Development of a Track Component Response Tool (I-TRACK)

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Outline

• Motivation to Develop I-TRACK
• Characterization of I-TRACK
• Radial Basis Function Neural Network
• Project Phases
  - Capabilities and features
• Case Study
• Conclusion and Future Work
FRA Tie and Fastener Research Program
Overall Project Deliverables

**Mechanistic Design Framework**
- Literature Review
- Load Path Analysis
- International Standards
- Current Industry Practices
- AREMA Chapter 30

**I – TRACK**
- Statistical Analysis from FEM
- Free Body Diagram Analysis
- Probabilistic Loading

**Finite Element Model**
- Laboratory Experimentation
- Field Experimentation
- Parametric Analyses
UIUC Finite Element (FE) Model

- UIUC has developed a comprehensive concrete crosstie and fastening system FE model to simulate and gain understanding on the track structural system, components interaction, frictional behavior, and load distribution.

  - Two models are used to simulate the track behavior (including substructure support):
    - **Global model**: five crossties and simplified fastening systems
    - **Detail model**: single crosstie and fastening system
Motivation to Develop I-TRACK

- FE models provide a powerful tool to accurately represent loading environments, support conditions, and component interactions to obtain the system and component level behavior.

- Accessibility and computational limitations are factors that make the use of the FE model impractical for the general user.

- I-TRACK was developed to overcome FE model limitations and provide users with quick access to track components responses with a good level of flexibility.

- Objective: develop a tool to assist improving the design of components and help railroad track engineers assessing the conditions, safety, and expected performance of the track structure.

UIUC FE Model (Chen et. al.)
Characterization of I-TRACK

- I-TRACK is a software based on statistical analyses of the UIUC FE model
- A neural network model was developed to predict track components responses based on user defined inputs (e.g. wheel loads, material properties, etc.)
- No proficiency in computer coding or knowledge in FE modeling is required from the user when using I-TRACK
- Practicality, adaptability, and statistical model reliability were the three main factors taken into consideration when developing the tool
- Microsoft Excel was the platform chosen to embed the initial versions of the model due to its wide spread use, flexible functionality, and ease of use
I-TRACK statistical model was developed using a Radial Basis Function Network (RBFN) approach.

RBFN is an artificial neural network that uses radial basis functions as activation functions.

RBFN gives zero error for the training data. FE model outputs will generate the same values when the same inputs are used as the Design of Experiments that was originally used.

Model was trained using 95 sets of input-output values and tested with 16 runs extracted from the FE model.

Average error in all outputs is below 20% and maximum error is below 30%.
Project Phases

- The development of I-TRACK follows a systematic process. The project was divided into 3 phases, which add additional complexity and analysis capabilities.

- Goal: expedite the development of I-TRACK, test the model accuracy and functionalities on a continuous basis, and provide interim utility to end users.

Phase I: I-TRACK Version 1.0

- Vertical Wheel Load
- Lateral Wheel Load
- Clip Young’s Modulus
- Insulator Young’s Modulus
- Rail Pad Young’s Modulus
- Track Vertical and Lateral Deflection
- Clamping Force
- Clip Max Stress
- Rail Base Lateral Translation
- Abrasion Frame Lateral Translation
- Rail Seat Load
- Max Rail Seat Pressure
Functionalities and Features

- I-TRACK Versions 2.0 and 3.0 will allow users to modify a larger number of inputs (interface interactions, support conditions, components geometry) and will provide additional output parameters.

- **Main Functionality and Features**
  - Simplified user’s interface
  - Tutorial
  - Selection of baselines
  - Selection of inputs
  - Generation of Inputs vs Outputs graphs
  - Analysis Report
  - Prediction of possible failure modes
Overview of I-TRACK Case Study

- **Purpose**: validation of I-TRACK’s results when compared to the FE model outputs

- **Test Case**:
  - Simplified framework for a rail pad assembly mechanical behavior study using I-TRACK
  - Test the accuracy and present the usefulness of this tool in the development of improved design methodologies for fastening system components

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Load (lbs)</td>
<td>30,000</td>
</tr>
<tr>
<td>Lateral Load (lbs)</td>
<td>7,500</td>
</tr>
<tr>
<td>Insulator Young’s Modulus (psi)</td>
<td>440,000</td>
</tr>
<tr>
<td>Rail Pad Young’s Modulus (psi)</td>
<td>7,500</td>
</tr>
<tr>
<td>Rail Pad Poisson Ratio</td>
<td>0.49</td>
</tr>
<tr>
<td>Clip Young’s Modulus (psi)</td>
<td>23,000,000</td>
</tr>
</tbody>
</table>

Magnitude of inputs used to conduct the case studies
• Good agreement was found between results, with magnitude of displacements close to each other.

• I-TRACK successfully captured the FE model behavior with $R^2$ value equal to 0.98.

• Error is present for all the simulated data due to the amount of variables in the system and reduced number of experiments used to develop the statistical model.
Effect of Rail Pad Modulus (RPM) on Track Vertical Deflection

Track Vertical Deflection (in)

Vertical Wheel Load (lbs)

RPM = 7,500 psi
RPM = 15,000 psi
RPM = 50,000 psi
RPM = 100,000 psi
RPM = 400,000 psi
Track Component Response Tool: I-TRACK

Effect of Vertical Load (VL) on Rail Base Lateral Translation

- VL = 10 Kips
- VL = 20 Kips
- VL = 30 Kips
- VL = 40 Kips
- VL = 50 Kips

Rail Base Lateral Translation (in)

Lateral Wheel Load (lbs)
Comparison Between Field Data and I-TRACK Results

- Field results from freight train consist (40 kips axle load)
Conclusions and Future Work

- The development of a tool based on FE model results using RBFN demonstrated satisfactory results.

- Accurate correlation between I-TRACK results and FE Model outputs was found.

- Field data has presented similar behavior to the statistical model results. This is a strong indication of I-TRACK’s accuracy and reliability.

- A systematic investigation of track and components responses using this tool proved to be viable.

- I-TRACK is still on its early stages, but it is a prospective tool to assist the development of mechanistic design practices focused on component performance.
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Questions or Comments?

Thank you!

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