

## PROJECT DETAILS - Effects of Implements of Husbandry (Farm Equipment) on Pavement Performance

### BACKGROUND:

The Iowa Department of Transportation conducted a study in 1999 to address pavement damage caused by heavy farm equipment. Based on the results from this study, Iowa passed legislation that was found acceptable to both the DOT and industry. South Dakota also performed a similar study in 2001. The South Dakota field test sections were constructed and instrumented to measure pavement responses such as strain, pressure, and deflection caused by some agricultural equipment. Theoretical modeling was also conducted to investigate pavement damage. The study resulted in recommendations on changing regulations concerning certain types of farm equipment.

In 2001 the Minnesota Department of Transportation conducted a scoping study on the impact of agricultural equipment (animal husbandry vehicles, grain carts, etc.) on Minnesota's low volume roads. The main purpose of the study was to determine if agricultural equipment caused excess pavement damage in Minnesota. The study reviewed several county roads that were claimed to have been destroyed by farm equipment. However, the study found that other heavy vehicles, such as trucks hauling gravel or rock from quarries, might also have contributed to the damage on the roads. This study concluded, "it is difficult to link specific pavement damage to agriculture equipment and quantitatively estimate the reduction in pavement life with current available information." One of the recommendations from the study was to conduct a field study at the MnROAD test facility to specifically address pavement damage due to agricultural equipment.

### OBJECTIVE:

The objectives of this study are to determine pavement response under various types of agricultural equipment (including the impacts of different tires and additional axles), to compare this response to that produced by a typical Class 9 5-axle tractor-trailer, and to calibrate the analytical models for prediction of relative damage caused by heavy farm equipment. Based on these results, it may be possible to provide recommendations on tire and axle configurations that would reduce pavement damage from agricultural equipment. In addition, this study will provide basic information for use by the state transportation agencies for potential legislative uses.

### SCOPE:

The objectives of this project may be accomplished by constructing new instrumented test sections at MnROAD and/or to retrofit instrumentation into the existing test sections. This pooled fund study, with contributions from Mn/DOT and other participating organizations, will fund both the possible construction of pavement test sections and the research on heavy farm equipment. This research will allow policy and design decisions to be driven by direct experimental results rather than by models that may not have been validated for the types of loadings and tire configurations of current and evolving agricultural equipment.

### LITERATURE SEARCH:

Heavy Agricultural Loads on Pavements and Bridges ,Ài Iowa State University (HR-1073), 1999  
Response of Iowa Pavements to a Tracked Agricultural Vehicle - Iowa State University (HR-1075), 2000  
Effects of Off-Road Tires on Flexible and Granular Pavements, Special Bulletin #44 ,Ài South Dakota 2001  
Scoping Study: Impact of Agricultural Equipment on Minnesota,Àôs Low Volume Roads ,Ài Mn DOT, 2001  
Vehicle Weight Exemption: Boon or Bust, Minnesota  
Effect of Off-Road Equipment on Flexible Pavements ,Ài Paper presented at the 2003 TRB annual meeting  
MnDOT Synthesis Study, 2005, Iowa State University

### MNDOT ASSISTANCE:

MnDOT will construct and instrument the test sections, collect the pavement performance and pavement response data, and upload the measured data into the MnROAD database.

### TASKS:

#### Task 1

Name: Design Experimental Pavement Sections

Description: The following activities will be conducted under this task:

1. Design pavement sections
2. Develop instrumentation plan
3. Develop data collection plan

The research team will finalize with MnROAD personnel the design of the proposed test sections and specify the instrumentation that will be selected and installed as part of the structural experimentation plan. Since this experiment is meant to address mechanistic pavement issues, it will be critical to employ sensors that have the ability to measure in situ pavement responses under load. Generally speaking, the instrumentation was devised to provide eight major responses:

1. Horizontal strain at the bottom of the HMA layer: H-shape strain gauge.
2. Horizontal strain at the side edge, top and bottom of the PCC layer: bar shape strain gauge.
3. Joint opening/closing movement at rigid pavement: horizontal clip gauge.
4. Displacement in base layer: 3D LVDT.
5. Vertical deflection at the corner of the PCC layer: LVDT
6. Vertical stress at the HMA/base interface and at the base/subgrade interface: pressure

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7. Temperature and moisture throughout the pavement depth: thermocouples and moisture sensors.
8. Frost depth of the subgrade: frost pin
9. Tire - pavement contact pressure: surface stress device.
10. Deflection at dynamic loads: FWD.

