Highway Speed Micro & Macro-Texture Data Collection & Processing for Pavement Friction

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PROBLEM STATEMENT

The current method for collecting pavement macro-texture data at the network level is built upon decades-old principles, specifically the Mean Profile Depth (MPD). Gathering micro-texture data at highway speeds remains unavailable, primarily due to the absence of established standards and limitations in sensor technology. However, both micro and macro-texture measurements are essential for accurately assessing pavement surface friction during adverse weather conditions. Water- and contact-based friction testers have their own limitations in accuracy and repeatability, in addition to their high operating cost. A potential solution is the new Safety Sensor at the Western Transportation Institute (WTI), offering texture measurement at 0.1-mm 3D resolution. This technology has the potential to enable the Montana Department of Transportation (MDT) to collect both micro and macro-texture data simultaneously at highway speeds in a single pass and produce friction information at higher accuracy and repeatability than those from the current methods.

BACKGROUND SUMMARY

Improving road surface safety is critical to save lives and reduce injuries and property damage. According to a survey from 2013 to 2015 (McGee Sr, 2018), roadway departures accounted for an average of 18,275 fatalities annually, representing 54 percent of all traffic-related deaths in the United States. The Federal Highway Administration (FHWA) defines a roadway departure crash as one that occurs when a vehicle crosses the edge line, center line, or leaves the traveled area of the road lanes. Roadway departure crashes involve a range of factors related to the driver, vehicle, roadway, and surrounding environment. Pavement surface friction during adverse weather conditions is a key contributing factor in many roadway departure crashes. State and local transportation agencies have implemented various countermeasures to optimize and maximize road surface friction or skid resistance to reduce roadway departure crashes.

One of the most effective countermeasures in reducing roadway departure crashes and improving road safety is to ameliorate the frictional performance of the pavement surfaces, such as by applying high-friction surface treatment on the pavement surfaces for improved skid resistance or friction (McGee Sr, 2018). Pavement texture is a pivotal characteristic that affects pavement surface performance by providing the ground surface for the tire-pavement interaction. Pavement texture is defined as the deviation of the pavement surface from a true planar surface (Hall et al., 2009). According to the Permanent International Association of Road Congresses (PIARC, 1995), pavement texture can be categorized into four classes: micro-texture, macro-texture, mega-texture, and unevenness based on the peak-to-peak profile wavelengths. Among these, micro-texture (wavelengths of 1µm to 0.5mm) and macro-texture (wavelengths of 0.5mm to 50mm) are two key components of pavement texture in the practice of evaluating pavement texture, skid resistance, and hydroplaning (Flintsch et al., 2003; Bitelli, 2012), as shown in Figure 1.

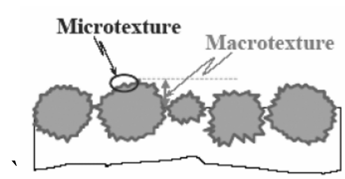


Figure 1 Microtexture and Macrotexture (Flintsch et al., 2003)

Pavement micro-texture is the degree of roughness imparted by individual aggregate particles, provided by the relative roughness of the aggregate particles in asphalt pavements and by fine aggregates in concrete surfaces. Research indicates that pavement micro-texture plays a crucial role in generating dry friction at low speeds, primarily through the adhesion between the tire and the micro-texture (Hall et al., 2009). In contrast, pavement macro-texture is the degree of roughness imparted by the deviating among particles, provided by proper aggregate gradation in asphalt pavement and by supplemental treatment such as tinning, broom, diamond grinding, or grooving in concrete pavement. Functionally, macro-texture significantly contributes to wet friction at high speeds in reliance on the hysteresis force induced in the viscoelastic properties of the tire (Hall et al., 2009). On the other hand, macro-texture is also responsible for offering open channels or pathways for the drainage of rainwater. When macro-texture is inadequate in depth, rainwater will gather on the pavement surface and build up until the tires of high-speed vehicles are completely lifted off the roadway, leading to hazardous hydroplaning (Vaiana et al., 2012).

Pavement texture deteriorates over time under repeated wheel loads of traffic passes and environmental factors of oxidation, erosion, or freeze-thaw-related deterioration. The deterioration of pavement texture degrades the in-service pavement surface friction and thus increases the risks of traffic crashes (Davies et al., 2005; Najafi et al., 2017). Accurate and efficient collection and processing of texture and friction data are essential for transportation departments in assessing pavement friction at both the project and network levels.

