Technical Report Documentation Page

1. Report No. TX-96/1978-2F	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle EXECUTIVE SUMMARY REPORT ON THE PRODUCTION OF THE PROTOTYPE TEXAS MOBILE LOAD SIMULATOR		5. Report Date March 1996 6. Performing Organization Code
7. Author(s) Frederick Hugo		8. Performing Organization Report No. Research Report 1978-2F
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin 3208 Red River, Suite 200 Austin, Texas 78705-2650		10. Work Unit No. (TRAIS) 11. Contract or Grant No. Research Study 7-1978
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Transfer Office P. O. Box 5080 Austin, Texas 78763-5080		13. Type of Report and Period Covered Final 14. Sponsoring Agency Code

15. Supplementary Notes

Study conducted in cooperation with the Texas Department of Transportation.
Research study title: Texas Mobile Load Simulator Implementation Assistance

16. Abstract

This report summarizes the 5-year development of the prototype Texas Mobile Load Simulator (TxMLS). As described in this executive summary, the project went through various phases, from conceptual design and manufacture, to commissioning and acceptance testing.

The project was a collaborative effort of CTR, VMW Industries (the manufacturer), and the end-users, represented by the Texas Department of Transportation (TxDOT). It required committed support from the executive MLS Management Committee of TxDOT in order to achieve the successful completion of the project. Only through this support was it possible to upgrade the machine as and when it became necessary. The report discusses these efforts as well as some of the innovative achievements.

The acceptance testing stretched over a period of one year. During this time, the MLS was upgraded and the methodology for using the machine developed. This effort provided the basis for the development of guidelines for operating the machine, as well as for the selection of test sites and for testing operations at field locations.

17. Key Words Texas Mobile Load Simulator, accelerated pavement testing, test section design, pavement instrumentation		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 28	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

EXECUTIVE SUMMARY REPORT ON THE PRODUCTION OF THE PROTOTYPE TEXAS MOBILE LOAD SIMULATOR

by

Frederick Hugo

Research Report 1978-2F

Research Project 7-1978
Texas Mobile Load Simulator Implementation Assistance

conducted for the

Texas Department of Transportation

by the

CENTER FOR TRANSPORTATION RESEARCH
Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN

March 1996

IMPLEMENTATION STATEMENT

The objective of this study was to provide the Texas Department of Transportation (TxDOT) assistance in implementing the prototype Texas Mobile Load Simulator. Meeting this objective entailed an on-going, interactive relationship with both the manufacturer, VMW Industries, and the end-users, represented by TxDOT and its researchers. In this process, recommendations were made regarding appropriate upgrading of the machine during prolonged acceptance testing. Concurrently, applications of the machine were developed, together with guidelines for the selection of test sites and testing operations at field locations. With the advent of the test program, this information was incorporated into the test plan, which was implemented as a modification to Project 1924. The first successful applications of the MLS have been completed.

Prepared in cooperation with the Texas Department of Transportation.

ACKNOWLEDGMENTS

The author acknowledges the support and expert assistance provided by both the TxDOT MLS Team and the VMW Industries staff. Mr. Doug Adams, in particular, assisted in resolving some of the extraordinarily difficult engineering problems associated with the MLS. The staunch support provided by Dr. Michael T. McNerney, Assistant Project Manager, during the manufacturing period is also gratefully acknowledged. Finally, the author expresses appreciation for the guidance provided by Mr. R. G. Welsch, retired TxDOT staff member whose continued support early in the project served as an inspiration towards its completion.

DISCLAIMERS

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Research Supervisor

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SUMMARY

This report summarizes the 5-year development of the prototype Texas Mobile Load Simulator (TxMLS). As described in this executive summary, the project went through various phases, from conceptual design and manufacture, to commissioning and acceptance testing.

The project was a collaborative effort of CTR, VMW Industries (the manufacturer), and the end-users, represented by the Texas Department of Transportation (TxDOT). It required committed support from the executive MLS Management Committee of TxDOT in order to achieve the successful completion of the project. Only through this support was it possible to upgrade the machine as and when it became necessary. The report discusses these efforts as well as some of the innovative achievements.

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EXECUTIVE SUMMARY REPORT ON THE PRODUCTION OF THE PROTOTYPE TEXAS MOBILE LOAD SIMULATOR

The Texas Mobile Load Simulator (TxMLS) was accepted by its sponsor, the Texas Department of Transportation (TxDOT), on November 17, 1996. The development of the machine took place over a period of some five years.

Because it is indeed a unique piece of apparatus, it is not surprising that many noteworthy events took place during its development. These have been reported to TxDOT's senior management on an on-going basis during specially scheduled meetings with the Executive MLS Management Committee, to enable the program to continue without undue delay. This involvement of senior management was found to be necessary for the success of the project.

PROJECT MANAGEMENT

The MLS's manufacture was undertaken through the Center for Transportation Research (CTR) of The University of Texas at Austin. Previously, Project 1246 focused on the development of a strategy for the acquisition of a mobile testing device based on the 1:10 scaled model patented system by Dr. Fred Hugo. Concurrent with this, an exploratory study examined the use of the scale model MLS for conducting tests in the laboratory. The design was initiated through project 1924, with Stress Engineering Services, Inc., providing the preliminary design. While this was underway, it was realized that there had to be a close working relationship with the manufacturer. Accordingly, the project was expanded to include VMW Industries on the basis of a partnering contract, through which the risk of the development was shared by TxDOT. CTR was responsible for the management of the project throughout all of its phases, with Dr. Fred Hugo, P.E., serving as project manager.

Partnering was found to work well. It provided a sound basis for the interactive process through which the parties cooperated. This made it possible to upgrade the device as its construction progressed. It is also the prime reason why the developmental cost could be contained to an amount close to the current estimated actual cost of a production model (i.e., 136 percent). It is not uncommon for the development costs of a prototype of this scale to be as high as 300 to 500 percent of the subsequent production cost.

FINANCING

Total direct expenditures for MLS development, up to the completion and acceptance of the prototype, has thus far totaled $3.4 million. These expenditures relate to the various projects that were awarded to CTR over the past five years, including:

1. The Development of a Strategy for the Implementation of Full-Scale Accelerated Pavement Testing for the Texas State Department of Highways and Public Transportation (now TxDOT) — Project 1246, 1990. [$164,098]
2. MLS Prototype Design and Construction — Project 1924, 1990. [$2,984,557]

3. Model Pavement Testing — Project 1934, 1990. Expenditures on this project only partially related to the MLS [$19,978]. The remaining $144,120 was for the testing of scaled pavements using the model MLS.
4. MLS Implementation Assistance — Project 1978, 1993. [$144,651]
5. Automated Process Control and Data Acquisition for TxMLS — Project 2912 [$87,467]. In addition to the funds spent on this project, a further $330,000 was spent by TxDOT for the acquisition and installation of hardware for the system.