When evaluating potential vendors of pavement instrumentation equipment, a number of criteria should be considered in selecting the final types of gauges, including:

1. Ability to measure desired responses.
2. Cost.
3. Availability (i.e., delivery times).
4. Reputation of reliability.
5. Continuity with previous research efforts at the test track.

The research team will work closely with MnROAD personnel to finalize the type of gauges. After that, a comprehensive instrumentation layout plan will be developed.

The research team will obtain from the industry representative (Kevin Erb) the list of farm equipment to be used in this study, its availability, and equipment specification. For each vehicle, the following technical information will be collected:

1. General vehicle information
  - o vehicle type
  - o vehicle manufacturer and general vehicle info (type, model, year, etc.)
  - o load configuration
  - o gross vehicle weight (lbs)
  - o fully loaded vehicle weight (lbs)
  - o typical operation speed (mph)
2. Axle information
  - o no. of axles
  - o axle spacing (center-to-center between main axles) (in.)
  - o dual spacing (center-to-center between left and right axes) (in.)
  - o axle load (lbs/axle) (driving/front axle)
  - o axle load (lbs/axle) (front main axle)
  - o axle load (lbs/axle) (rear main axle)
3. Tire information
  - o number of tires for each main axle
  - o tire type
  - o product code
  - o tire spacing (center-to-center) (in.)
  - o overall tire diameter (in.)
  - o tire/section width (in.)
  - o rim width (in.)
  - o tire size
  - o tread depth (in./32)
  - o weight (lbs)
  - o maximum load (lbs)
  - o tire pressure (psi)

It is anticipated that for each type of equipment testing will be conducted both in spring and either summer or fall. The research team will develop a detailed testing program for each type of equipment as well as the FWD testing program. The Professional Nutrient Applicators Association of Wisconsin (PNAAW) will help in providing each of these equipment types.

**Duration:** This task runs from month 1 to month 6.  
**Deliverables:** Instrumentation plan and data collection plan  
**Cost:** 21,744

**Task 2**

**Name:** Database development

**Description:** The research team will evaluate the information to be collected during the experiment (farm equipment characteristics, material properties, measured pavement responses (displacements, strains, and stresses), temperature and moisture distributions throughout pavement layers, pavement responses, etc. The research team will review the relevant tables in the MnROAD database. The utmost effort will be made to use the existing tables to store the data collected in the proposed study. If necessary, needs for the modification of existing tables or for the addition of new tables will be identified and appropriate recommendations will be made.

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The research team will also identify the required ,Áúcomputed parameters,Áù that should be derived from the raw data collected in this study. These parameters may include backcalculated layer moduli, maximum strains and deflections, joint load efficiencies, frequencies of temperature distributions, etc. Like for the measured parameters, the utmost effort will be made to use the existing tables to store the computed parameters. However, needs for the modification of existing tables or for the addition of new tables will be identified and appropriate recommendations will be made.

The research team will also develop the data quality control (QC) procedure, which will include data checks for each table and cross-reference checks for the data elements stored in the different tables.

**Duration:** This task runs from month 3 to month 8.

**Deliverables:** Letter-report containing detailed description of the proposed tables.

**Cost:** 22,845

### Task 3

**Name:** Predict pavement responses

**Description:** In this task, the research team will use appropriate models (like layered elastic analysis program MnLAYER, finite element program ISLAB2000, or Enhanced Integrated Climatic Model [EICM]) to predict data to be measured in this study. This data will be used for verification of the measured data immediately after the measured data are collected. If a significant discrepancy is observed the data will be re-measured and flagged for further evaluation.

**Duration:** This task runs from month 2 to month 4.

**Deliverables:** A letter-report containing the tables with predicted parameters.

**Cost:** 18,441

### Task 4

**Name:** Construction of the test sections

**Description:** The research team will assist MnROAD personnel in construction of the pavement sections ("arm loop") and collecting information pertaining to constructed pavement material properties. At a minimum, the the following information will be collected:

1. DCP test data for the subgrade and base layers
2. LWD deflection data for the subgrade and base layers
3. Base gradation
4. FWD deflections basins

The research team will also assist in installation of the sensors according to the plan developed in Task 1.

