OECD DIVINE PROJECT AND IMPLICATIONS FOR FREIGHT PRODUCTIVITY IN AUSTRALIA

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1. INTRODUCTION

The OECD has carried out a number of infrastructure research projects in recent years under its Road Transport Research (RTR) Programme. In 1993, the OECD RTR initiated a major international infrastructure research project known as DIVINE (Dynamic Interaction of Vehicle and Infrastructure Experiment). This project follows a series of heavy vehicle and pavement-related OECD Expert Groups and the FORCE Project, which utilised the LCPC Nantes accelerated pavement testing facility to study the effect of axle load on pavement distress.

DIVINE is truly international, has a budget administered under the OECD Road Transport Research Programme, involves close interaction with national road and road research agencies and involves the private sector. The DIVINE research is being overseen by the OECD Expert Group IR6 (Dynamic Loading of Pavements) of which the author is Chairman. The DIVINE Co-operative International Research Programme is due to be completed in late 1995.

This paper presents an outline of the objectives and research directions of DIVINE and considers ways in which the results might be implemented in Australia.

2. OUTLINE OF DIVINE PROJECT

2.1 Objectives

The scope of the research includes participation by vehicle, pavement and bridge experts as well as vehicle manufacturers. The main purpose of the research is to improve vehicle construction, pavement construction and pavement maintenance.

The research will contribute to:

- encouragement of the design and use of road-friendly vehicles and procedures for the design and assessment of the road-friendliness of vehicles
- evaluation of the consequences for bridge design of introducing new vehicle technologies
- lessening of the deterioration of road networks (including pavements and bridges)
- evaluation of policy options pertaining to axle weights, axle configuration and number of axles

- allocation procedures for road costs and maintenance planning related to truck weight

- a common international basis for future joint standards, testing procedures and policy initiatives for heavy freight vehicles.

2.2 Research Programme

Accelerated dynamic pavement testing, vehicle-pavement testing and vehicle-bridge testing are being used to explore the question of the effect of dynamic loading on pavement life and bridge behaviour and essential tools are being developed for measuring, understanding and predicting dynamic loading from heavy vehicles. A further stage of the programme may be needed to extend this knowledge to a representative range of pavements, bridges and vehicle types.

The OECD DIVINE programme consists of six inter-related research elements.

(1) Accelerated Dynamic Pavement Testing

The CAPTIF accelerated pavement testing facility at the University of Canterbury, New Zealand is being used to directly compare pavement distress under the dynamic behaviour of "good" and "bad" suspensions.

A flexible test pavement is being prepared in CAPTIF's circular test track and contains primary response transducers. Two separate tracks of the test pavement will be trafficked simultaneously using 10 t test wheels - one fitted with a steel suspension and one fitted with an air spring. Measurements include the dynamic wheel load on each wheel, plus regular profile and distress measurements in each wheel track, plus primary pavement response measurements in each wheel track. Depending on the results of the first test, a possible second pavement will be constructed and trafficked in a similar manner.

This work will provide the first real insights into the extent of the effect of suspensions on pavement life and the mechanisms of pavement distress under dynamic loading.

Experts from FHWA US, VTT Finland, ARRB and Transit NZ are leading this work.

(2) Primary Pavement Response Testing

Measurement of pavement primary response to heavy vehicles provides a means of monitoring the likely damaging effects of heavy vehicles on pavements. This is being carried out under dynamic conditions. Existing strain-gauged test roads (in USA, Great Britain and Finland) are being used, in conjunction with three instrumented vehicles (operated by NRC, FHWA and TRL) to relate dynamic pavement responses to dynamic wheel loads and the pavement profile. This will provide comprehensive evidence of the effect of dynamic wheel loads on pavement primary response.

The US Federal Highways Administration is leading this work.

(3) Road Simulator Testing

Standard methods of measuring road-friendliness of vehicles are being developed. Canadian vehicle shaker (or "road simulator") facilities are being used to test the above three vehicles. The dynamic parameters of these vehicles are being measured and the vehicles are being tested on three pavements of varying unevenness and of measured profile characteristics. The test programme has been designed to fully calibrate the test vehicles, to measure their dynamic parameters, to validate the road simulator in its ability to reproduce dynamic wheel loads in response to profile inputs and to develop validated vehicle tests of road-friendliness.

