Transport Research Programme

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1. Project Title

Implication for Ireland's Road Infrastructure of Heavier European Trucks

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3.   List of specific deliverables and outputs arising from the project.

List of peer reviewed publications:

Gonzalez, A., Papagiannakis, A.T. and OBrien, E.J, "Evaluation of an Artificial Neural Network Technique Applied to Multiple-Sensor Weigh-In-Motion Systems", *Journal of the Transportation Research Board*, Record 1855, Transportation Data Research, pp.151-159.

O'Connor A.J. and OBrien, E.J., 'Mathematical traffic load modelling and factors influencing the accuracy of predicted extremes', *Canadian Journal of Civil Engineering*, **32**, 1, 2005, pp. 270-278.

Brady, S.P., OBrien, E.J. and Žnidarič, A., 'The Effect of Vehicle Velocity on the Dynamic Amplification of a Vehicle crossing a Simply Supported Bridge', *Journal of Bridge Engineering, ASCE*, in press, 2005.

Brady, S.P. and OBrien, E.J., 'The Effect of Vehicle Velocity on the Dynamic Amplification of Two Vehicles crossing a Simply Supported Bridge', *Journal of Bridge Engineering, ASCE*, in press, 2005.

Getachew, A. and OBrien, E.J., 'Simplifed Site-Specific Traffic Load Models for Bridge Assessment', *Structure and Infrastructure Engineering*, in press, 2005.

Li, Y-Y, OBrien, E.J. and González, A., 'The Development of a Dynamic Amplification Estimator for Bridges with Good Road Profiles', *Journal of Sound & Vibration*, in press, 2005.

OBrien, E.J. and Caprani, C.C., 'Headway Modelling for Traffic Load Assessment of Short to Medium Span Bridges', *The Structural Engineer*, Vol. 83, No. 16, 16th Aug. 2005, pp. 33-36.

OBrien, E. J., Quilligan, M. J. and Karoumi, R., 'Calculating an Influence Line from Direct Measurements', *Bridge Engineering, Proceedings of the Institution of Civil Engineers*, in press, 2005.

List of conference papers

González, A., O'Connor, A.J., OBrien, E.J., 'An Assessment of the Influence of Dynamic Interaction Modelling on Predicted Characteristic Load Effects in Bridges', *Proceedings of the 3rd International Conference on Current and Future Trends in Bridge Design, Construction and Maintenance*, Eds. B.I.G. Barr et al., Shanghai, China, Thomas Telford, Sep./Oct. 2003, pp. 241-249.

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OBrien, E.J., Žnidarič, A., González, A., 'Assessing the Safety and Serviceability of Existing Highway Structures', *9th International Bridge Management Conference*, Transport Research Circular No. E-C049, TRB, Orlando, USA, Apr. 2003, pp. 309-322.

OBrien, E.J., Belay, A.T., Collop, A.C., 'The use of Truck Populations Models for the Calculation of Pavement Design Life', *Proc. 8th Int. Symp. on Heavy Vehicle Weights and Dimensions*, South Africa, Document Transfer Technologies, Paper No. 23, March 2004.

Harris, N.K., Li. Y., OBrien E.J. and González, A., 'Dynamic Interaction of Bridges and Heavy Vehicles utilising Semi-active Suspensions', in *EUROMECH 455 on Semi-Active Vibration Supression*, Eds., M. Valasek and A. Preumont, CTU in Prague, Czech Republic, July 5-7, 2004.

Rattigan, P., González, A. and OBrien E.J., 'Investigation of the Dynamic Amplification Caused by Traffic Loading on Medium Span Bridges', *Proceedings of the 4th IASTED International Conference on Modelling, Simulation, and Optimization*, MSO 2004, Kauai, Hawaii, USA, August 17-19, 2004, pp. 348-353.

Harris, N., OBrien, E.J., and Timoney, S., 'Spatial Repeatability of Heavy Vehicles Utilising Semi-Active Suspensions', Proc. AVEC '04, HAN University, The Netherlands, August 23-27th,

2004, pp. 683-688.

Getachew, A. and OBrien, E.J., 'Simplified Site Specific Models for Determination of Characteristic Traffic Load Effects for Bridges', 4th International Conference on Weigh-In-Motion – ICWIM4, Eds. E.J. OBrien, B. Jacob, A. Gonzalez & C.-P. Chou, National Taiwan University, 2005, pp. 341-350.

