Integrating Weigh-In-Motion data with Mechanistic Pavement Analysis and Design

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Synopsis

This paper outlines recent work on integrating Weigh-In-Motion (WIM) data into the Australian-developed Mechanistic Pavement Analysis and Design software, HIPAVE (Heavy Industrial Pavement Design System), a special version of CIRCLY with unique features for detailed modelling of traffic load spectra. CIRCLY is an integral component of the Austroads Pavement Design Guide (Austroads, 1992, 2004) that is widely used in Australia and New Zealand.

The prototype system calculates the cumulative damage induced by a traffic spectrum consisting of any combination of user-specified vehicle types and load configurations. The WIM data is imported via an XML (eXtensible Markup Language) format data file that is generated by WIM-Net. The WIM-Net system allows vehicle-by-vehicle data from a variety of WIM devices to be integrated, and allows a user to produce a load spectra consolidated across a group of sites. The prototype system overcomes the disadvantages of conventional pavement analysis and design approaches that are based on the assumption of an 'equivalent' single axle load. This approach avoids the approximations used to calculate the equivalent single axle load, as the contribution of each vehicle/load combination is explicitly analysed. The new “WIM-aware” analysis and design methodology offers considerable benefits for pavement designers, as it transparently considers site-specific traffic data. It can readily and rigorously assess the impact of changes of axle loads on pavement design options. The WIM-aware approach can also be used to calibrate pavement design systems to long-term pavement performance databases, without biasing the data by equivalent axle assumptions.

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INTRODUCTION

Road traffic consists of a mix of vehicles ranging from bicycles to road trains. But because light vehicles such as cars contribute very little pavement damage, only heavy vehicles are considered in pavement design.

The pavement damage caused by a passage of a heavy vehicle depends not only on its total weight but also on how this weight is transferred to the pavement. In particular, it depends on:

- the axle groups - the way the axles are grouped together; and
- the axle group loads - the loading applied to the pavement by each of these axle groups.

Modern pavement design methods are now "mechanistic", that is they are based on structural mechanics principles, for example layered elastic models. Conventionally the actual traffic distribution is simplified to a given number of repetitions of a single, "standard" axle (in Australia this is defined as an axle with four wheels and a total load of 80 kN). Broadly, the Standard Axle repetitions are calculated using theoretical assumptions about the pavement damage contributions from each axle group type and the axle group load. The number of repetitions is commonly called the number of "Equivalent Standard Axles" or ESAs. To fully characterize the damage for different pavement material types some additional "Traffic Multipliers" are calculated that depend on the combined load spectra.

As well as using the usual standard axle load, optionally a layered elastic system can explicitly analyse the contribution of many vehicle or axle load configurations. This approach is defined to be the "load spectra" approach and is being used in many countries such as Australia and the US.

One of the implications of the load spectra approach is an increased burden on data managers. A software system that can produce load spectra from a set of vehicle-by-vehicle data in response to a user's query is a more complex system than one that just returns ESAs and Traffic Multipliers. There are two reasons for this – firstly, much more data must be made available online and secondly, because the spectra is made up of scores of values and is not readily typed into design software.

If road designers are to take full advantage of mechanistic design with load spectra, software developers working on different parts of the design process must collaborate far more on industry standard data transmission standards for load data.

This paper reports on work conducted by two software organizations to connect different systems – "HIPAVE" and "WIM Net" – in a way that helps pavement designers leverage the full value of the Weigh-In-Motion data collection program in load spectra based design. The resultant combined system allows collected data to pass seamlessly from the roadside into the design software, resulting in "WIM aware" pavement designs. It is a paper mainly about improvements in managing data and not about improvements in performance prediction gained by using a load spectra approach.

This complete system has implications for the way other software companies collaborate on open standards in the road industry.