Two formal audits of VMW's costs found the records to be well organized; all queries were satisfactorily answered.

Project 7-2912, *"Automated Process-Control and Data-Acquisition for TxMLS,"* was undertaken to integrate the approximately $320,000 in computer and computer-related equipment procured by the Pavement Design Section into a unified system. This system is capable of receiving, transmitting, and processing the pavement data generated by the Mobile Load Simulator. The integrated system consists of two subsystems located in two separate sites: a process-control trailer that accompanies the MLS at the particular test site, and a headquarters location in Austin. An additional $10,000 has been expended to procure a combination of replacement and other equipment to ensure that the system operates as efficiently as possible and according to the original plan that pre-dated Project 7-2912. This system is operational and can be used to monitor MLS operations from Austin, if necessary.

NOTEWORTHY ACHIEVEMENTS AND INNOVATIVE DEVELOPMENTS

During the development of the MLS it was often necessary to improvise or create a new process, mechanism, or methodology in order to ensure the proper functioning of the unique MLS-APT system. Some of these developments are discussed below.

Multiple Axle Bogies

A unique feature of the MLS is its use of sets of regular truck bogies having tandem axles. Its twelve axles make it possible to accelerate the traffic loading without having to revert to overloading of the axles. This differentiates it from other linear APT devices. Thus far the vehicle-pavement interaction has produced performance characteristics that are very promising; a future goal will be to correlate this with in-service pavements.

Lifting Jacks

A special and specific operational requirement prohibited the use of hydraulic jacks on the machine. This led to the use of the current screw jacks. The design is such that the screw is always in tension, a feature that enhances the safety of the system. A further innovative application of the jacks was to use the jacks to maneuver the MLS for applying the load, as well as using them to erect and dismantle the MLS for transportation.

Use of Captels WIM Scales

It is necessary to know the accurate value of the wheel loads of the bogies on the MLS. A French system developed by Captels is used to measure this. It has the unique ability to measure both the static load and the transient or dynamic load during trafficking. Until a system of strain gauges on the wheel axles has been implemented, the Captels will form an integral part of the MLS system.

Model MLS

The use of the scaled model MLS provided a sound basis for an improved understanding of the operation of the MLS. It also served to prepare the research team for the application of the MLS. This has been clearly demonstrated through the successful use of the SASW to detect micro cracking. This process was developed with tests using the MMLS (refer to Project 1934).

Solutions to Problems Identified During the Prototype Development

As could be expected, several problems were experienced during the development of the MLS. Each of these was addressed when it occurred. To some extent the development of the machine was a daunting task. While the machine used off-the-shelf truck components, it applied them in an innovative, totally non-standard way. The bogies had to run upside down and were constrained between fixed sidewalls. The latter constraint gave rise to extraordinary and unexpected side forces. Another challenge was to keep up with the rapidly developing control systems and electronics in general.

Acceptance testing was conducted over a period of twelve months to determine whether the MLS was in accordance with the original Specific Operational Requirements (or amendments to it). During this time, several change items had to be commissioned by TxDOT to upgrade the MLS to a more durable level and to address some of the unknown factors impeding the functioning of the machine. This entailed:

- switching from AC motors to DC motors;
- redesigned load wheels that are able to resist side-thrust;
- new power rails;
- a three-point support system on the two drive bogies to steer the bogie train centrally;
- the installation of mechanical and gas sprung loaded side rollers on all bogies to assist with steering and to control the side load;
- the installation of redesigned dampening springs (isolators) to support the PLC control boxes;
- the installation of Halogen flood lights; and
- the installation of catcrawls in the upper deck.

In addition, VMW undertook some structural strengthening of the bogie carriages after an early failure occurred (attributed to the particularly high stresses in a section of the loop traversed by the bogies).

The following items were to be evaluated in terms of prescribed rules for acceptance of the machine:

1. safety
2. durability
3. structural and mechanical integrity
4. functional capacity in terms of:
   a) speed
   b) load
   c) axles alignment
   d) control systems
   e) ability to function on a rutted surface
   f) ability to function over surfaces with pot-holes
   g) environmental restriction on operations
5. assembly and disassembly
6. mobility-short haul and long haul
7. diagnostic monitoring systems and maintainability
8. availability of manuals, data sheets and guidelines on activities that have to be executed when operating the MLS

The machine complied either with the operational goals that had been set originally, or with those that had been formally amended during the manufacturing. In regard to the latter, an important change was the decision to reduce the speed of the MLS to a value that was deemed optimal for its operation with the current design — that is, to 20 kph. This equates to about 6,150 axles per operational hour.

The production of the MLS presented VMW with some very arduous design and manufacturing challenges. Their commitment was demonstrated by the fact that during the test that was run in July 1995, VMW decided to stop short of completion of the test in order to rewire the entire MLS, redesign and manufacture the side-rollers and install a new computer control system!

Lessons Learned

In overcoming constraints and other difficulties, many valuable lessons were learned that would not have been possible with any of the current APT devices that are in operation. Some of these are set out below:

1. A better understanding of the complex interaction between pavement and wheel load has developed, particularly, with respect to the four-wheel bogie system. Much of this goes unnoticed in the normal functioning of a bogie, when it is mounted on a truck. However, when mounted in the MLS, the structure is such that some of the freedom of movement is limited, and any malfunctioning of a part of the bogie can affect the functioning of the MLS, as well as the performance of the pavement. The most significant findings in this regard are:

a) the tendency of the axles to wander laterally, particularly when the axles are skewed for whatever reason;
b) the possibility of individual wheel loads differing from each other, not only statically, but dynamically. This can for example occur when the respective spring constants are not the same, as occurred during a recent acceptance test. The extreme nature of the problem was seen when it was discovered that bogie number 4 had one of its four load springs (right-front) carrying only 2/3 of the loads on the other three springs. These data were obtained using the Captels WIM scale. This necessitated the replacement of the suspension spring.

2. The wheel load distribution along the length of the pavement is naturally of importance. Any abnormal variance would have the effect of causing unrealistic pavement response and performance. The physically observed behavior of the pavement surface and its measured characteristics were not found to be a problem. The nature of the rutting, given the concentrated application of the wheel loads, was also found to be realistic in terms of the pavement's engineering characteristics. Other pavement response has likewise been realistic with regard to:

   a) multi-depth deflection;
   b) pavement strains as measured by retro-fitted gauges; and
   c) loss of stiffness of the asphalt surfacing due to fatigue under load.