**Duration:** This task runs from month 3 to month 8.

**Deliverables:** A letter-report and a Power Point presentation.

**Cost:** 11,285

### Task 5

**Name:** Pavement Response Monitoring

**Description:** It is anticipated that fourteen vehicles will be tested at the farm loop for two weeks each. Testing will occur in the spring and late summer over three years, beginning in October 2007. Each type of equipment testing will be conducted in spring and then either the summer or fall. Spring testing will provide data regarding Spring Load Restrictions, which exist due to a springtime softening of subgrade typical in northern climates. The late summer (July - August) testing will provide pavement response data for conditions when the subgrade and base are fully recovered in stiffness. The exact testing schedule will be coordinated with PNAAW. PNAAW will ensure that the farm equipment is delivered for testing. PNAAW will also ensure that the industry will provide equipment operators (drivers) to conduct testing.

The research team will develop a detailed testing program for each type of equipment as well as the FWD testing program. The preliminary testing plan is to test 3 types of farm equipment twice a day at 10 passes each. One test will be run in the morning and one test will be run in the afternoon to account for temperature differences. The time in between will be spent testing tire pressures, vehicle speed, braking, effect of vehicle gross weights, etc. At least two days of testing out of each two week period will be dedicated to testing of concrete pavements. Pavement responses (stresses, strains, and deflections), climatic information, temperature distribution throughout the asphalt layers, and moisture data for the base and subgrade will be collected.

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At the farm loop, the following loading tests will be conducted:

1. Effect of vehicle speed. Each vehicle will run over the instrumented sections with a creep speed (5mph) and operation speed.
2. Effect of vehicle gross weight. Each vehicle will be tested 50%, 80%, and 100% of the maximum gross weight.
3. Effect of tire pressure. Two levels of tire pressure will be tested for each vehicle. The range of tire pressure for each vehicle type will be coordinated with PNAAW, the industry, and tire manufactures.
4. Effect of traffic wander. Two wheel paths (positions of the edge of wheel with respect to the pavement edge) will be tested.
5. Effect of tire/pavement interface conditions. Occasionally during testing, a thin layer of sand will be placed above the asphalt surface to reduce the effect of friction between the tires and the road.

At the concrete section of the low volume loop, the equipment will be tested at the maximum gross weight and tire pressure. Two wheel path positions will be tested.

The research team expects to get information on specific types of farm equipment to be tested in each test cycle (two-week testing) at least three weeks prior to testing. This information will be used to develop a detailed testing plan for each day of testing for each vehicle. The detailed plans will be submitted to MnDOT not later than a week prior to the beginning of each test cycle.

The research team also plans to measure contact tire pressure distribution using the CSIR South African device if it is available. It is anticipated that the device will be leased by MnDOT for a 6-month period (from spring to fall). The research team will contact PNAAW for help in obtaining each of the equipment types for one day of tire pressure testing at the MnROAD facility when the device is available.

In addition to at least 14 farm equipment vehicles, the following vehicles will be tested:

1. 80-kip and 102-kip trucks used for testing of the MnROAD Low Volume loop
2. an MTV

The testing with 80 and 102-kip trucks will be conducted prior to the beginning of the two-week farm equipment testing cycles, in the middle of the cycles, and after completion of the cycles. The MTV testing will be conducted when Iowa DOT provides an MTV, but it will not be done during the weeks of the farm equipment test cycles. If the MTV testing is conducted in the first or second year of the project, the research team may not perform testing at 100% of the gross weight. If the responses (deflections and strains) at lower MTV weights are found to be higher than the corresponding responses from the heaviest farm equipment, then the maximum MTV test weights will be reduced to avoid an a premature pavement failure.

The research team will assist MnROAD in collecting tire pressure, pavement responses, and pavement performance data and in population of the corresponding tables of the MnROAD database. The research team will prepare the tables of computed parameters and populate them into the MnROAD database. The research team will also conduct data quality assessment tests according to the QC procedures developed in task 2. Finally, the research team will compare the measured responses with the responses computed in task 3 and identify the discrepancies between the computed and measured responses.

Duration: This task runs from month 5 to month 32.