MECHANISTIC DESIGN USING LOAD SPECTRA

In older design methodologies, just a few numbers represented the load from traffic: the number of ESAs and the Traffic Multipliers. The ESAs have been relatively simple to work with because they are properties of a vehicle, derived from the measured axles' spacing and load. Calculating the total "load" at a point on the road is simply the sum of each vehicle's ESA value. However one problem with using an ESA has been its physical interpretation – an interpretation that implies the load bears on a particular type of pavement and often not the kind being designed for.

Also the Standard Axle approach inherently involves loss of information due to the very crude assumptions made about "equivalent" damage for different loads and axle groups.

Using load spectra is a far better starting point for designers because the input "loads" are the actual load of the vehicles independent of any kind of pavement materials or response. The "spectra" are tables of histograms of loads for different axle group types and, by its definition, means that they consist of scores of values.

Essentially, load spectra are replacing ESAs and Traffic Multipliers as the primary load input into modern mechanistic design and as a result, the situation for designers becomes ever more challenging. Whereas they had been working with just a few numbers previously, now they are required to input a great many.

COLLECTING AND MANAGING MASS INFORMATION FOR PAVEMENT DESIGN

Weigh-In-Motion (WIM) devices are able to measure the weights and dimensions of vehicles at highway speed and are the largest source of actual vehicle mass data around the world. A large number of countries collect WIM data from permanent and temporary stations and many are using the information to assist in pavement design.

There are a number of stages for data to pass through before it reaches design, all of which are handled by software. Figure 1 represents some of these and Table 1 outlines the key components in the WIM data management process.

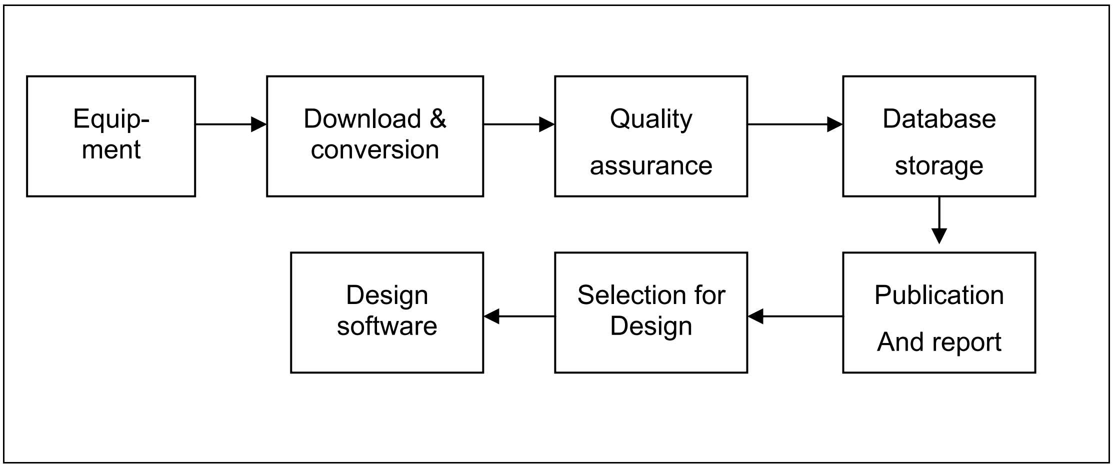

Figure 1: WIM data management process

Table 1: Components in the WIM data management process

	Component	Purpose	Data and data formats
1	WIM equipment	Record traffic loads	every axle and vehicle event in compressed binary
2	download and conversion software	Downloads binary data and converts it into a standard format	Vehicle-by-vehicle or tallied formats such as the "card" formats in the US.
3	Quality assurance system	decides which data records are valid, resulting in some data records being discarded	As above
4	storage system	created by the DoT and holds data in a schema they have developed	database tables
5	Publication and report	Publish data for consumption by end users and software	printed paper or image formats such as PDF
6	Selection for design	Choose which sites represent the design site	-
7	Design software		Load schema

A major problem encountered in passing data from one software package to the next is that data is lost due to aggregation or mismatch between various formats.

Data managers face a number of hurdles in this process, none of which are impossible to overcome, but together have restricted the use of WIM data in pavement design.

