UK, the HA has supported the establishment of a European Reference Group to ensure that the findings from DIVINE and associated issues are given maximum consideration by European authorities.

The project also includes work to establish a better relationship between the longitudinal profile of a road surface and the dynamic response in a heavy vehicle. The deterioration on real roads will be related to the response measured in an instrumented vehicle.

Associated work in conjunction with several European countries has also examined various wide tyres to assess the effects of these on road pavements as their use is developed in the coming years. The work has shown that not all tyres have the same detrimental effect as earlier versions, but effects can be various, in particular where they may be used in different positions on a vehicle and also considering the possible future variations in width, diameter and pressures.

The project will clarify many aspects that reflect the findings from DIVINE to the UK road/vehicle condition but will also establish the criteria for the possible development of an optimised vehicle infrastructure system that could bring benefits both to operators and in respect of a reduction in road maintenance.

The views expressed in this paper are those of the authors and not necessarily those of the UK Highways Agency, the Transport Research Laboratory or the Forum of European Highway Research Laboratories.