Technical issues — the way forward

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Many important technical issues have been raised at this conference. The purpose of this paper is to bring these together and to suggest next steps.

1. INTRODUCTION

The title *Third International Symposium on Heavy Vehicle Weights and Dimensions* belies the extent and depth of the technical programme that has just been completed. A more appropriate title would have been *Interaction Between Vehicle and Road.* With the word *road* changed to *track*, that was the title of a conference of the Railway Division of the Institution of Mechanical Engineers held in London in 1965. Many of the rail problems that were discussed then have close parallels with topics discussed at this conference. There was particular interest in the static and dynamic properties of rail track with a key paper by F Birmann of the Deutsche Bundesbahn entitled *Track parameters: static and dynamic.*

Rail track suffers from many of the same problems that roads experience. For example rail cracking is an insidious and repeating problem where a transverse crack grows through the steel rail until eventually the rail fractures. Uneven wear on the top of the rail generates corrugations which increase noise while at the same time increasing the dynamic loading between wheel and rail and increasing track and train wear rates. A topical example is the UK-France Channel Tunnel. It is possible that rail track through the tunnel will corrugate. If it does so, the ambient noise level inside the Channel Tunnel may increase by up to 10 dB.

At this conference we have heard presentations on the stability of articulated and trailer vehicles. The paper by Fancher and Winkler dealt with the rearward amplification of the lateral movement of coupled vehicles. The lateral stability of trains is an important aspect of their performance and can lead to an uncomfortable ride and to potential derailment situations.

The intention of the railway engineer is to provide track which is as far as possible straight and level. This is not always achieved but it is practicable, on modern track bed constructions, to obtain alignment accuracies to the order of millimetres on long lengths of track. This is considerably greater than the accuracy achievable on public highways.

The parallel between railway technology and road vehicle and road highway technology is one that we should not overlook. The railway community have made giant strides between 1965, when their conference on the interaction between vehicles and track was held, and the present date. It is important that those of us who work with heavy road vehicles should be aware of what has been done in that sphere and should take advantage of knowledge gained there.

2. THE SCALE OF ROAD PROBLEMS

In his opening address, Byron Lord quoted some startling statistics for the USA.

In that country alone, on average in excess of 100 people are killed on the roads everyday. Worldwide, the figure must be several times that number, perhaps the population of a jumbo jet. If a jumbo jet were to crash today, the consequences of that crash would become major news. Were it to

USA statistics
$800 billion per year spent on transportation
187 million vehicles travel 2.1 trillion miles per year (over 11 000 miles per vehicle)
50 000 road deaths annually
250 000 miles of roads below acceptable standards
134 000 bridges have speed/weight restrictions
8 billion person hours of delay per year (30 hours per person ?)

Box 1 Source: Byron Lord, this conference

happen again tomorrow, there would be front-page headlines around the world. Were it to happen tomorrow, and tomorrow, and tomorrow, and to continue happening, Governments would be taking emergency action. Here we have a situation with virtually no one noticing except those who are directly involved. It has therefore been right that there have been papers at this conference addressing safety issues and I shall return to that topic later.

Equally startling is the quarter of a million miles of roads below acceptable standards in the USA and the 134,000 bridges with speed or weight restrictions.

The problem is a vast one and it raises a fundamental question about who pays for road transport.

In his introductory paper describing the forthcoming report of OECD Working Group IR2, Peter Sweatman suggested (box 2) that the annual cost of road maintenance worldwide may be in the order of £50 billion but that the annual operating costs of trucks and lorries may be in the order of £1500 billion. These figures assume a 30-year life model for the roads and a 5-10 year life model for the trucks. The assumptions are obviously debatable but the upshot is that the ratio of truck costs to road costs is in the order of 30:1. On that basis it can be argued that much more money should be spent on the construction of stronger and safer roads and that it is unrealistic to expect truck operators to bear the full brunt of necessary improvements.

In the UK, estimated road expenditure in 1991 (box 3) included the sum of £1.2 billion for resurfacing and patching roads.

World estimates	
Annual cost of roads (30 year life model)	£50 billion
Annual operating costs of trucks/lorries (5-10 year life model)	£1500 billion
Ratio of truck costs to road costs	30:1

Box 2 Source: Peter Sweatman, this conference

The total cost per year is in the order of £6 billion. An estimate of the cost of traffic congestion in the UK, based on an OECD suggestion that this may be calculated on the basis of a country's GNP, leads to the conclusion that in the UK the cost of traffic congestion may be in the order of £15 billion a year.

Also in the UK, the income received by the Government as a result of fuel tax and vehicle licensing is approximately 2.5 times the Government's total expenditure on roads (box 4).