The Canadian National Research Council is leading this work.

(4) Vehicle Simulation Comparison

The ability of computer models to predict heavy vehicle dynamic loading is being evaluated. The owners of existing computer simulation models have been invited to participate in an exercise to compare the results of their models with actual test results, based on the same input information being supplied to all participants. Road profile and vehicle parameter data from the Road Simulator Testing Programme is being packaged and provided to participants. The participants will then run their own models and provide the results to IR6 who will compare the results, provide feedback to participants and prepare a report with recommendations for validated and useable models.

TNO Netherlands is leading this work.

(5) Spatial Repeatability Testing

The damaging effect of heavy vehicle dynamic loading depends critically on the tendency of such loads to repeat at particular points of the pavement. Three high-speed highway sections of flexible pavements, covering a representative range of pavement unevenness, are being fitted with load sensing devices and dynamic loadings as a function of distance along the pavement are being recorded for a significant time period at each site. This work is being carried out in Germany, UK and France. Data will be analysed for variations in the accumulated dynamic loading at each load sensor.

Experts from TRL UK, LCPC France and the University of Hanover are leading this work.

(6) Dynamic Bridge Loading

It is by no means certain that pavement-friendly vehicles will also prove to be bridge-friendly. Three bridges in Switzerland with varying fundamental frequencies are being load tested dynamically using the Canadian NRC instrumented vehicle. Tests are being carried out with both leaf-spring and air suspensions.

The Swiss EMPA is leading this work.

In addition, a related study involving short-span bridges is being carried out in Australia with support from AUSTROADS. The objectives of this study are compatible with the DIVINE programme and the results will be made available to the IR6 Group as a further in-kind contribution from Australia to the DIVINE Programme.

The Queensland University of Technology is leading this work.

2.3 Output

The research will provide information on the magnitude of the effect of dynamic loading on the life of the infrastructure and on means of increasing the road-friendliness of heavy vehicles.

Direct outputs will include:

- new insights for pavement engineers into the design and maintenance of pavements for increased life.
- a method for rating the road-friendliness of vehicles
- a proven and generally useable computer model of heavy vehicle dynamic loading

- information on the dynamic bridge loading as influenced by the vehicle suspension type

- policy options contributing to improved road freight industry productivity.

3. DEVELOPMENT OF RESEARCH PROGRAMME

The DIVINE programme is broad and diverse and depends on clear identification of research plans, standardisation of research techniques and good co-ordination. The DIVINE programme is the result of a significant process of synthesis of national research programmes, national road freight policy options and international needs for vehicle performance standards.

3.1 Background

World-wide experience is that there is a good return on infrastructure research. Opportunities to increase road freight productivity and to reduce road maintenance costs provided a compelling incentive to attempt to synthesise what may appear to be an ambitious research programme.

Previous OECD Expert Groups, including Impacts of Heavy Freight Vehicles (1) and the FORCE Project (2), had focussed on the emerging importance of scientific knowledge of the effects of heavy vehicles and associated regulatory policies, including axle weight limits.

For real change to occur, it was necessary to develop a new and common language for use by scientists from all disciplines and which could be used by policy-makers.

3.2 IR2 Report

In 1988, the OECD initiated Expert Group IR2 to bring together vehicle, pavement and policy experts and produce a state-of-the-art assessment of the significance of dynamic road loading, to explain how the vehicle and pavement behave and interact dynamically, and to consider means of policy implementation to reduce road costs and improve productivity in road transport.

The Group held its first meeting in 1990 and moved to produce a review report which clarified many issues which were previously too complex to include in policy formulation. Due to the interdisciplinary nature of the group and the close involvement of vehicle manufacturers, the Group was able to identify priority research projects requiring international co-operation and the specialist expertise in the many disciplines represented on the Group.

These specialists include pavement and bridge researchers, pavement designers and managers, vehicle researchers, vehicle and suspension designers, road profile experts, weigh-in-motion experts, regulatory experts and policy experts. The interactions between these individuals resulted in significant technical growth and developed a partnership for charting the course for the future of heavy vehicles and pavements.