As mentioned earlier, the latter results correlated well with test results of the scaled model testing pavement, and it is expected to be an invaluable tool for diagnosing pavement condition. More details about the findings are discussed later in this report.

From the forementioned observations it has become clear that the process of learning and understanding the nature of the MLS-pavement interaction will be an extended one. Only by empirically establishing constraints and guidelines will it be possible to guard against unduly overstressing the machine in striving to achieve or meet some pre-set functional criteria. This was clearly demonstrated by the operational history of two comparable but less complex linear testing devices, namely, the South African HVS and the Australian ALF. Table 1 shows the operating performance statistics associated with these two devices. From these it is clear that it will require time for the MLS to attain to the same production levels. In this regard it is important to note that the MLS can and has achieved high axle production rates when it is mechanically balanced. This is precisely the reason why it is gradually being phased into production with appropriate upgrading to the system.

In the most recent operational tests using the MLS (March 1996), the Field Crew reported a production rate of 57 percent of the daily operational time. This equates to about 33,000 axle load applications per hour.

Table 1. Extracts from operating performance records of the HVS and the ALF

Machine Type	Trafficking %	Breakdown %	Servicing %	Res Msrmnt and Testing in situ %	Inoperative %
HVS* 4 (1982-1984)	**42.7**	15.2	13.5	6.9	21.6
HVS 3 (1982-1984)	**44.7**	12.6	11.4	9.9	21.5
HVS 2 (1982-1984)	**48.2**	16.2	10.9	7.0	17.7
HVS Ave (1980-1986)	**54.7**	12.4	9.4	8.5	14.8
HVS Ave (1985-1986)	76.7	4.3	8.4	4.3	6.3
ALF-1986 (1st trial total 40 weeks)	**30**	52	4	3	11
ALF-1986 (1st trial weeks 4-8)	**45**				
ALF-1986 (1st trial first 16 weeks)	**53**				
ALF-1987/88 (2nd trial first 17 weeks)	69	7	3.4	6.4	13.7
ALF-1991 (Mulgrave Test)	71	9.4	1.5	3.1	15

Conclusion Regarding Application of the MLS

The MLS has already proven to be a unique pavement testing tool. Indeed, its ability to provide some early implementable information makes it imperative that it should be utilized as a testing tool using the highest possible rate of application of axle loads. This is in fact one of its major attributes. The research management system that was activated at the beginning of the fiscal year should ensure a smooth transition from manufacture to implementation, with due regard to the responsibility and activity schedule of all the parties that are involved.

Most recently, another unique feature of the machine was explored to establish its effect on the behavioral characteristics of the MLS. The box structure of the MLS is by nature very stiff, as is indeed demonstrated by the fact that it can easily have one jack clear from the ground. However, despite this rigidity the top of the machine is free to move in 3-D space; it was found that the unequal adjustment of the jacks relative to each other causes the upper structure to twist. In fact, it rotates about a point near the level of the ball joint of the screws of the jacks and between them, on either end of the machine. This, in turn, affects the travel of the bogies-chain system.

This is most probably the prime cause of the side thrust experienced when the bogies travel between the upper and lower decks. To counteract this phenomenon, the MLS needs to be set up parallel to an imaginary plane that produces the least variance from the average load applied to the pavement by the bogies along the wheel paths. By doing this, the side thrust that has been a major stumbling block should be minimized. This action may also have been the cause of the stress softening of one spring of a bogie during the acceptance testing. By the very nature of the pavement structure, this imaginary plane will have to be adjusted from time to time, as trafficking progresses.

In order to further reduce the sideward wander of the MLS, and to relieve the pressure on the side rollers, a spline is being added to the roof of the MLS. The spline will be mounted along the centerline, and each of the trailing bogies will have two sets of guide wheels suspended from their axles. In addition, two sets will also be mounted on the chain to guide it. This is expected to improve operation significantly, since it should reduce the risk of having the bogie train rubbing against the sidewalls, which are very stiff and rigid. This is in contrast to the lower half, where the sidewall is transversely more flexible and forgiving.

The foregoing discussion explains the prolonged nature of the acceptance testing, as well as why the MLS was accepted and put it into operation under strong management surveillance. In this way it would be possible to gain useful pavement engineering information during the time that the MLS is being studied. Some aspects of these are discussed below.

AGREEMENT ON ACCEPTANCE OF THE MLS

In terms of the Memorandum of Agreement No. 1924/I/92 (Agreement) between The University of Texas at Austin and VMW Industries, Inc., ***final inspection and acceptance of services,*** as per Clause A-23, has been on-going since September 1994. During this period it was found that the Design and the Specific Operational Achievements of the MLS (machine) were iterative, and that the process had led to a number of upgradings that were implemented through Compensation Events. Furthermore, the originally anticipated testing of the machine on the on-site test pavement at VMW was superseded by a pre-operational test phase on a special test section constructed by the Yoakum District, as part of a frontage road of US59, east of VMW's site.

In view of the operational record demonstrated since commissioning the machine (fall 1994), the parties to the Manufacturing Agreement agreed to the following terms for the acceptance of the MLS:

1. Acceptance

The TxMLS would be accepted and used by TxDOT's Field Operations crew in a partnering relationship between TxDOT, CTR, and VMW, contingent upon the operational readiness of the MLS being demonstrated, by running it for one hour at a speed of 19.2 kph (12mph), with at least the following electronic systems functioning:

1.1 Temperature sensing of the side rollers
1.2 Monitoring of chain tensions
1.3 Monitoring of machine speed and axle log
1.4 Monitoring of the load pins

The agreement on acceptance further entailed the specific obligations by each of the respective parties, as set out hereinafter:

2. Deliverables

All deliverables by VMW in terms of the Manufacturing Agreement were to be submitted to and accepted by TxDOT at the machine. Where such items are subject to completion after final determination of the MLS's operational capacity, they were to be delivered within two weeks of such information becoming available. This was done. Deliverables included, among other things, the following:

2.1. A full final set of as-built drawings, in hard copy and in AutoCad 11 or 12 format on Colorado tape;

2.2. A full set of specifications and vendors or suppliers, including a list of recommended spare parts and special tools; and

2.3. A set of operational manuals and maintenance prescriptions.

3. Training

On-the-job training of the TxDOT Field Operations crew was to be provided for a period of **ten working days** after hand-over, by two qualified **VMW personnel**, each being on duty for 12 hours per day, starting no more than twenty-four hours after hand-over. Thereafter, the MLS (machine) would be operated by the TxDOT Field Operations crew. The training program covered, among other things, set-up, adjustments, and running of the machine.