UK estimated road expenditure 1991	
New construction	£2.3 billion
Resurfacing and patching	£1.2 billion
Bridges, crash barriers, signs, lighting, drainage, etc	£1.4 billion
Policing	£0.4 billion
Hospital services (excluding compensation for pain and suffering)	£0.3 billion
Total	about £6 billion per year
Costs of traffic congestion	
OECD estimate within EC is 3% of GNP	
United Kingdom estimate	£15 billion per year

Box 3 Source: The allocation of road track costs in the UK 1990/91, DTp, April 1990

This disparity, which I believe also exists in a number of other countries, means that the road user pays much more than he or she receives in return. Of some £14 billion received by the Government in the UK per year, only £6 billion is spent on road construction, maintenance and servicing. The remaining £8 billion goes into the important areas of health care, welfare, education and defence from which the revenue raised from other sources is insufficient.

3. TRAFFIC GROWTH

In his paper on *Lorry transport: the British experience*, David Lyness included figures for predicted traffic growth in the UK. These included figures for the growth of road freight (box 5).

UK Government Income & Expenditure on Roads				
	Income/vehicle		Spending/	Ratio
	Fuel	Licence fee	vehicle	
Under 3.5 t	£324	£105	£136	3.2:1
Over 3.5 t	£2919	£1231	£3206	1.3:1
All vehicles	£360	£119	£193	2.5:1

Box 4 Source: The allocation of road track costs in the UK 1990/91, DTp, April 1990

If these figures are correct, and generally traffic growth has exceeded forecasters' predictions in the past, the rate of road wear in the UK is likely to double in the next 20-25 years (assuming a simple linear relationship between freight volume and road wear). Reductions in the dynamic load coefficient (dynamic load/static load) of lorries/trucks although important will not be enough to offset this increase. Nor will better load distribution or more axles, important though these matters are, be sufficient. The essential requirement is surely that road construction must ensure that roads are stronger to cope with the loads to which they will inevitably be subjected.

Figures for the predicted growth of road maintenance costs were included in the paper by P J von Becker.

Predicted traffic growth in the UK		
Amount of road freight in billion tonne kilometres		
1965	1990	2015
69	136	220-300

Box 5 Source: David Lyness, this conference

Dr von Becker pointed out that, because of the predicted increase of axle loads and traffic volumes in Germany, the predicted cost of maintenance will increase by some Dm 700 million in the next ten years.

One can see from these figures that the sums of money involved are truly staggering, even by standards of the aircraft or space industries.

4. ROAD AND BRIDGE MECHANICS

There is not time to mention all the excellent papers that have been presented to this conference, but I do want to highlight just one or two which I believe are especially relevant or especially appropriate to the work that lies ahead.

The paper by F Wu was an experimental study of in-service cracking of bituminous pavements. Dr Wu concluded that

Field investigations of in-service bituminous pavements have given little evidence for the widely held concept of road based fatigue cracking. Surface cracks were often observed where the road based layers were still intact without any sign of cracking.

Since fatigue cracking is unlikely to be a major mechanism for the structural weakening of the road base, a closer examination of some aspects of the current practice of pavement design and condition assessment is needed.

That is an understatement. The findings reported in this paper challenge part of the accepted practice of pavement design. If these experimental results are borne out by more comprehensive studies, then pavement engineers will have to completely re-think their design procedures which will be found to have been based on an inadequate hypothesis.

I would like to mention also the short paper by A E Woodside and G X Liu which is concerned with the development and testing of a special-purpose strain gauge transducer to examine interfacial stresses on the chippings and binder at a pavement surface. The problem of surface wear is extremely important because a great deal of money has to be spent on surface dressing roads to maintain their skid resistance. It is good that this topic is being addressed at a fundamental level and the equipment that was described appears to offer good prospects for the collection of valuable experimental data.

Recently I was in Washington DC and had the opportunity to examine the badly damaged road surface on one of the main bridges across the Potomac River. The matter of bridge vibrations is one that has been considered by a number of papers at this conference. The evidence of crazing in one lane of the road and of substantial surface failure and patching in another lane indicates merely the complexity of this problem and the detailed data on pavement and bridge materials that is going to be needed to understand properly what is happening. The importance of bridge/vehicle interaction and the influence of suspension design has been highlighted.