The DIVINE programme is based on the work of Expert Group IR2, which published its scientific review of dynamic road loading (3) in October 1992. The IR2 report found that dynamic pavement loading is currently increasing in OECD member countries, leading to an increasing rate of road wear and to constraints on productivity improvements through liberalisation of vehicle weight limits.

The IR2 report concluded that this may be counteracted by a significant increase in the use of "road-friendly" vehicles and that policy initiatives could be developed to bring this about.

3.3 Process

In the case of DIVINE, the overall process used to arrive at a viable international research programme included:

- expression of national research needs, by researchers and road managers, leading to a critical mass of support for a study by the OECD

- elaboration, review and reinforcement of national research results at an international level by the OECD (as in the IR2 report)

- development of a new and common language to encompass researchers and policy makers, by the OECD IR2 Group

- use of the new language to better focus national research needs and present an international co-operative research programme

- specification of a research programme which directly relates to economic benefits and has specific outputs which will contribute to economic benefits and can be translated into road freight transport policies in most countries; the research programme needs to be scientific in nature but capable of fully demonstrating existing research knowledge and enhancing the credibility of the research.

3.4 Role of Co-operative International Programmes

The DIVINE Co-operative International Research Programme differs from most research efforts of national research institutes, national co-operative programmes and international standards organisations in that:

- it addresses a broad and complex question
- it is truly multi-disciplinary and crosses the interface between vehicles, roads and bridges
- the close interaction between researchers improves scientific standards, and enhances parallel national research projects
- in-built peer review increases the credibility of results
- each element of research may be carried out using the most appropriate facilities and locations
- quality audit will be carried out on the final results
- the results will be developed and presented as a complete package and will be expressed in a readable and non-technical way
- total costs, viewed in relation to outputs, are significantly reduced and efficient use of scarce research funds is enhanced.

3.5 Problems in Developing the DIVINE Programme

Potential problems with co-operative international research programmes are:

- a large amount of time and effort required to set up management and administrative arrangements
- ownership and availability to all of the results

- the need to compromise on test plans, in order to accommodate prevailing conditions in all participating countries

- due to the need to develop confidence in some existing results, every element of the research may not always appear to be at the scientific cutting edge.

In the case of the DIVINE Programme, significant difficulties were encountered with regard to:

- the wide scope, large number of interconnecting projects and significant total cost of the programme may be viewed as ambitious

- even then, not all national objectives can be addressed fully

- trying to obtain financial commitment from a large number of countries for a large overall objective when the terms of individual commitment may require changes to the research programme

- trying to obtain funding from all available sources within each country; the need to seek industry support on a national rather than an international basis and difficulty of seeking industry support within some countries

- the tendency of industry to offer equipment or practical assistance rather than finance for the programme

- the high cost of transporting instrumented research vehicles between countries

- raising and assuring the total amount of money needed for the DIVINE Programme without compromising on the total programme of research needed to meet high objectives and expectations

- significant delays in fully developing and funding the DIVINE Programme and the relatively long time to carry out the total programme, which make it difficult to keep up with the demands of national policy development cycles

- increasing commercial orientation of research institutes which restricts the travel of national experts and increases financial resources required by the project.

4. DIVINE RESEARCH INTO DYNAMIC BRIDGE RESPONSE

4.1 Findings of IR2 Report

The OECD IR2 report [3] found that, in general, the dynamic interaction between heavy vehicles and bridges is rather different from that between heavy vehicles and pavements and that it would be difficult to derive useful transport policy initiatives without giving specific consideration to bridge effects.

The response of a bridge to moving constant or moving dynamic wheel loading is greater than its response to stationary constant loading:

- for very short span bridges, moving constant vs stationary constant loading can increase the bridge response significantly

- for bridges with high natural frequencies, the bridge response is proportional to moving dynamic wheel loads

- for bridges with lower natural frequencies, the bridge interacts with the vertical dynamics of the vehicle, especially with the vehicle bounce and pitch motions, to further increase the bridge response to moving dynamic wheel loading; it is unusual for axle bounce motions to affect bridge responses.

Bridge design codes include both 'static' and 'dynamic' components. The stationary constant wheel loads of representative trucks are used to compute bridge stresses. The dynamic component is represented by an increase in the stationary constant loading. In many codes the "dynamic factor" used to increase stationary constant loads is dependent on the natural frequency of the bridge.