4. Engineering Support

VMW was to provide engineering support, including electronic software support for debugging, for 30 days after acceptance. This was done in terms of the conditions of the current Manufacturing Agreement. In circumstances where this was not applicable, the engineering was to be done and charged at an agreed, reduced rate per person per hour, under a purchase order issued by TxDOT to VMW. This system has thus far worked well. CTR is continuing to provide support relative to pavement /MLS-interaction as part of its obligation in terms of the Modified 1924 Agreement.

5. Machine Performance Data

TxDOT Field Operations are logging MLS performance data in accordance with a pre-established, prescribed schedule of items that have been mutually agreed to. These include:

- details of machine settings;
- operational records with details of speed, loading and frequency of stoppages;
- monitoring of mechanical behavior including minor maintenance, breakdowns and mechanical and structural repairs.

6. Expendable Parts

Expendable spare parts that are required during operations were to be acquired by TxDOT and supplied to the operational crew. Insofar as these are available from VMW, these would first be utilized before considering other sources of supply.

7. Technical Support in Maintenance and Repair During Testing at Victoria

VMW undertook to provide short-term technical support for "quick trouble shooting," maintenance and repair during operations at Victoria; this service is generally not to exceed two hours in a particular instance, free of charge, except in circumstances considered to be beyond the scope of the current Manufacturing Agreement. When this does apply, the work shall be done under a purchase order issued by TxDOT to VMW at an agreed fee per person per hour.

8. Technical Support During Testing at Lufkin

VMW also undertook to provide on-site technical support during testing at Lufkin in accordance with a schedule to be provided by TxDOT, at least two months prior to starting operations on-site. The level of assistance is to be mutually agreed upon and the work shall be done under a purchase order issued by TxDOT to VMW. The fee per person per day, including traveling time plus expenses, was once again agreed upon. Where other services are required they shall be provided in accordance with a tariff schedule to be provided by VMW at the time of hand-over.

9. Upgrading of Spare Bogies

The two spare bogies (one trailing and one driver) are to be upgraded to the same quality and operational capacity as the equivalent operational bogies currently in the machine. The cost for this was set at $7178.75, and the work was to be done under a purchase order issued by TxDOT to VMW. Delivery was set at two weeks after the order to continue with the work.

10. Mechanical, Electrical, and Electronic Check-Out and Cleaning of the Machine

Final mechanical, electrical, and electronic check-out, cleaning, and painting of the machine shall be performed immediately prior to moving the machine to Lufkin. Thereafter, these tasks will be the sole responsibility of the Field Operations crew. Spare tires and wheels will then also be relocated by TxDOT.

11. Warranty

Final acceptance of the services or the manufactured MLS shall not be deemed a waiver of any guarantee, warranty, or other rights assigned to UTA or TxDOT under the agreement.

FIRST EXPERIMENTAL TEST RESULTS

During the acceptance testing, performance of the pavement that was trafficked was carefully noted. It was apparent that it was responding very well to the MLS and that it was losing its structural and functional integrity progressively as axle loads were being applied. It was then decided that the results of the non-destructive tests on the acceptance test pavement relative to the performance characteristics would be investigated. These will now be discussed.

1. Layout of Test Pad and Response under Traffic

Figure 1, a layout of the test pavement, shows the location of the different measuring devices and the two wheel paths. The structure of the pavement is shown in Figure 2, together with the location of the MDD's in the pavement.

	MDD
• 50 mm asphalt concrete	
	✱ 91 mm
• 300 mm flexible natural gravel base	
	✱ 356 mm
• 150 mm lime-treated subbase	
	✱ 572 mm
• Asphalt untrafficked for 9 months	

• Dual-tandem axles of ±75 kN [17,000 lb] each

Figure 2. Nominal pavement structure, MDD position and axle loads.

The MLS loading on the pavement was a nominal 75 kN on each axle of the six bogies. However, this load was not constant, but varied along the length of the trafficked section. This can be seen in the load variation of a typical load pin in the bogie structure as it travels along the pavement length (see Figure 3). Unfortunately, the response of the load pins is still subject to validation; this has necessitated the use of some form of weighing to measure the exact load. This was initially done by using a German PAT-WIM plate. The results are shown in Table 2. Subsequently, French Captels scales were utilized; these have proven to be valuable tools for determining the axle loads at the pavement/tire interface since they can measure both static and transient loads. An example of the Captel data is shown in Table 3.

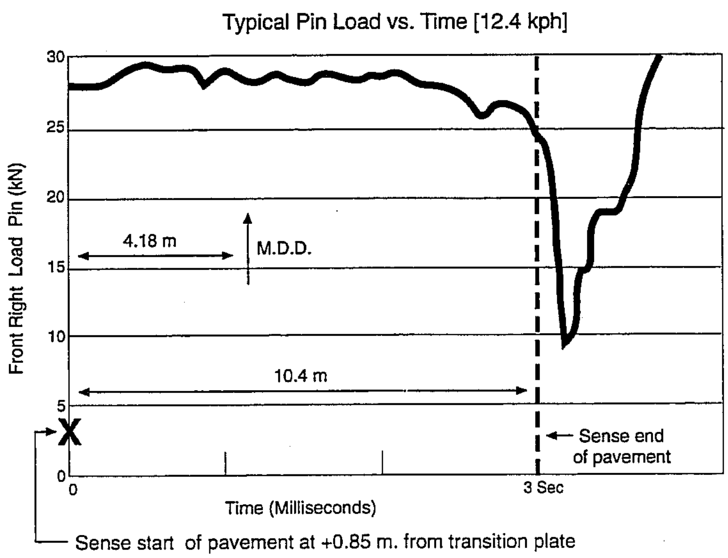

Figure 3. Load variation along the length of the MLS.

Table 2. Loads measured by bending plate.

Bogie Sets	1		2		3	
Axles	Front (kN)	Rear (kN)	Front (kN)	Rear (kN)	Front (kN)	Rear (kN)
Average	42.8	38.4	39.7	37.3	36.4	33.7
STD	0.22	0.97	0.22	0.31	0	0.44
Bogie Sets	4		5		6	
Axles	Front (kN)	Rear (kN)	Front (kN)	Rear (kN)	Front (kN)	Rear (kN)
Average	43.6	38.9	45.8	40.4	40.0	42.1
STD	0.22	0.22	0.18	0.88	0.88	0.26

Table 3. Example of the Captel data.

Axle	**Left wheel Weight (kN)**	**Right Wheel Weight (kN)**	**Axle Weight (kN)**	**Axle Spacing (m)**
1	40.2	36.9	77.2	
2	40.0	34.5	74.5	1.37
3	40.4	35.5	76.0	3.83
4	34.9	33.7	68.6	1.37
5	40.0	34.5	74.5	3.76
6	43.2	36.2	79.5	1.39
Total	239.0	211.5	450.5	11.75

It is apparent that the axle loads vary according to the pavement profile and the corresponding suspension deformation. The goal is, of course, to ultimately capture the total spectrum of loads to provide more accurate information for modeling.