Deliverables: Results of pavement monitoring. The tables with computed parameters.

Cost: 38,809

### Task 6

Name: Conduct Comprehensive Data Analysis

Description: The research team will conduct a comprehensive data analysis of the data collected in task 5. It will involve the following activities:

1. Tire pressure models. Comprehensive models of tire/pavement contact stress distribution models will be developed for each type of tire used in this study. The CSIR device test results will be used for the model development.
2. Selection and validation of the structural model. The responses collected under task 5 will be used for verification of the structural models. The structural responses (stresses, strains, and deflections) predicted by visco-elastic layered analysis program MnLAYER and finite element analysis

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program ISLAB2000 will be compared with the measured responses. If a significant discrepancy in predicted and measured responses is identified then a more sophisticated 3D model using a general purpose finite element program (like ABAQUS) will be developed.

3. Adjustment of the measured responses for temperature and moisture conditions. Since various types of equipment will be tested on different days, the temperature of the AC layer and moisture conditions will be measured on those days. Adjustment of the pavement responses for the moisture and temperature conditions by adjusting asphalt, base, and subgrade moduli will permit more adequate comparison of the pavement responses induced by different types of equipment.
4. Statistical analysis of measured responses. A preliminary statistical analysis of the measured responses will be conducted. The structural responses (stresses, strains, and displacements) induced by different types of equipment will be compared with the responses from the standard 80-kip and 102-kip trucks. A comprehensive statistical analysis will be conducted and the statistical significance of the difference in the responses will be determined.

**Duration:** This task runs from month 9 to month 33.

**Deliverables:** A letter-report documenting development and calibration of the structural models and results of the statistical analysis

**Cost:** 75,415

**Task 7**

**Name:** Damage analysis model

**Description:** In this task, a procedure for determination of the relative damage from various types of farm equipment compared to the damage caused by a standard truck will be developed. The development of this procedure will involve the following steps:

1. Selection of damage model. For each type of pavement distress (cracking, rutting, faulting, etc.) the available damage models, like the MEPDG, MnPAVE, NATIONAL Pavement COst allocation Model (NAPCOM), Portland Cement Association, US Corp of Engineers, Asphalt Institute, and other models will be identified and compared. The most appropriate models will be selected for further use in this study.
2. Simulation of the responses induced by various types of equipment for a factorial of design features and site conditions. Pavement responses (stresses, strains, and deflections) will be predicted for typical combinations of site conditions (climate and subgrade support) and pavement design features. Both flexible and rigid pavements will be included in the analysis.
3. Predict pavement damage. The calculated pavement responses will be used to predict relative damage from each of the farm equipment types included in the analysis using the selected damage models.
4. Develop recommendations on relative damage from different equipment for different combinations of site conditions. Using the results from the previous step, recommendations on the relative damage for different site conditions and design features will be made. These recommendations will help equipment operators in selecting equipment that produces the least damage to the pavement system. The transportation agencies will be able to determine the combinations of the site conditions, pavement design features, and equipment types that would induce excessive damage in the pavement system.

**Duration:** This task runs from month 13 to month 34.

**Deliverables:** A letter-report summarizing the damage analysis.

**Cost:** 47,341

**Task 8**

**Name:** Prepare draft final report

**Description:** The research team will prepare a final report that contains the following:

1. A description of the MnROAD test sections.
2. A detailed description of the data that has been collected, where the data is stored, and how it can be accessed.
3. A detailed description of the calibrated structural models.
4. A detailed description of the procedure for determination of relative damage caused by farm equipment as compared to a typical Class 9 truck.
5. Results of the comparison of the structural response under various types of agricultural equipment (including the impacts of different tires and additional axles) and the response produced by a typical Class 9 5-axle tractor-trailer.
6. Results of the relative damage caused by the various types of agricultural equipment as compared to a typical Class 9 5-axle tractor-trailer. These results

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will also be useful to provide recommendations on tire and axle configurations that will minimize damage caused by agricultural equipment.

**Duration:** This task runs from month 27 to month 34.  
**Deliverables:** Draft final report  
**Cost:** 25,597

**Task 9**

**Name:** Prepare final report  
**Description:** The research team will address the panel comments on the final report.  
**Duration:** This task runs from month 35 to month 38.  
**Deliverables:** Final written report  
**Cost:** 13,762