New bridge design approaches are being researched which model both the bridge and vehicle and take into account vehicle vertical dynamics. This is more readily applied to single span bridges than to multiple-span bridges.

Loss of serviceability means that the structure retains part or all of its load-carrying capacity, but no longer satisfactorily fulfils its purpose, due to:

- pavement and deck deterioration
- excessive deformation of the structure
- joint deterioration, or
- excessive vibration.

Usually, pavement and joint deterioration is subject to maintenance before structurally hazardous vibrations are generated by traffic over the bridge.

Design against fatigue is becoming a more important part of bridge design codes, and this requires better knowledge of wheel loads. This is currently addressed by attempting to determine representative data on stationary constant wheel loads, using WIM methods.

4.2 DIVINE Bridge Research

Background

The vehicle/bridge interaction process is mainly governed by the frequency relationship between the vehicle's dynamic wheel loads and the bridge's natural frequencies. Further parameters are the mass relationship between vehicle and bridge and the time duration of the interaction (resonance effects).

Systematic research into the vehicle/bridge interaction has been performed using vehicles with mechanical suspensions. Bridges having a fundamental natural frequency of f = 3 Hz responded more strongly that other bridges and this is related to the fact that the dominant wheel load frequency for mechanically-suspended vehicles is in the region of 3 Hz.

Vehicles with air suspensions can be expected to show a dynamic wheel load pattern which is substantially different from that of mechanically-suspended vehicles:

- the wheel load frequency will be f = 1.5 - 2 Hz and frequencies of 3 Hz will not occur

- wheel load frequencies related to axle hop vibrations (f = 10 - 15 Hz) will occur with considerable magnitude for rough pavements and relatively high vehicle speed; this is not generally the case for mechanically-suspended vehicles.

The first of these issues will be studied in the Swiss testing programme being carried out for DIVINE. The second issue will be addressed by the AUSTROADS/QUT project being carried out co-operatively in parallel with DIVINE.

Swiss Test Programme

The basic question to be answered is:

what will be the response of a bridge with a fundamental frequency f = 1.5 - 2 Hz (and a span of 70 - 80 m) to the dynamic action of a vehicle equipped with air suspension in relation to the response of a 3 Hz bridge (with a span of 40m) to the action of a mechanically-sprung vehicle?

The results will have significance for validating current highway bridge design procedures as far as dynamic bridge response to the implied traffic loads is concerned (in terms of dynamic load allowance, dynamic increment and amplification factor).

Three bridges have been selected for the test programme, with fundamental frequencies of 1.5, 3 and 4.5 Hz. The NRC fully-instrumented five-axle tractor-semitrailer, equipped with interchangeable mechanical and air suspensions, will be used for the test programme.

The tests will consist of driving the vehicle at different speeds in the range 5 - 80 km/h over the bridges and measuring:

- the vehicle's dynamic wheel loads
- the dynamic bridge response (in terms of deflection) at five to ten locations on the bridge
- the pavement longitudinal profile.

The following data analysis will be carried out:

- time domain analysis of the bridge response (dynamic increments)
- frequency domain analysis of dynamic wheel loads and bridge response (auto power spectra, cross power spectra)
- time domain analysis of the dynamic wheel loads to study spatial repeatability.

Comparison of these results with the large number of results already available for a wide range of bridges interacting with mechanically-suspended vehicles will provide information on which bridges are sensitive to air-sprung vehicles and the extent to which air-sprung vehicles may excite these bridges.

Australian Test Programme

Plans for the Australian tests are currently being developed. It would appear that two instrumented tractor-semi-trailer vehicles will be used, equipped with instrumented axles. One vehicle will be mechanically-suspended and one will be air-suspended; the dynamic characteristics of the suspensions on both vehicles will be measured and efforts will be made to ensure that the dynamic responses of the suspensions are similar to those used in the Swiss tests. Interaxle spacing in triaxle groups will be included as a variable in the testing. Two bridges with natural frequencies in the range 10 - 15 Hz will be selected for testing and bridge deflections and strains will be measured. Bridge and approach profiles will be measured with a portable profilometer.