The load's variation along the length of the pavement is also reflected in the MDD profiles shown in Figures 4, 5, and 6. It can be seen that the peaks vary between bogies, as would be expected. The deflection of the lower layers in the pavement can also be discerned. It is interesting to note the difference in response between the test pavement in Victoria and an equivalent South Africa pavement's response shown in Figure 7. Of particular importance is the large deflection that takes place in the basecourse of the Victoria pavement (i.e., the upper layer).

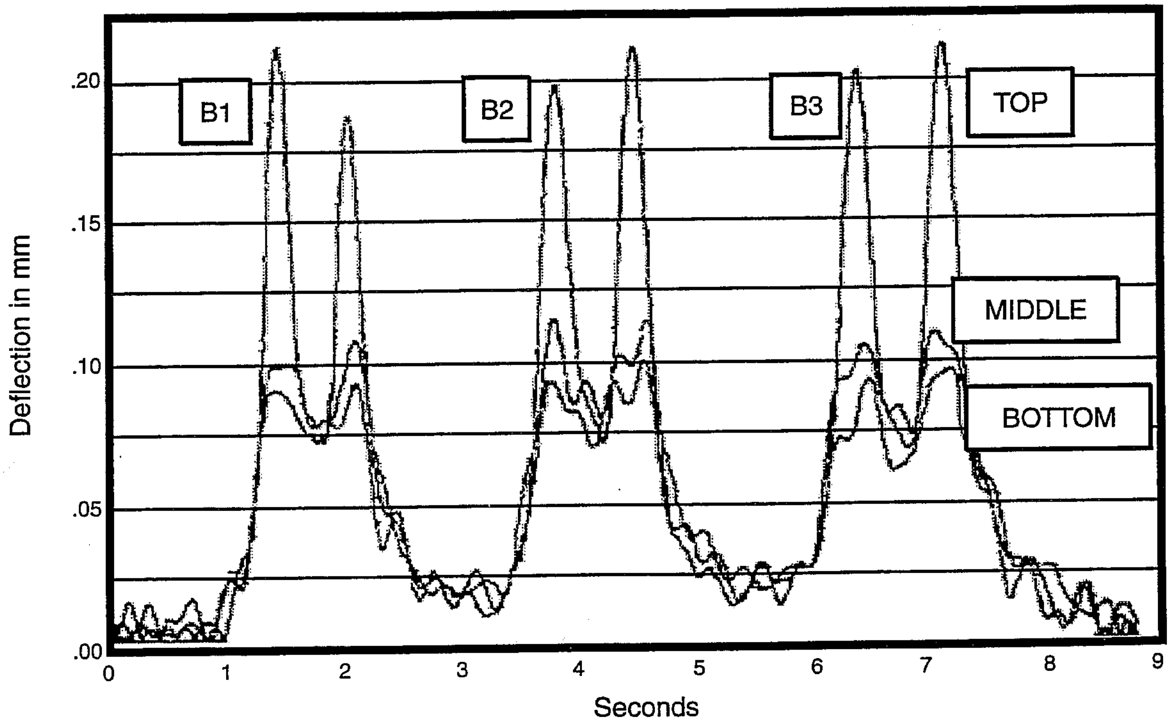

Figure 4. TTI's MDD filtered plot MLS bogies 1, 2, and 3.

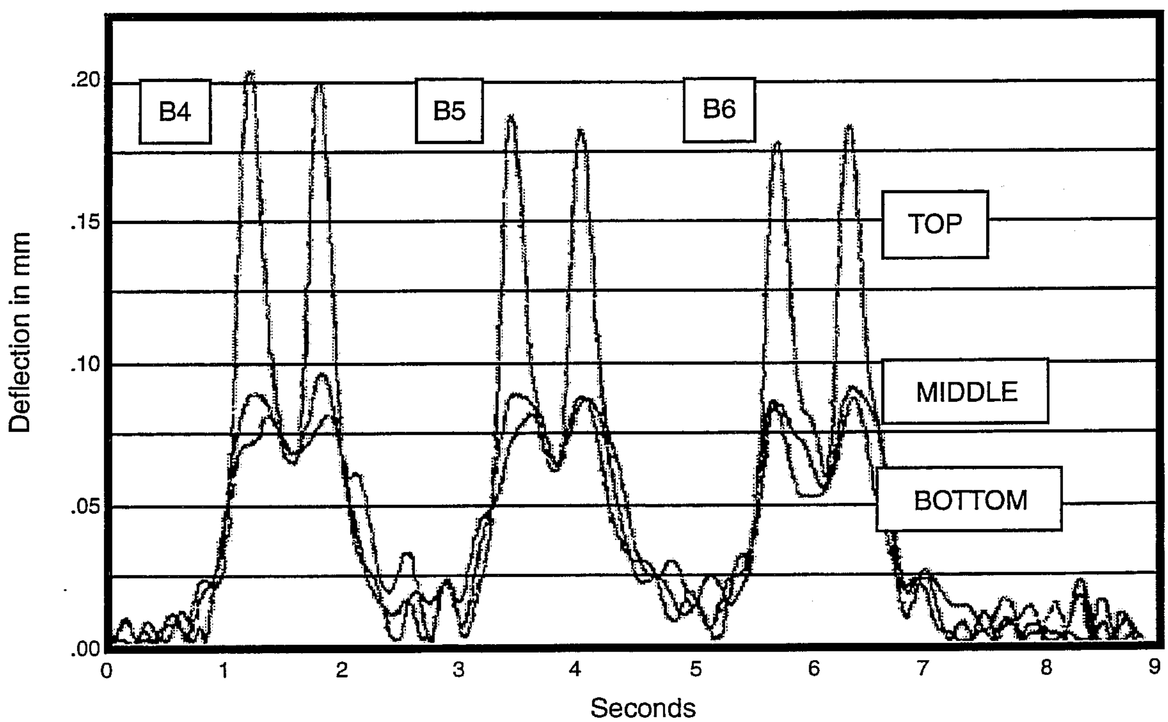

Figure 5. TTI's MDD filtered plot MLS bogies 4, 5, and 6.