Firstly, WIM data devices often produce data of dubious quality, so a quality assurance system that looks for: errors in measurement; loss or duplication of data; clock errors and others must be in place. In some Transport Departments it is one person's full time job to operate the quality system and define which data is valid for the various downstream applications. If this process is not managed properly, designers are less inclined to use the data.

Secondly, anecdotal evidence suggests that many databases built by Transport Departments over the past decade store ESAs and mass averages per defined period, but not enough information to deliver full mass spectra in a format easily imported into design software. This has forced designers to use software that operates on raw WIM data files which re-introduces the quality problems explained above.

Thirdly, information is often not presented in a readily consumable format by the next software component in the chain. As an example, publication of load spectra printed on paper or in an image format such as PDF, creates a great deal of work for pavement designers compared to when that format is readable directly by the design software. Requiring designers to transcribe over 100 data points of load spectra by hand into design software is unlikely to encourage great use of the data.

Here we describe a software system that efficiently manages the WIM data lifecycle from the logger to the design software. In the past 12 months it has been adopted by four State Transport Departments in Australia. This is enabling them to start reducing the amount of software components in their data management.

This system exports load spectra in an XML format that is consumed directly by pavement design software, "HIPAVE". This is explained in the sections below.

AN INTEGRATED SYSTEM USING XML LOAD SPECTRA

About XML

There are two major paradigms in transferring data: tabular and hierarchical. Most readers will be familiar with “tabular” because it is the model represented in a spreadsheet or relational database. Each row in tabular data is a record, and the columns represent the fields of that record. A standard way of transmitting this form of data is in a “comma separated variable” file.

Hierarchical data appears as a “tree” structure, such as directories on a file system. Records in this kind of data not only can contain fields but also other records. E.g., a directory can contain both files and other directories.

XML, or “eXtensible Markup Language”, is a standard way of storing such hierarchical data. XML has quickly become a standard in information management because it allows better modeling of data records that are “composed of” other data records.

Consider how pavement information can be represented in XML: the pavement is composed of layers, layers are composed of materials, and materials have engineering properties of elastic modulus. Instead of storing this information as three or more separate delimited files, XML allows us to store and exchange it – and much more - in just one file, dramatically reducing the work involved in connecting different systems.

Software built by different organizations can therefore more easily collaborate if they share data as XML.

About CIRCLY and HIPAVE

CIRCLY is a layered elastic program with special features for mechanistic analysis and design of road pavements. CIRCLY was originally released as a mainframe version in 1977 (Wardle, 1977). The latest Microsoft Windows version, CIRCLY 5.0, was released in early 2004 (Wardle, 2004). CIRCLY is an integral component of the Austroads Pavement Design Guide (Austroads, 1992, 2004) that is widely used in Australia and New Zealand.

HIPAVE (Heavy Industrial Pavement Design System) is a special version of CIRCLY with unique features for detailed modelling of traffic load spectra. HIPAVE is also targeted at container terminal design. It automatically takes account of the load transfer characteristics of vehicles such as forklifts, gantries etc. It also integrates detailed container mass distributions.

About WIM Net

WIM Net (Vaultage Media, 2004) is server software for managing traffic data and is used in the majority of Transport Departments in Australia. WIM Net can store and retrieve vehicle records including speed, axle group configuration and all axle loads from sites in the WIM collection program. It also:

- accepts data from a wide variety of collection devices
- automatically imports vehicle data files
- efficiently manages the quality of vehicle data
- allows users to create their own vehicle class schemes and report on them
- responds to queries over the internet
- exports information to other traffic software systems

Figure 2 shows a sample vehicle record report in WIM Net.