Gonzalez, A. and OBrien, E.J., 'The Use of Functional Networks to Optimise the Accuracy of Multiple–Sensor Weigh-In-Motion Systems', *4th International Conference on Weigh-In-Motion – ICWIM4*, Eds. E.J. OBrien, B. Jacob, A. Gonzalez & C.-P. Chou, National Taiwan University, 2005, pp. 47-57.

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Getachew, A. and OBrien, E.J., 'Sensitivity of predicted bridge traffic load effects to the tails of truck weight distributions', *Bridge Management 5*, Proceedings of the 5th International Conference on Bridge Management, Eds. G.A.R. Parke & P. Disney, Thomas Telford, London, 2005, pp. 275-282.

OBrien, E.J., Li, Y.Y., Gonzalez, A., Brady, S.P., 'The influence of speed on the dynamic amplification of two loads crossing a simply supported bridge', *Bridge Managment 5*, Proceedings of the 5th International Conference on Bridge Management, Eds. G.A.R. Parke & P. Disney, Thomas Telford, London, 2005, pp. 452-458.

Rattigan, P.H., Gonzalez, A., OBrien, E.J., Brady, S.P., 'Transverse variation of dynamic effects on beam-and-slab medium span bridges', Eurodyn 2005, Paris, eds. C. Soize & G.I. Schuëller, 2005, pp. 1643-1688.

Thesis submission
McNamara, C. (2004), *Improvement of the Accuracy of multiple-sensor weigh-in-motion systems using functional networks*, University College Dublin.

Implication for Ireland's Road Infrastructure of Heavier European Trucks

Technical Report

This project addresses the issue of growth in road freight transport and the likely emergence, in the medium term, of longer and heavier trucks on Irish roads. This has implications for the rate of deterioration of road pavements and will result in a shortening of the safe working lives of our bridges. An opposing trend is the emergence of "smart" suspensions that can reduce the aggressiveness of heavy trucks for roads and bridges. The research is wide-ranging and addresses a number of issues related to the common theme of longer and heavier trucks in Ireland.

The greatest financial implications are in the deterioration of road pavements – an increase in the typical number of axles from five to six could keep axle loads at existing levels, even if gross vehicle weights increased by 20%. However, this assumes no illegal lifting of one axle and an even distribution of loads between axles. Research has been carried out on the mechanisms through which pavements deteriorate in response to applied axle load. This allows the effect of new truck configurations to be found.

The implications of heavier trucks for Ireland's bridge stock have also been considered.

A further contribution has been made to the technology of weighing trucks in motion which has the potential to be used for automatic enforcement of legal truck weight limits in the near future.

1. Probabilistic Dynamic Truck Model

A key goal of the research was a heavy truck dynamic model to reflect the existing and future truck population. Many models have been developed in the past for particular trucks but what is needed to determine the implications for road infrastructure is a probabilistic model which reflects the range and frequency of the different heavy trucks on the road. There have been three work packages relating to this issue:

WP1.1– Truck Dynamic Model: A probabilistic truck dynamic model has been developed to represent a typical truck population. Truck properties such as axle spacing, spring stiffness, etc. are represented as randomly varying parameters. The *NASTRAN* software was initially tested for this purpose but it was found to be easier to solve the dynamic equations directly from first principles. Models have now been developed for 1-, 2- and 5-axle trucks, including an allowance for the articulation between tractor and trailer in the latter. Computer simulations have been developed and tested for the dynamic motion of trucks travelling on road pavement and across bridges (including dynamic interaction between truck and bridge).

WP1.2– Spatial Repeatability Model: The truck model has been used to simulate and predict the dynamic impact forces applied by typical traffic to road pavements. The goal was to have a model for which the *histogram* for the applied dynamic force is consistent with measurements recorded by road sensors.

Optimisation was tested as a means of finding the statistical parameters that best describe the truck population. However, it was eventually found that Bayesian Updating was the best technique. This is now operational and it is possible to use the model to accurately predict mean patterns of applied force to pavements (i.e., to predict spatial repeatability patterns).