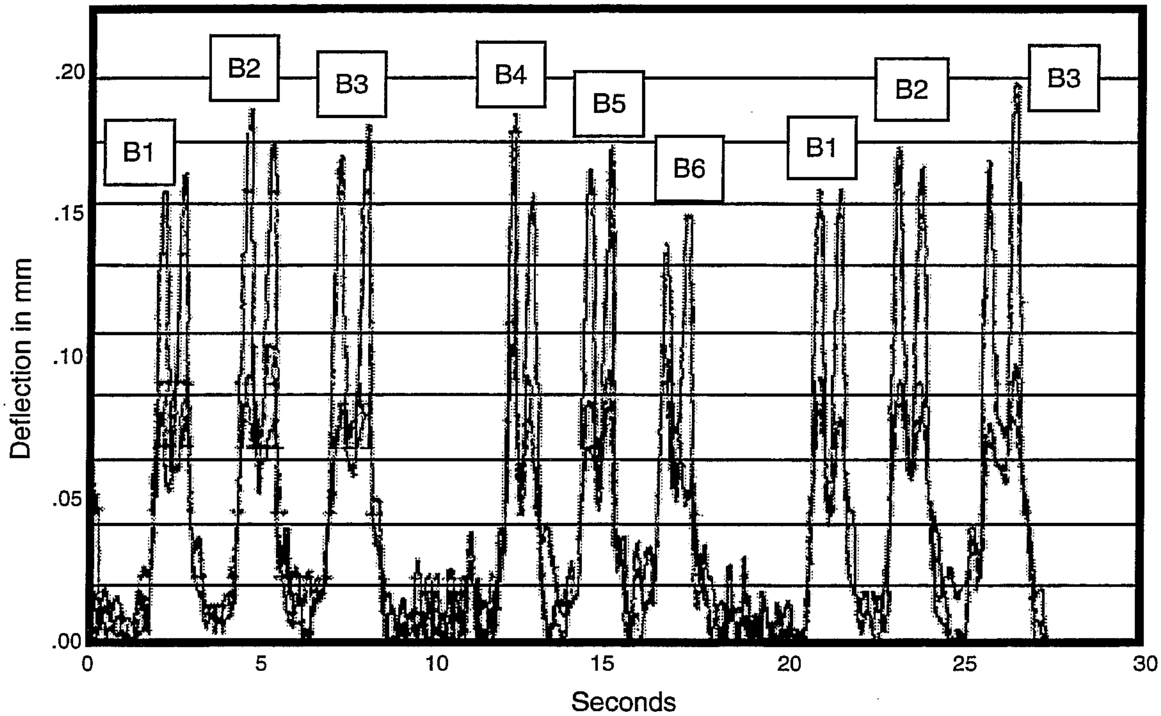

Figure 6. TTI's MDD filtered plot MLS run.

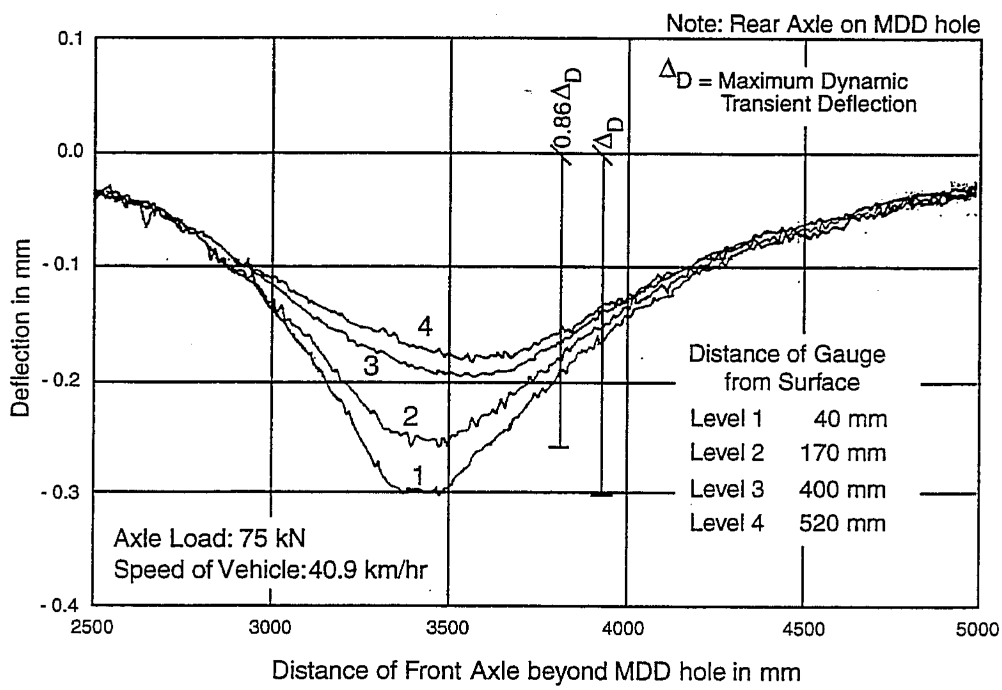

Figure 7. Response of a typical equivalent South African pavement.

2. Rutting and Cracking

The longitudinal surface profiles (see Figure 8) are equally interesting in that they depict the performance along the length of the machine: It is apparently very uniform. This is a feature that was sought, and it appears as if no extraordinary dynamics are induced into the pavement where the bogies enter or exit. The rutting was studied by means of two transverse profiles in relation to the loads that were measured on the WIM and static scales (see Figures 9 and 10 and Tables 4 and 5).

The results were used to evaluate rutting damage (performance) during the early life of the test pavement. It was found that the apparent load equivalency varied between 6 and 8. This is discussed more fully below. While this is significant, it will need to be studied in much greater depth before any meaningful conclusions can be drawn.

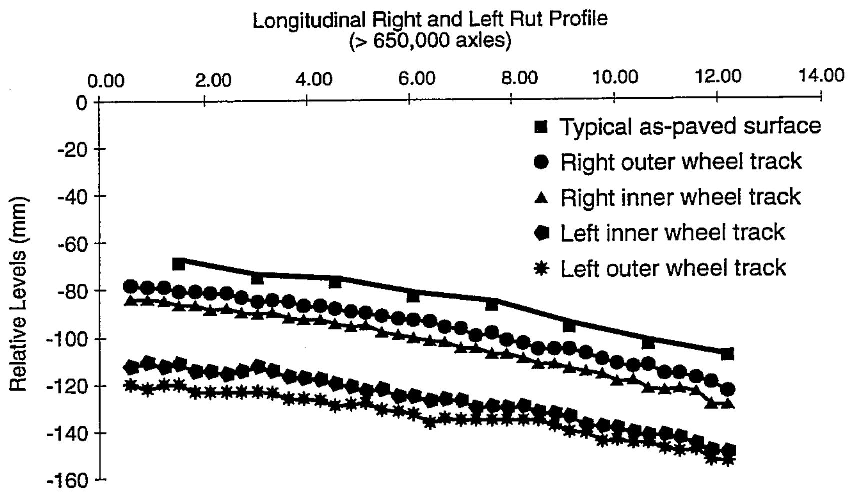

Figure 8. Longitudinal profile after 650k axles.