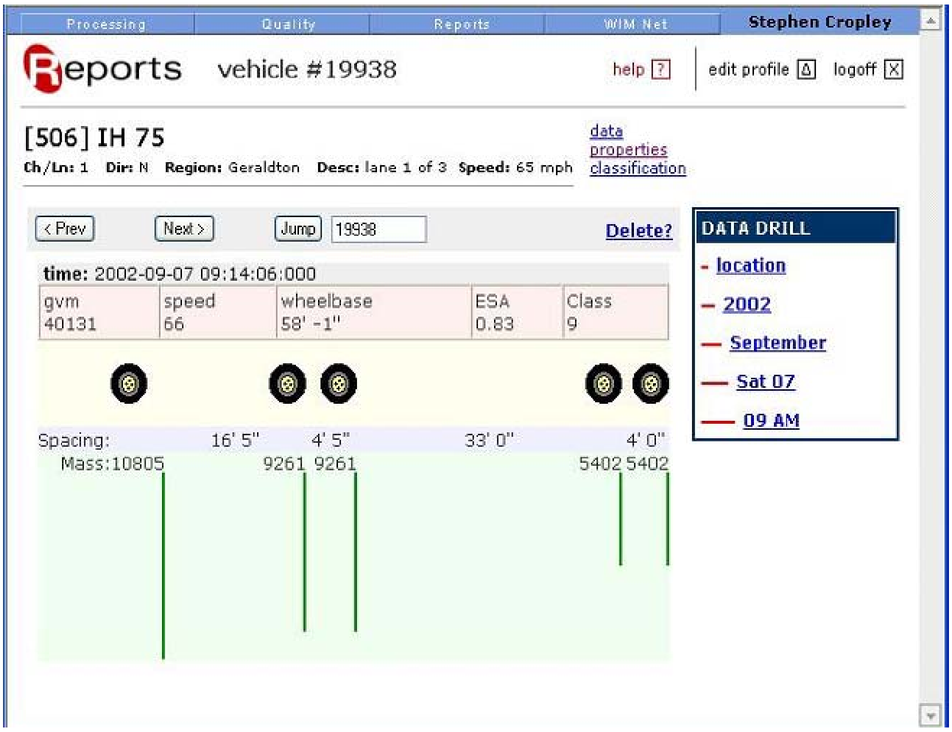

Figure 2: A vehicle record in WIM Net

The WIM Net – HIPAVE collaborative system in Australia

Using the combination of WIM Net and HIPAVE, a pavement designer can simply obtain the latest load spectra information available from one or more sites from the WIM collection program. The spectral data is passed as XML from one system to the next to create a seamless path from the logger to the designer. Figure 3 is a schematic of the WIM Net - HIPAVE system.