Pavement engineers have the difficult problem of distinguishing between system failures and component failures. The structure of any road is a complex mixture of nonlinear, time-dependent and temperature-dependent components. Full-scale experimental wear tests necessarily involve the whole system. But fundamental performance data for the components is still lacking. There needs to be an urgent experimental programme to discover more about the fundamental behaviour of road materials. Making an aircraft analogy, designers need fatigue data on metal alloys before they can predict an aircraft's performance under fatigue loading. It is unsatisfactory to find, as Wu and his colleagues apparently have found, that bituminous pavements do not fail in the way that their designers have *assumed* that they would fail. There is too much at stake to allow road design to be based on wrong assumptions. The development of satisfactory design procedures can only be based on reliable data on the wearing properties and failure mechanisms of road materials. So far we do not have that data

5. SPATIAL REPEATABILITY

One of the enduring results of this conference will undoubtedly be that spatial repeatability of road loading appears to have been measured for the first time. I mention particularly the paper by L Gyenes and C G B Mitchell who said the following:

The effect of the spatial concentration of dynamic loads is additive to the effects of randomly distributed dynamic loads predicted by Eisenmann (1975).

There can be little doubt that Eisenmann's predictions substantially underestimate the effect of dynamic loads on road wear.

It is therefore even more worthwhile than had previously been thought to improve the suspensions of heavy vehicles to reduce dynamic wheel loads.

The prospect of dynamic loads being concentrated at particular positions on the road is something that I think was foreseen first by Ervin and others at UMTRI in 1983. It was used in the prediction of road damage by David Cebon in his PhD thesis in 1985 and was also discussed by Professor Hahn in 1987. It is now a major topic for research and I mention, in addition to those names, also the names of David Cole and Matti Huhtala who have carried out confirmatory calculations. But the measurements that Gyenes and Mitchell report appear to be the first published results which bear out predictions from road measurements.

The work that is continuing in the UK on the A34 road near Oxford and which will shortly be started in Germany near Hanover is necessary to confirm the experimental findings to date. But I think that this conference will be remembered for the fact that the topic of spatial repeatability has not only become acceptable: it has become conventional wisdom even before comprehensive results have been obtained by measurement.

6. MAJOR FINDINGS

From these papers, and others at this conference, I am led to the following principal conclusions on the subject of vehicle-road interaction:

(i) There is a serious lack of knowledge of the fundamental mechanisms of road wear: the fourth-power law cannot be relied on.

(ii) Improved understanding of vehicle dynamics has been obtained and reliable calculations of road loads are now possible.

(iii) There are good prospects for reliable road load measurements soon, using currently available measurement technology.

(iv) A theoretical road-life model will be possible shortly but it will have to be based on conjectural models of road wear.

The consequences of these conclusions are:

(v) We shall soon know all about road loading but not about its effects on polishing, rutting, cracking and other modes of failure of the road.

(vi) Road damage predictions will not be reliable because there is inadequate data about material properties and failure mechanisms.

The action that is needed as a result of these conclusions is:

(vii) A major international effort to learn about the wearing and failure mechanisms of road materials. This issue must have the highest priority and is one which deserves international support as a matter of extreme urgency. If the road wear mechanisms are better understood it will be possible to construct stronger roads, possibly without additional cost. As the figures given above indicate, the stakes are enormous and there are massive savings to be made. If researchers can construct and carry through imaginative programmes aimed at obtaining *fundamental* data on road materials, they will have made a magnificent contribution to what is surely one of the major problems of the civilized world.

7. REGULATIONS

In his keynote address, Luc Werring described to us very clearly the complicated process of negotiation and lobbying which is part of reaching international agreements. If I can paraphrase what he said in a short sentence, I would put it like this:

Regulations necessarily simplify and compromise.

It seems to me that to help the regulators we have to ask ourselves the question:

How can regulations encourage genuinely road friendly suspensions without needlessly reducing design options ?

We know that existing EC regulatory proposals favour airbags over steel springs for driven axles. Their problem is that they do not address other design features, for example:

- super single tyres v dual tyres on trailer axles
- static load sharing between multi-axles
- the dynamics of tandem suspensions.

With such a complicated technological problem as dynamic road loading, it is hard to see how more widely acceptable regulations can be drafted unless a realistic performance test can be devised. Therefore a consequential challenge to the engineering community is to seek answers to the question:

Can a realistic performance test be devised?

8. PERFORMANCE TESTING

In their paper L Gyenes, C G B Mitchell and S D Phillips reported that

Considerable research will be required to develop and validate a realistic performance test for road-friendly suspensions.

In his verbal presentation, Dr Mitchell said that

Highway engineers cannot build test roads with calibrated undulations.

As I have already mentioned, railway tracks can be laid down to very high standards of level and alignment and there is no reason why, if railway technology is followed, such standards could not be achieved for the bed of a calibrated test road. On such a flat concrete table, it would surely be possible to construct a test road with the desired height and cross level variations for an agreed standard test.

