Development of Approaches to Quantify Superloads and Their Impacts on the Iowa Road Infrastructure System

tech transfer summary

September 2024

RESEARCH PROJECT TITLE
Development of Approaches to Quantify Superloads and Their Impacts on the Iowa Road Infrastructure System

SPONSORS
Iowa Highway Research Board
(IHRB Project TR-781)
Iowa Department of Transportation
(InTrans Project 19-726)

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The Program for Sustainable Pavement Engineering and Research (PROSPER) is part of the Institute for Transportation (InTrans) at Iowa State University. The overall goal of PROSPER is to advance research, education, and technology transfer in the area of sustainable highway and airport pavement infrastructure systems.

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The user-friendly analysis tool developed as part of this project can help county engineers and other road asset owners quantify structural damages and associated treatment costs of Iowa road infrastructure under diverse superload scenarios.

Objective

This study aimed to develop methods for evaluating the impact of superloads on Iowa's road infrastructure. Specific objectives included the following:

- Quantify damage to pavement and granular roads and associated treatment costs
- Developing a prototype tool employing predictive models based on artificial intelligence (AI)
- Identify repair and rehabilitation alternatives and propose funding alternatives

Background

The term superload encompasses vehicles that exceed the standardized dimensions outlined in traditional vehicle classifications and that pose unique challenges to road networks due to their diverse loading configurations and high gross vehicle weights (GVWs) or axle weights. Examples include implements of husbandry (IoHs) and superheavy loads (SHLs).

The Iowa legislation that governs vehicle weight restrictions is encountering new complexities caused by modern farm implements and other SHLs that often exceed permissible weight limits. Recent legislative changes allow vehicles to exceed gross weights by up to 12%, intensifying challenges to road infrastructure maintenance.

Dual-row modular SHL as a representative superload type

Local law enforcement lacks equipment to measure superload weights and instead reports overloaded vehicles to the Iowa Department of Transportation, whose responses are not always prompt. Therefore, counties must adapt their road design strategies to accommodate superloads. This requires precise methodologies for identifying traffic types and quantifying their impacts.

Problem Statement

While Iowa state law has traditionally standardized vehicles by size and weight, shifts in the agricultural implement and energy industries have led to substantial changes in the vehicle market sector in recent years, most notably in the use of larger vehicles with substantially high GVWs or axle weights. The result has been significant unexpected damages to infrastructure.

Current Iowa state weight permits for superload traffic are more or less subjective based on guesswork, and there is a need for a better way of determining more accurate traffic types and counts that take into account the presence of superloads.

Research Description

This study assessed the performance of both paved and unpaved roads and quantified potential structural damages and associated treatment costs when roads are subjected to various types of superloads and levels of payload.

Damage Quantification

The study investigated 18 IoH types and 16 SHL types that commonly travel in the Midwestern United States, along with a Federal Highway Administration class 9 truck as a reference vehicle. These vehicles represent a spectrum of payload levels.

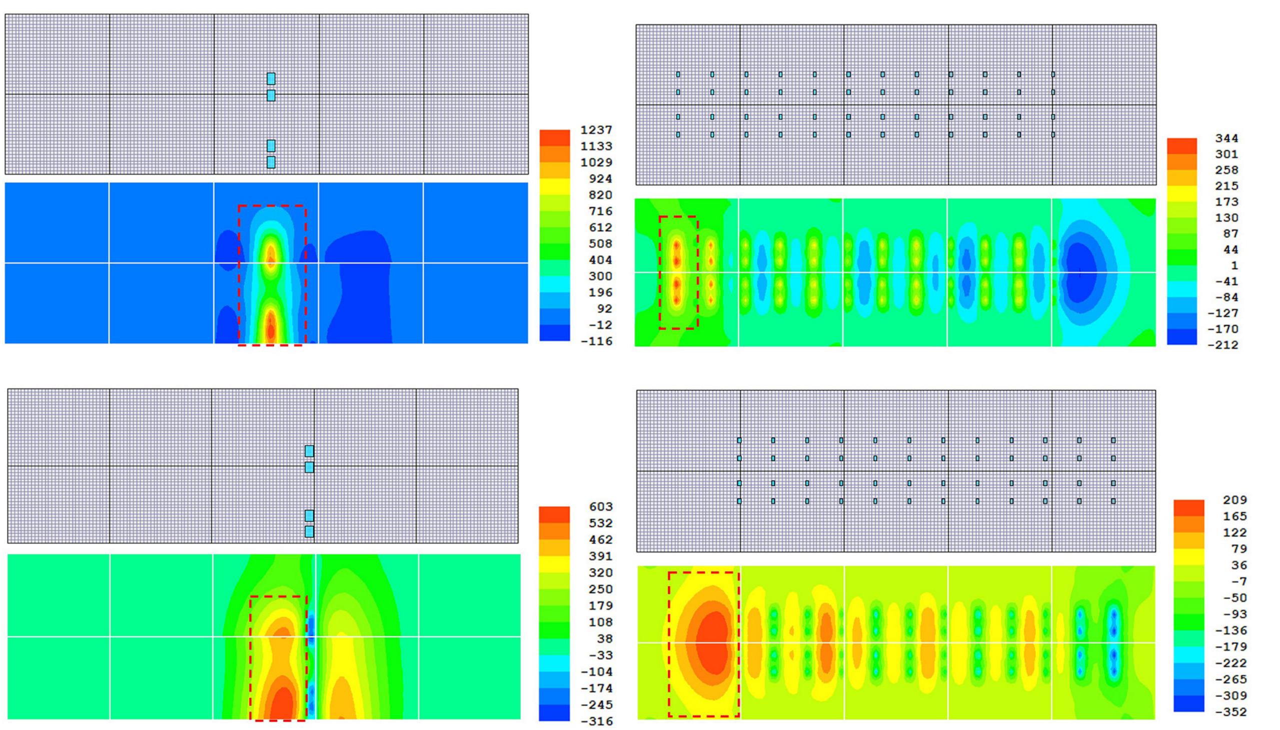
Experimental matrices were developed to conduct finite element analysis (FEA) for jointed plain concrete pavements (JPCPs) and layered elastic theory-based analysis for flexible pavements and granular roads. Approximately 33,000 JPCPs, 25,000 flexible pavements, and 3,300 granular roads underwent numerical analysis.