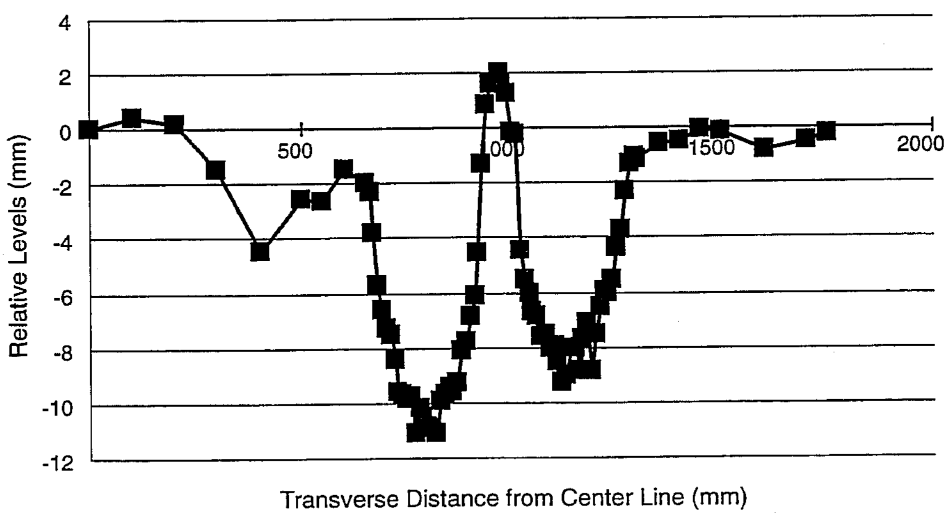

Figure 9. Rut profile at 10.1 m.

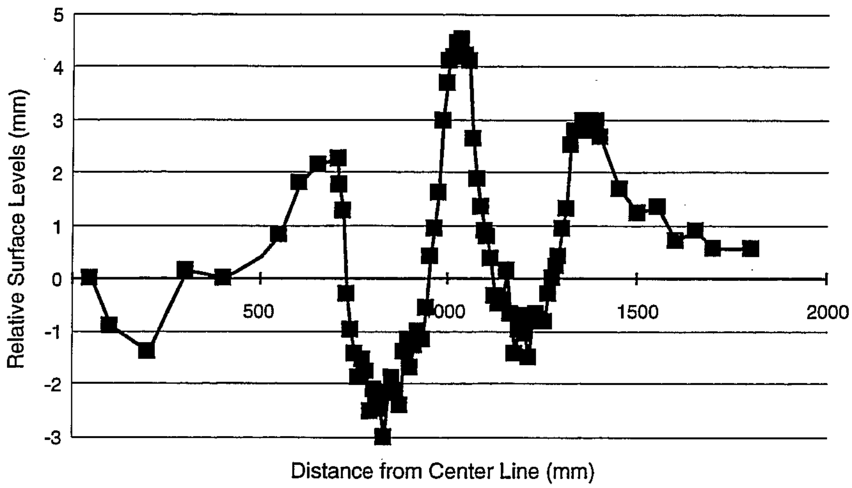

Figure 10. Rut profile at 10.7 mL.

Table 4. Evaluation of bogie settings using DPS scales

Relative Loads	Left	Right
B4, B5, B6		
Before adjustment	100%	107.9%
After adjustment	100%	101.4%
B1, B2, B3		
After partial adjustment	100%	103.2%

Table 5. Actual axle loading on selected bogies (lb)

Relative Loads	Left	Right	Total
Bogie #5			
After adjustment	(F) 8028	(F) 8573	16601
(excl. ruts)	(R) 8078	(R) 8328	16406
(with ruts)	(F) 75328	(F) 7728	15266
	(R) 7578	(R) 7483	15601
Bogie #2			
After partial adjustment	(F) 7178	(F) 9073	16251
(excl. ruts)(	(R) 7628	(R) 8178	15806

(F) = Front Axle
(R) = Rear Axle
1 lb=0.453 kg

Another unique finding was the unexpected premature deterioration of the asphalt. Cracks were already beginning to form in a portion of the wheel path at 650,000 axle load applications. By using SASW tests it was found that the degradation of the asphalt could be monitored in real time. The basis for this is demonstrated by the test results shown in Figures 11 and 12 and Tables 5 and 6. In Table 6 the results are given for the stiffness of uncracked asphalt at 4.5m in the right wheel path. In Table 7, which relates to Figures 11 and 12, the effect of cracking in the wheel path can clearly be seen by the drop in the stiffnesses. This unique test promises to become a valuable tool for monitoring pavement degradation as part of the pavement management system.

- Temperature 21°C
- Test Section at 4.6 m on the right side of the MLS.
- SASW after 650,000 loading cycles

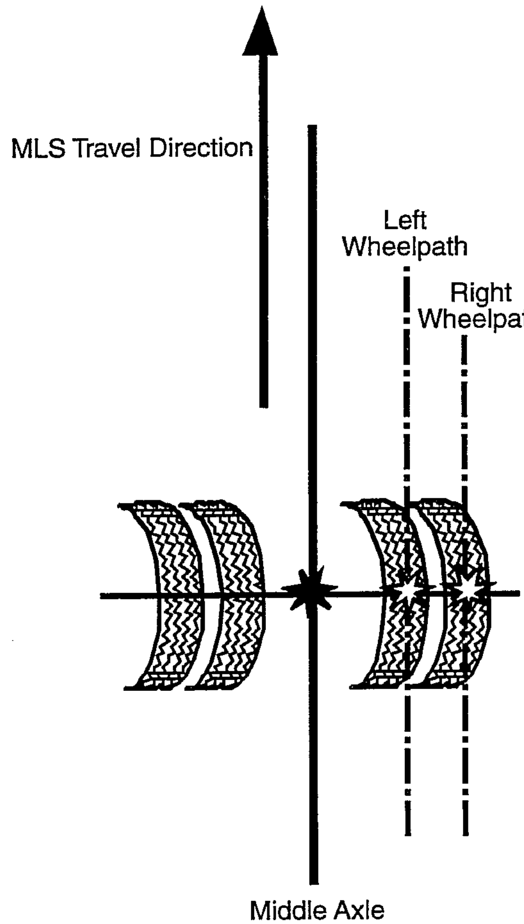

Figure 11. Plan view of intact section.