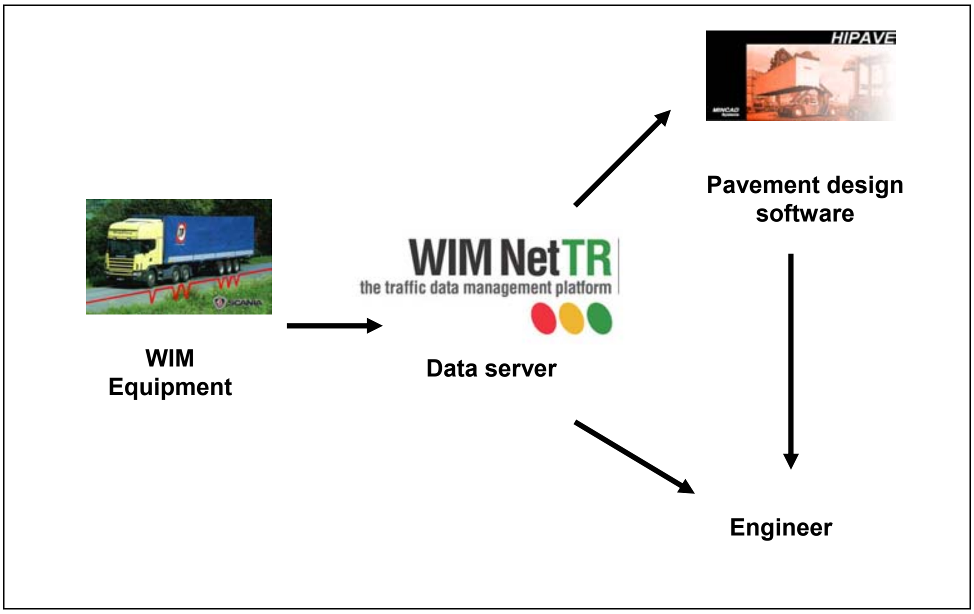

Figure 3: Components in the WIM Net - HIPAVE system

Importantly, this transaction is initiated and completed without the request being handled by a member of data services group and it therefore happens fast enough for the designer to be able to test various traffic loading conditions, in the same way a designer of a building might test different loading conditions due to wind or earthquake.

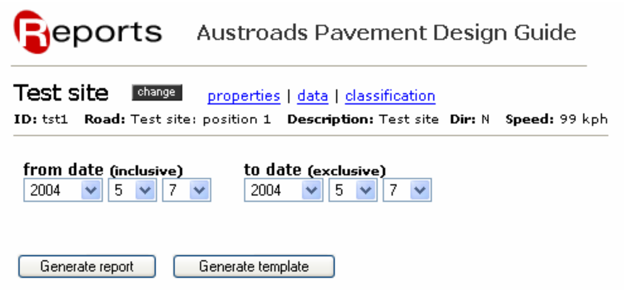

Figure 4: Selecting data in WIM Net

TABLE 8.3 (b) DISTRIBUTION OF AXLE LOADS WITHIN EACH AXLE GROUP FOR EXAMPLE DESIGN CHARTS

	Proportion of each axle group with Designated Load			
Load on Axle Group (kN)	**Single (single)**	**Single (dual)**	**Tandem (dual)**	**Triaxle (dual)**
10.0	0.0445	0.1659	0.0476	
20.0	0.6386	0.5341	0.0490	
30.0	0.2234	0.2061	0.0323	0.0002
40.0	0.0115	0.0444	0.0208	0.0004
50.0	0.0047	0.0129	0.0115	0.0007
60.0	0.0023	0.0062	0.0046	0.0018
70.0	0.0019	0.0027	0.0046	0.0049
80.0	0.0030	0.0022	0.0055	0.0095
90.0	0.0031	0.0016	0.0052	0.0167
100.0	0.0031	0.0022	0.0066	0.0270
110.0	0.0040	0.0022	0.0113	0.0484
120.0	0.0031	0.0018	0.0162	0.0554
130.0	0.0033	0.0015	0.0265	0.0626
140.0	0.0051	0.0015	0.0248	0.0738
150.0	0.0074	0.0009	0.0289	0.0729
160.0	0.0087	0.0011	0.0355	0.0784
170.0	0.0124	0.0015	0.0384	0.0619
180.0	0.0101	0.0018	0.0407	0.0587
190.0	0.0051	0.0013	0.0361	0.0455
200.0	0.0027	0.0009	0.0375	0.0399
210.0	0.0010	0.0013	0.0424	0.0347
220.0	0.0003	0.0010	0.0369	0.0232
230.0	0.0003	0.0006	0.0265	0.0196
240.0	0.0003	0.0006	0.0263	0.0148
250.0	0.0001	0.0006	0.0188	0.0139
260.0	0.0001	0.0003	0.0144	0.0112
270.0		0.0004	0.0118	0.0092
280.0		0.0004	0.0089	0.0063
290.0		0.0005	0.0069	0.0031
300.0		0.0003	0.0078	0.0036

Export load spectra to HiPave

Figure 5: WIM Net load spectra

Figures 4 and 5 show how the user selects load spectra and exports it as an XML file that is readily imported into the HIPAVE design software. Figure 6 shows a sample of a resulting Damage Factor Graph created in HIPAVE using Load Spectra Analysis option.