Life-Cycle Cost Analysis (LCCA)

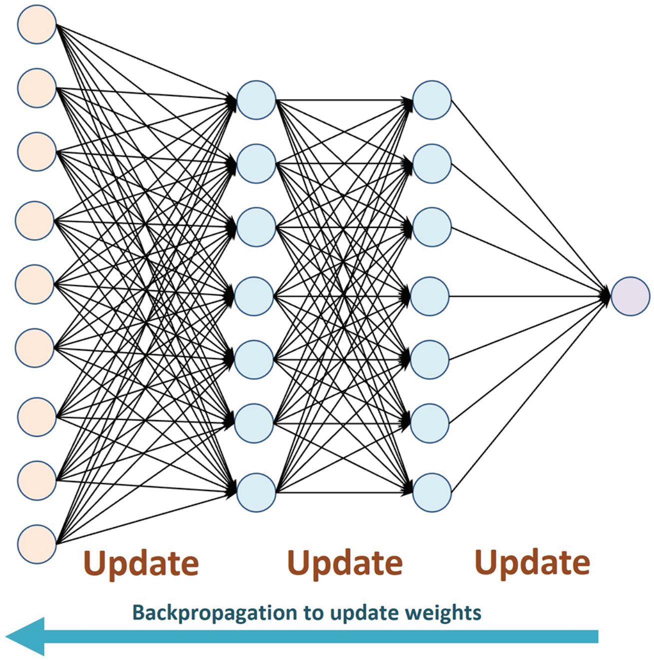
An economic analysis was performed to determine road damage-associated cost and the reduction in service life of JPCPs, flexible pavements, and granular roads subjected to different IoH and SHL types. Different road structures and materials, treatment types, superload types, and payload levels were considered in order to provide a mechanistic basis for permit decisions.

AI-Based Predictive Modeling

Artificial neural network (ANN)-based models for each superload and road distress type were developed and optimized to accurately predict critical pavement and granular road responses related to (1) bottom-up and top-down fatigue cracking of JPCPs, (2) bottom-up fatigue cracking and rutting of flexible pavements, and (3) rutting of granular roads.



FEA for JPCP damage quantification under superloads



Backpropagation ANN-based predictive modeling

Navigation panel of RISAT

Field Instrumentation and Monitoring

Remote data acquisition systems encompassing sensors, data loggers, modems, and power components were installed across JPCP, full-depth flexible pavement, and granular road sections to collect the responses of paved and unpaved roads under traffic loads.

The performance-monitoring data collected from these three road sections, coupled with traffic load data from a portable weigh-in-motion system, underwent thorough analysis and validation using the mechanistic-based analysis results.

Remote data acquisition system instrumentation

Prototype Tool Development

A user-friendly prototype tool, the Road Infrastructure-Superload Analysis Tool (RISAT), was developed that incorporates the ANN-based models developed for two distinct pavement types: JPCPs and flexible pavements.

RISAT is a Microsoft Excel-based automation tool comprised of a navigation panel and several sub-tools. The ANN models developed and optimized in this study are used in RISAT to quantify potential pavement damages, associated treatment costs, and reductions in road service life resulting from diverse superload scenarios.

Key Findings

- In the mechanistic analysis, grain cart IoHs and modular SHLs emerged as primary contributors to structural damage to all three road types evaluated (JPCPs, flexible pavements, and granular roads).
- The LCCA showed that grain cart IoHs and modular SHLs exhibited particularly significant impacts on treatment cost and service life reduction for all three road types.

- The ANN-based prediction models exhibited high accuracy in predicting critical pavement and granular road responses for evaluating fatigue-related damage in JPCPs, rutting and fatigue-related damage in flexible pavements, and rutting damage in granular roads.
- The remote data acquisition systems used for field instrumentation and monitoring were successfully installed in the selected road sections, supporting real-time monitoring of pavement and granular road responses under environmental conditions and traffic loads, especially for superload traffic. The collected field data were used to validate the mechanistic-based analysis models developed for JPCPs, flexible pavements, and granular roads.
- The RISAT incorporates the ANN-based models developed in this research, allowing users to input pavement and superload properties to obtain highly accurate predictions of pavement damages, treatment costs, and service life reductions.
- Incorporating field data into the RISAT enhanced its reliability and applicability in pavement management practices, providing engineers and planners with valuable insights to inform their decision-making regarding pavement design, maintenance, and rehabilitation strategies.

Implementation Readiness and Benefits

The advanced methodology developed in this study addresses the critical need to quantify the impacts of superloads on Iowa's road infrastructure and evaluate the performance of paved and unpaved roads subjected to superload traffic. This research contributes to sustainable strategies for preserving Iowa's road network amidst evolving heavy-transportation demands.

The insights gained into the impacts of different superload types on pavement and granular road distresses, treatment costs, and service life reductions can enable county engineers to quickly make informed decisions regarding repair and rehabilitation plans for their roads and to determine appropriate permit fees or weight permits for superloads.

The culmination of this effort was the development of the RISAT, which offers engineers and planners a user-friendly platform for efficient design and management of road infrastructure subjected to superload traffic.