The results will be analysed to provide:

- bridge natural frequencies and damping
- static response in comparison to analytical models
- dynamic response
- dynamic increment versus suspension type and speed
- fatigue.

5. MANAGEMENT & FUNDING OF DIVINE

5.1 IR6 Structure

The IR6 group has overall responsibility for the development and conduct of the research programme. A management system is needed which will provide the necessary administrative, budget and quality controls, monitor outputs and progress reporting and meet deadlines. At the same time, a synergistic, co-operative approach needs to be retained.

IR6 members obtain national feedback concerning research priorities, industry requirements and the availability of research facilities for the project. Contact with industry is mainly at the national level and through vehicle industry representation on IR6.

IR6 has set up Research Leaders and Analysis Groups for each of the six research elements. Research Leaders are responsible for technical quality, and are advised by Analysis Groups who also carry out the later stages of data analysis. The research, including preliminary data analysis, is actually carried out by Research Contractors and Lead Centres.

The overall DIVINE Programme is managed by a Programme Manager, under contract to the OECD. An Executive Committee operating under the OECD RTR Programme is responsible for overseeing budgets and progress.

5.2 Funding Arrangements

The DIVINE Programme operates under an OECD budget which was developed according to the following principles:

- common charging rates and lowest possible overhead component included in costings
- only project-specific research activities and travel is charged to the OECD
- "in-kind" contributions of the use of research facilities at reduced rates and access to the results of parallel national studies are not costed into the OECD budget
- some countries place caveats on their financial contributions and require that some or all of the money is spent in that country; this can be generally accommodated, provided that such stipulations are in the minority.

The total budget required for the DIVINE Programme is approximately US$1.5 million, spread over a period of two years. In addition, "in-kind" support valued in excess of US$1 million is included in the DIVINE Programme, but is not part of the OECD DIVINE Budget. Contracts are currently being set up to cover the first year of the DIVINE Programme. Further financial assistance and strong commitment to the overall DIVINE objectives and outcomes is needed to assure the financing of the second year of the OECD DIVINE Budget.

6. IMPLEMENTATION AND BENEFITS - AUSTRALIAN VIEWPOINT

6.1 Needs

Australia has actively supported international co-operative research into the dynamic loading of pavements and the interaction between heavy vehicles and roads and bridges. In 1989, Australia prepared a background paper to assist in initiating the OECD Expert Group IR2. Australia's interest was in ways of implementing road-friendly vehicles which would take into account the global nature of the vehicle industry, difficulties in legislating unique vehicle standards and implications for road user charging mechanisms.

Since that time, interest in improving international competitiveness of Australian industry, and in the role of micro-economic reform in achieving productivity and efficiency improvements has accelerated. Steps have been taken to reduce administrative burdens placed on road freight transport and to harmonise road vehicle regulations throughout the nation. However, it is apparent that increasing demands for road freight productivity improvements through "non-selective" increases in axle loads are no longer sustainable in terms of road maintenance costs and bridge loadings.

Increased weight limits result in greater productivity for truck operations and lower costs. To a large extent, these savings are passed on to the users of transport services and result in lower transport costs to the community. However, increased costs in the construction and maintenance of the nation's highways are an increasingly important limitation on the extent to which economic benefits may be achieved in practice.

Australia is currently seeking to implement policies whereby road wear may be reduced and productivity many be increased. The National Road Transport Commission (NTRC) is currently undertaking a review of axle weight limits, particularly for road-friendly vehicles. The NRTC has expressed a strong interest in the results from the DIVINE Programme.

6.2 Process and Benefits

IR2 Report and Conference

The IR2 report was presented at a conference held in Melbourne in 1992 and Australian government, industry and research representatives had the opportunity to hear directly from the IR2 experts. This was beneficial in creating increased technical substance for existing proposals for road-friendly vehicles and in re-focussing research needs from the Australian viewpoint.

IR6 Reference Group

Australia also set up a national IR6 Reference Group in 1992, for the purposes of identifying areas of greatest interest to Australia, discussing how Australia could best contribute to the project and outlining methods of disseminating the findings of IR6 in Australia. This group has representation from all relevant government agencies, the transport industry, the vehicle manufacturing industry, and research agencies.