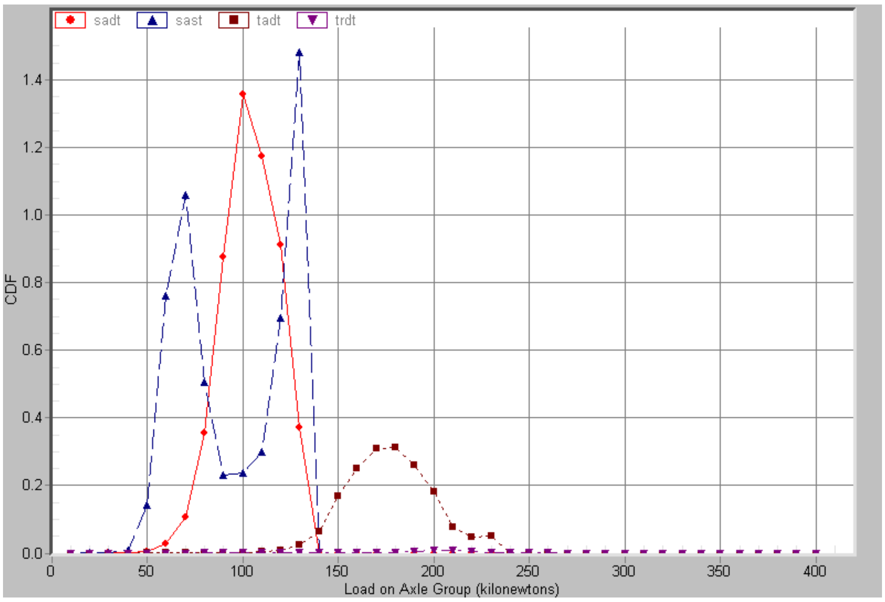

Figure 6: Damage Factor Graph in HIPAVE – Load Spectra Analysis

In Figure 6 there is a separate result set for each axle group considered, i.e.:

- single axle with single tyres (SAST),
- single axle with dual tyres (SADT),
- tandem axle with single tyres (TAST),
- tandem axle with dual tyres (TADT),

NEW OPPORTUNITIES FOR LOAD SPECTRA

Once load spectra can be rapidly produced from all WIM devices in the collection program, the design software can be used to make improvements in the modeling of the life of a pavement.

1. Models can now accommodate predicted growth in traffic mass, as well as volume. It is far more difficult to accommodate a 5% growth of truck masses in a model that uses ESAs rather than load spectra.
2. Where it is known that the pavement response will vary with the differences in day and night time temperatures, or summer and winter, the difference in traffic load patterns can be explored by selecting data based on time or season.
3. Groups of sites can be combined into an “average site” for different kinds of geographical areas or road function types. This approach is used in the United States 2002 Design Guide (AASHTO, 2002).
4. Theoretically there is no need to aggregate any of the traffic data – every individual axle group repetition could be modeled.

CONCLUSIONS

The WIM Net system allows vehicle-by-vehicle data from a variety of WIM devices to be integrated, and allows a user to produce a load spectra consolidated across a group of sites. The prototype system overcomes the disadvantages of conventional pavement analysis and design approaches that are based on the assumption of an 'equivalent' single axle load. The Standard Axle approach inherently involves loss of information due to the very crude assumptions made about "equivalent" damage for different loads and axle groups.

The spectral approach avoids the approximations used to calculate the equivalent single axle load, as the contribution of each vehicle/load combination is explicitly analysed. This new, "WIM-aware" analysis and design methodology offers considerable benefits for pavement designers, as it transparently considers site-specific traffic data. It can readily and rigorously assess the impact of changes of axle loads on pavement design options. The WIM-aware approach can also be easily generalized to more sophisticated mechanistic models that take account of how pavement materials vary with temperatures and vehicle speeds. The WIM-aware approach can also be used to calibrate pavement design systems to long-term pavement performance databases, without biasing the data by equivalent axle assumptions.

The WIM Net – HIPAVE collaborative system in Australia shows how WIM information can be brought seamlessly into the models through the use of an XML open standard.

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