In their paper these authors discussed the possibility of a slow-speed performance test using a road structure artificially contracted in the direction of travel. It seems to me that this proposal introduces extensive complications in the measurement and analysis areas and is unlikely to be accepted by the road transport community at large as an acceptable test. Far better to have a genuine piece of realistic road, constructed to high accuracy, and used at representative road speeds.

9. OTHER MAIN TOPICS

I am glad that issues of safety have been addressed by the papers dealing with the roll-over and manoeuvrability of heavy vehicles. The UK took the lead in the introduction of side underrun guards several years ago but, as David Lyness pointed out, the research on which the design of underrun guards was based was itself conducted many years ago. There is ongoing work on vehicle safety among the operators, particularly some of the firms in the oil industry, but there is not as yet a coordinated programme for the advancement of heavy vehicle safety. That is surely something that needs looking at.

Unfortunately the absence of its authors led to the paper entitled *Semi-active suspensions to reduce road damage: theoretical design and implementation* not being presented to the conference. That was a pity because one of the underlying themes, referred to from time to time by a variety of speakers, was the possible potential of cheap semi-active suspension elements. The extent to which these will permit real gains of performance sufficient to justify their cost remains to be seen but it is important for this technology to remain on the agenda and for work to continue as a possible line for product development.

The advent of weigh-in-motion equipment has now resolved itself into a battle between strip sensors which operate either on the capacitance principle or on the piezoelectric principle. We shall see in due course which of these two systems triumphs. There is no doubt of the commercial importance of effective weigh-in-motion systems. It is interesting, I think, that the effective operation of such systems depends on knowledge of vehicle dynamics and of the acquisition and processing of data obtained from an array of measurement sensors. As a result of improvements in this field, the introduction of automatic axle weight enforcement procedures is likely to follow before long. No longer will it be necessary to stop traffic and laboriously weigh axles. Instead instrumented road sections will permit vehicle and axle weights to be recorded automatically and offenders will probably find the first that they know of their transgression is the arrival of an appropriately worded letter in the mail.

10. ENVIRONMENTAL MATTERS

An outstanding feature of this conference has been its interdisciplinary nature. Civil and mechanical engineers have met together to discuss matters of common interest and to learn something of the other's problems and priorities. It is a pity that the conference was necessarily organised with parallel sessions so that the civil community and the mechanical community did not always meet together. Nevertheless, much has I think been gained. But there is a criticism. Where were the environmental engineers ?

At least there was one paper by A Gurney which addressed environmental issues. Although quite a short paper reporting a limited amount of data obtained from public consultation, it made clear that public concerns are

(i) Safety
(ii) Noise and Vibration
(iii) Pollution

in that order and that the public's perception of nuisance increases with the number of axles rather than with the overall size of a heavy vehicle.

Since whatever we do will eventually be implemented (or not) as a result of political decisions, it is most important to take full account of public perceptions. I suggest that the proposed Road Transport Forum, the successor body to the informal group which has organised this conference, should make all environmental issues priority subjects. These are surely as important as the more straightforward issues of vehicle and highway design. Without changing public perceptions, road-friendly lorries may be wrongly classed as unfriendly juggernauts.

11. THE GENTLE JUGGERNAUT

Some years ago the Economist magazine published an article entitled *Back to the drawing board for lorries*. The essence of the article was that the performance of a freight vehicle should be comparable in every way with the performance of a passenger carrying vehicle. It was argued that trucks and lorries should have the same handling properties, the same braking performance, the same noise and vibration characteristics, the same road loading potential and should be of no greater danger to the public than a private car. The article had many flaws but its central message is one that it behoves us to consider. If a 40 tonne vehicle has eight axles equally loaded, its axle load will be 5 tonnes. Compare that with a vehicle with an 11.5 tonne drive axle and there is a substantial difference in the road damaging potential, whatever the road wear law is finally found to be. Introduce steered intermediate axles, improved braking, automatic checks of tyre pressure and weight distribution, noise and vibration control measures and possibly active or semi-active load levelling and suspension control, and the commercial vehicle that is commonplace today would be transformed.

Rightly this conference is emphasising urgent research on pavement mechanics and on the determination of fundamental materials data for road materials. That must be the first and highest priority. All the financial figures suggest that that is where the primary effort should be. But we should not lose sight of the fact that roads are for vehicles and roads have to be shared with much lighter, more versatile and more easily controlled passenger vehicles. To remain acceptable members of the road-user fraternity, commercial vehicle designers must take account of all the improvements that are genuinely possible within adequate cost-benefit constraints. That is something for the engineering community to address rather than for a primarily financial magazine to lecture us on.

I wish the new Road Transport Forum all success in addressing these complex but vitally important issues and look forward to the next symposium on Heavy Vehicle Weights and Dimensions in Michigan in 1995.