A multiple-sensor Weigh-in-Motion site is needed to calibrate the truck population model. There are very few of these worldwide and, at the moment, there is no operational system in Europe. Agreement was reached with the Dutch Ministry of Transport (DWW) to collaborate with them in processing the data from a Dutch site under development. After many delays, testing finally started in February 2005. However, the sensors broke down and have only been replaced and recalibrated in October 2005. This means that, while a truck population model has been successfully developed and tested numerically, it has not been calibrated using real field data at this time.

WP1.3 – Smart Suspensions: A smart suspension has been designed to counter the dynamic amplification of traffic loading on bridge structures which is up to about 40% in some instances. Active or semi-active suspensions rely on very quick responses to applied forces and, as a result, are expensive in terms of fuel/power input. Our approach has been to adjust the damping coefficient of the suspension prior to the bridge crossing and to maintain it at a constant optimal value during the crossing. This has been shown to be most effective in reducing dynamic amplification in short-span bridges. These are by far the most widespread bridge type and collectively represent the most valuable component of the bridge stock.

2. Pavement Deterioration Model

A key goal of the proposed research was to develop a numerical model of pavement deterioration in response to applied loading. The deterioration of pavement in an actual road is complicated by the phenomenon of *statistical* spatial repeatability. As the road deforms, the surface profile changes and it is known that this profile controls the *mean* pattern of dynamic force that is applied. This work is now complete – a computer model has been developed which models all parts of the process – dynamic motion of the vehicles, fatigue and hence deformation of the pavement over time and feedback of this deformation into the pavement profile to generate new patterns of applied dynamic force. This body of work represents a major advance in this field and a great improvement in understanding of the process of pavement deterioration.

WP2.1 – Pavement Deterioration at a Point: With assistance from the University of Nottingham, a numerical model is now developed for the fatigue and deformation of pavement at a point in response to an applied spectrum of variable loading.

WP2.2 Pavement Deterioration on a Road: The road surface profile controls the mean pattern of applied force applied to it which in turn causes permanent deformation which influences the surface profile. An accurate numerical model of pavement deterioration on a road can only be achieved by allowing for this phenomenon. The truck dynamic model developed in work package WP1.2 is combined with the pavement deterioration model of WP2.1. This model has now been completed.

3. Multiple-Sensor Weigh-in-Motion

The degree to which legal weight limits are enforced is equally as important as the limits themselves. It is well established that trucks with weights substantially in excess of the legal limits are widespread in Ireland and many other European countries.

WP3. – Enforcement through Weigh-in-Motion: The spatial repeatability model of WP1.2 has been used to simulate the errors in Weigh-in-Motion (WIM) systems that result from the dynamic motion of trucks. This is now being used to remove the effects of statistical spatial repeatability from multiple-sensor WIM arrays. The algorithm development work is complete and it will be used to process data from the Dutch site. Numerical simulations have shown that the results from the new algorithm are more accurate than from any algorithm developed in the past and represent the upper limit of what is possible from the data available.

4. Bridge Traffic Loading

The development of longer and heavier trucks will have significant implications for road bridges as it results in a greater concentration of weight in a shorter length of bridge. A high frequency of heavier trucks could greatly increase the characteristic load level for existing bridges and the cost of the strengthening and replacement is considerable. There were two work packages addressing the bridge issue:

WP4.1 – Bridge Statistical Load Model: Statistical (static) models of traffic loading on bridges have been developed and extended to identify the implications of new truck configurations emerging in the truck population. This workpackage has achieved a major breakthrough – existing methods of calculating characteristic stresses in bridges have been shown to be inaccurate and new, reliable, methods have been developed. Critical combinations of trucks on bridges have been identified that were previously thought to be infeasible. The gaps between following trucks has been shown to be a critical issue which strongly influences the result. A framework has been developed which allows for the accurate calculation of characteristic stresses on bridges with and without new heavier truck configurations.

WP4.2 – Modelling Dynamic Amplification Factor: The dynamic interaction of a single moving truck with a bridge has been studied in the OECD *DIVINE* project and this is the basis for the Eurocode on Bridge Loading (EC1, Part 3). However, the critical loading event for most bridges consists of *two* or more trucks meeting or overtaking on a bridge. The dynamics of such multiple-truck crossing events is little understood. This work package has extended the traffic loading model of WP4.1 to include the effect of dynamics. For an example bridge, the correct allowance that should be made for dynamics has been calculated. It is shown to be just 5.8%, far less than that specified in the Eurocode for bridge design. This is a major finding which will greatly reduce the need for bridge strengthening works in older bridges.