The Reference Group adopted and re-affirmed the credo of the IR6 DIVINE Project:

"The overall objectives of research into the pavement-vehicle interaction and bridge-vehicle interactions are to reduce the total costs of road transport to society, to improve safety and to reduce environmental impacts. These objectives may be addressed by providing better-performing vehicles, providing and maintaining stronger and smoother pavements and building safe bridges."

The Reference Group also identified the following key issues:

- quantification of wear of Australian pavements in relation to axle weight and suspension type, including the development of predictive models

- quantification of economic benefits of IR6 research outcomes

- expediting consideration of bridge response issues.

The Reference Group decided that it could best contribute to the IR6 project through providing financial support - directly from those organisations represented on the group - and by providing technical expertise. Australia has contributed approximately $120,000 directly to the OECD DIVINE budget and is providing in-kind assistance valued at a further $250,000. DIVINE funding is being provided by the following Australian Government agencies and Australian companies:

- AUSTROADS
- Department of Transport and Communications
- National Road Transport Commission
- Mercedes-Benz (Australia) Pty Ltd
- York Transport Equipment Pty Ltd
- Australian Bus and Coach Association.

Dissemination and implementation of the IR6 findings will be done principally through road authorities and the road transport industry, and it is recognised that different approaches may be needed for these two sectors so that industry uncertainty and speculation are avoided. The Reference Group has so far provided a good focus for translating government and industry interests into research needs.

<u>NRTC Review of Mass Limits</u>

The National Road Transport Commission announced a review of Australian axle weight limits in 1993 and has focussed the review on the feasibility and net benefits of increasing axle weight limits for vehicles fitted with road-friendly suspension systems.

The components of this review are:

- definition of "road-friendly" vehicles and means of assuring compliance with a more complex axle weight limit regime

- assessment of effects on roads and bridges

- safety and environmental impacts

- operational effects on a current national fleet of which only a minority of vehicles may be "road friendly"

- implications for variations in road user charges.

Benefits of IR6 Research

In relation to national interests to accelerate the introduction of productivity benefits, the IR6 project has a relatively long time scale and it may be necessary to make an interim estimate of the benefits of the IR6 findings in Australia. Such an estimate would tend to be conservative, with the possibility for further consideration when all IR6 results become available.

It is generally considered that the largest economic benefits will be obtained through improved vehicle standards qualifying industry for improved productivity, although other categories of benefit are also anticipated, as indicated in Table 1. Benefits through the implementation of vehicle standards are generally able to be realised sooner than benefits related to road standards.

TABLE 1. BENEFITS OF IR6 RESEARCH

BENEFIT SECTOR	MEANS OF IMPLEMENTATION	
	VEHICLE STANDARDS	ROAD STANDARDS
Industry Productivity	significant reduction in vehicle operating costs - available in short term	anticipated reduction in vehicle operating costs - available in longer term
Public Road Costs	anticipated reduction in road maintenance costs - available in short term	anticipated reduction in road maintenance costs - available in longer term

7. CONCLUSION

The OECD DIVINE Programme provides an example of co-operative international research which is expected to provide an important package of useable results addressing a complex infrastructure issue at very reasonable cost, and hopefully in a relatively short time.

The main benefits of co-operative international research are: credible, focussed, timely, integrated, affordable, policy-related outputs in a complex area. Possible disadvantages are necessary compromises on research specifics, resources required to set up and administer the programme, and time required to develop and fund the programme.

Additional long-term benefits for participating countries are:

- enhanced research capabilities for national projects as a result of the interaction of researchers on an OECD project

- enhanced visibility of national research capabilities, both nationally and internationally.

Full national commitment to the DIVINE Programme is required to assure the integrity of the outcomes and potential benefits of the international research programme. In the case of Australia, the potential economic benefits of the OECD IR6 research are recognised, benefits to national productivity are being examined and an interactive process involving the work of the OECD Expert Group and a national Reference Group is being used to assist in funding the DIVINE Programme and in implementing the benefits of the research.

8. REFERENCES

1. OECD (1983) Impacts of Heavy Freight Vehicles. Paris.

2. OECD (1991) OECD Full-Scale Pavement Test. Paris.

3. OECD (1992) Dynamic Loading of Pavements. Paris.

9. ACKNOWLEDGMENTS

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