The common approaches to collecting pavement texture data include contact-based tests and non-contact measurement methods. The contact-based macro-texture measurement can be achieved in situ through either the Sand Patch Test (SPT) (ASTM E965-15, 2019) or the Outflow meter (ASTM E2380/E2380M, 2019). The SPT method measures macro-texture through straightforwardly evaluating the Mean Texture Depth (MTD) which is interpreted as the ratio of the known volume of sand to the area of its spread on the pavement surface. The Outflow Meter also measures macrotexture through the indicators of the Mean Profile Depth (MPD) or MTD, which is estimated from the time taken for a fixed volume of water to flow through the voids in the pavement's macrotexture. The contact-based tests are generally used in research or project-level scenarios.

Non-contact 2D profiling collection devices, such as vehicle-mounted high-speed profilers, have been extensively used to measure pavement macro-texture in 2D profiles (Kane et al., 2015; Yang et al., 2018; Oracheff, 2021). At the heart of these electronic devices are point laser displacement sensors. These sensors typically feature a point laser that projects a beam onto the pavement surface, and a charged coupled device (CCD) positioned at an angle to detect and capture the reflected laser light. The laser, pavement surface, and CCD sensor constitute a triangulation relationship, which formulates the standard trigonometric functions to capture the information of pavement texture profiles in a longitudinal line. The data from the 2D laser profiling devices are analyzed based on decades-old MPD as a common practice. However, MPD uses a simple average of 2D profile changes, and does not contain comprehensive macro-texture information. Numerous studies in recent decades indicate that the correlation between MPD and friction on pavement surfaces is inconsistent (Li et al., 2020; Pranjić & Deluka-Tibljaš, 2022).

Compared with 2D texture profile data which underrepresents the characteristics of pavement texture due to lack of the third dimension, 3D texture data in the image format with richer information, collected by 3D laser imaging technology, is preferred in the practice of texture information collection (Vilaça et al., 2010; Yang et al., 2021). Similar to 2D profilers, 3D laser scanners also work on the basis of trigonometric relationships between the laser, pavement surface, and camera. The key distinction lies in laser projection: rather than emitting a single point of light, the 3D laser scanner disperses the laser into a thin strip of light through an optical lens. Specifically, a 3D laser scanner collects pavement 3D texture data by capturing sequential 2D laser line profiles in the transverse direction as the scanner moves over the pavement surface. Pavement surface in 3D is then reconstructed by merging the collected 3D transverse profile lines. There have been extensive applications of 3D laser scanners in recent years for 3D texture collection. 3D laser scanners equipped with advanced cameras and additional positioning devices enable dynamic highway-speed data collection. The Laser Crack Measurement System (LCMS) (Laurent et al., 2017) and Digital Highway Data Vehicle (DHDV) (Li and Wang, 2016) are two vehicle-mounted 3D laser scanners capable of collecting pavement surface data at full-lane coverage (4-meter wide) for macro-texture measurement at highway speeds.

In addition to analyzing MPD data from 2D pavement profiles for potential friction information, current practices of conducting friction measurement for pavement friction assessment still rely on contact-based equipment, including British Pendulum Tester (BPT) (ASTM E0303-22, 2022) and Dynamic Friction Tester (DFT) (ASTM E1911-19, 2019), or dynamic devices, including Mu-Meter, the Side-Force Coefficient Road Inventory Machine (SCRIM), Locked-Wheel Skid Trailers (LWST), Grip Tester and among others (Henry, 2000; Kuttesch, 2004; Yang et al., 2018). Compared with stationary friction measurements based on BPT and DFT, high-speed devices can offer continuous measurements but experience insufficient data consistency, repeatability, and accuracy, primarily due to hard-to-control factors such as varying measuring speeds and temperature, water film thicknesses, and tire wear (Henry, 2000; Luo, 2003; Kotek and Florkova, 2014).

The alternative to conducting pavement friction evaluation at the network level is to use 3D sensors that can collect both micro and macro-texture data in a non-contact manner, and reduce or eliminate the negative impacts of the stated hard-to-control factors. Recent advances in 3D laser imaging technology and related software tools are making this implementation possible. This proposed approach utilizes an advanced sensor system at the Western Transportation Institute (WTI) called Safety Sensor with 0.1-mm 3D laser imaging capability. The Safety Sensor and related software solutions can deliver information for both micro- and macro-texture at 0.1-mm resolution. The proposed research would be a major initiative in validating the data collection, processing, testing new computation methods, and ultimately providing support in setting new standard practices in defining pavement surface properties in terms of texture and friction.