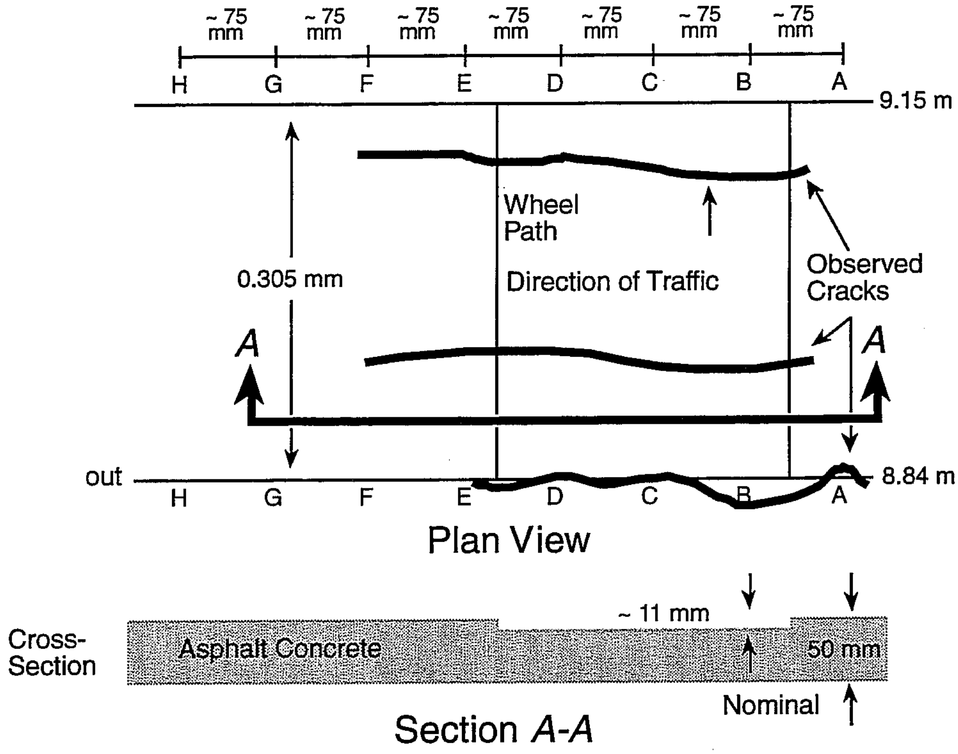

Figure 12. SASW test positions.

Table 6. Results of SASW tests at 4.57 m R.

	V_S (m/s)	G (MPa)	E (MPa)
Asphalt Concrete	1600	606	1698
Untreated Base	475	53	150
Treated Base	550	72	201
Subsoil	150	5.3	15

Table 7. Results of SASW tests at 8.5 to 8.8 m R.

Sections	V_S (m/s)	G (MPa)	E (MPa)
A-A	1000	268	751
B-B	950	242	678
C-C	675	122	342
D-D	800	172	480
E-E	900	217	608
F-F	1500	603	1689
G-G	1450	564	1578
H-H	1500	603	1689

Density = 2324 kg/m^3; υ =0.4

ANALYSIS OF THE "DAMAGE" POWER LAW

In discussing the results of the tests obtained with the acceptance pavement, it should be remembered that it was not intended to be a formal test. The opportunity was merely used to capture some interesting phenomena during the acceptance testing program. The following assumptions should also be noted:

- Damage is proportional to the number of axle loads applied.
- Damage caused by an axle relative to a reference axle load can be defined by an equivalency factor F_j.

Thus,

$$F_j = \frac{d_j}{d_{ref}}$$

Also:

$$F_j = \left(\frac{P_j}{P_{ref}}\right)^n$$

where:

P = axle load, and

n = dependent exponent.

If Dt_j = total axles:

$$\frac{Dt_j}{Dt_{ref}} = \left(\frac{P_j}{P_{ref}}\right)^n$$

and

$$n = \frac{\log\left(Dt_j / Dt_{ref}\right)}{\log\left(P_j / P_{ref}\right)}$$

By measuring the relative rut depths and determining the corresponding loads on the bogies, it was possible to draw some conclusions regarding the "damage" equivalency of the axle loads. This will be demonstrated by means of an example.

Example:

For the respective ruts depths of 7 and 12mm, and using the relative loads that were measured on bogies 4, 5, and 6 (see Table 3), we have:

$$n = \frac{\log 1.71}{\log 1.079} = 7.06$$

Effect of such a change in the power law

The effect of such a change in the power law would be dramatic as can be demonstrated:

- Assume 6000 ESAL's/day with 20 percent having 20 percent overload

  i.e., 1200 at 1.20 ESAL's are

$$= (1.2)^7 \bullet 1200 \text{ standard axles}$$
$$= 3.58 \times 1200$$
$$= 4296$$

- This yields total AD Traffic = 9096 ESALs

$$= 152\%$$

CLOSING REMARKS ON THE EXPERIMENTAL TEST RESULTS

From the above results it is apparent that the MLS promises to be a valuable tool for studying the behavioral characteristics of pavements. It is indeed anticipated that it will enhance the understanding of items such as

- remaining life
- pavement performance
- vehicle/pavement interaction

Evidence of this has already been exhibited in the findings of the first test that was performed in phase I of the MLS test plan.

NOTEWORTHY PERIPHERAL ITEMS

Along with the MLS, a number of peripheral activities have taken place. Special efforts were made to keep the research community and the public in general informed about the MLS' development. During the third International Pavement Management Conference in 1994 a field trip to the MLS at the VMW factory was arranged. More recently, an exhibition stall was taken at the PIARC meeting in Montreal. A number of short videos have been made in collaboration with the Travel and Information Division of TxDOT. The model MLS was exhibited in Washington, D.C. at the Transportation Research Board (TRB) Annual Meeting, as well as at an annual shortcourse held at Texas A&M University, College Station, Texas. It has been used to test scaled-down pavements at both low temperatures (<5°C) and at high temperatures (40°C). Furthermore, a study was commissioned by TxDOT to investigate the effect of the scaling using dimensional analysis. A report on this was completed in 1995.

FUTURE DEVELOPMENTS

It is clear that it is neither feasible nor advisable to continue along a path of re-engineering the existing prototype. It already has the capacity for rendering a useful and important contribution towards the goals set for it. The first test in Victoria on a frontage road of US 59 built by the Yoakum District has clearly demonstrated this. The results have also been reported at the 1995 TRB meeting by Mr. Ken Fults, the Project Director for the study.

The focus has therefore shifted towards the production of the next MLS. Lessons learned will of course be heeded. It is likely that the mechanical construction of the bogies will be changed to achieve the higher speed set in the original Specific Operational Requirements (SOR). This may necessitate some adaptations to the mounting of the axles. Nevertheless, the original goal is still to use regular truck components. Overall, the design is expected to be more cost-effective, since there is a greater understanding of the forces involved and of the behavioral characteristics of the truck bogies.