Many surface treatments are applied in routine maintenance plans to restore or improve the performance of in-service pavement surfaces (Merritt et al., 2015), including thin Hot Mixture Asphalt (HMA) overlay, Open Graded Friction Course (OGFC), Ultra-Thin Bonded Wearing Course (UTBWC), micro-surfacing, shot-blasting/abrading, High Friction Surfacing Treatment (HFST), chip seal, cape seal, scrub seal, slurry seal, micro-milling, diamond Grinding, grooving, and next generation concrete surface. Particularly, the chip seal, also known as surface dressing or seal coat, is a widely used pavement preservation technique designed to protect and extend the life of existing asphalt pavements (Khattak et al., 2023; Gransberg & James, 2005). It involves the application of a thin layer of asphalt binder followed by a layer of aggregate chips, which are then embedded into the binder to form a durable surface. Chip seal serves as an effective method for improving surface friction, waterproofing the pavement to prevent moisture infiltration, and sealing minor cracks to mitigate further deterioration (Khattak et al., 2023; Gransberg & James, 2005). It is proposed in this MDT project that the effectiveness of chip seal applications and other surface treatments in the state of Montana will be assessed using the highway-speed non-contact Safety Sensor.

BENEFITS AND BUSINESS CASE

The proposed research of implementing advanced 3D laser imaging technologies for collecting both micro- and macro-texture data at highway speeds can improve pavement frictional performance assessments and the efficacy of MDT's Pavement Management System (PMS). The potential benefits of the proposed research are outlined below:

- **Improved data quality**: The use of the advanced Safety Sensor with 0.1-mm 3D resolution improves the accuracy and precision of pavement surface data, leading to more reliable assessments of pavement texture and surface conditions. Particularly, although the Safety Sensor can achieve network-level pavement data surveys at highway speeds, the research team does not anticipate long-distance data collection for each road section, considering the limited research budget and the fact that processing the very large 0.1-mm 3D texture data with AI models is both time-consuming and costly.
- **Better pavement surface condition evaluation**: Accurate assessment of both micro and macro-texture at highway speeds would lead to a better understanding and interpretation of pavement friction characteristics, and efficiently identifying high-risk pavements.
- **Improved infrastructure monitoring and predictive maintenance**: Continuous high-resolution data from highway-speed texture measurements allows for better predictive maintenance, enabling proactive interventions before road surfaces deteriorate to unsafe levels.
- **Improved systemic pavement management**: By collecting high-quality surface texture data and combining other safety-related data such as geometric information and crash data, maintenance and rehabilitation efforts can be better targeted to improve pavement performance, prolonging infrastructure lifespan and life cycles.
- **Reduced congestion and efficiency gains**: Highway speed data collection in one pass without disrupting traffic allows for network-level or large-scale texture data collection and analysis, significantly reducing time spent gathering and processing data for road skid resistance evaluations.
- **Cost savings**: Simultaneous collection of micro and macro-texture data at highway speeds reduces operational costs. Automated data analysis can also help optimize future maintenance budgets for MDT by addressing pavement issues more proactively.

OBJECTIVES

The objectives of the proposed research include:

- The network level data collection for MDT using the new WTI data vehicle equipped with the Safety Sensor at 0.1-mm 3D resolution.
- Development of technical solutions in data processing and computation using various tribology principles to better represent the frictional properties of pavement surface than the traditional methods, such as MPD.
- Development of PMS-based friction indices for the network-level survey that would pinpoint potential pavement sections with low-friction issues.
- Development of performance evaluation method on pavement section with chip seal treatments for texture & friction properties.

RESEARCH PLAN

The project is proposed to last two years with an aim to conduct data collection of 0.1-mm 3D resolution pavement texture and develop processing procedures based on the new 3D Safety Sensor at the Western Transportation Institute (WTI). The Safety Sensor is capable of collecting 0.1 mm texture data covering both micro and macro-texture data in a single pass at highway speed. The outcome of the project would resolve many limitations in current pavement texture and friction data collection practices. The proposed research includes five major tasks:

Task 0: Project Management

The project management is conducted to ensure the project is executed efficiently with proper resource management, coordination, risk mitigation, and adherence to timelines.

Key Activities:

- **Project meeting and coordination**: There will be a kick-off meeting with the MDT Technical Panel to affirm the contractual obligations, scope of work, data requirements and source, deliverables, project milestones, timetable, and other project elements. The research team will schedule regular meetings to discuss progress, challenges, and budget updates. At the end of the project, there will be an implementation meeting to review implementation recommendations with the implementation report having the sections on introduction, implementation summary, and implementation recommendations.
- **Resource management**: Allocate personnel, equipment, and financial resources efficiently, ensuring each task is carried out appropriately.
- **Risk mitigation**: Develop contingency plans to address potential risks such as equipment failure, data quality issues, or delays caused by weather.
- **Timeline monitoring**: Track the progress of task completion and adherence to deadlines.
- **IT infrastructure**: Manage data collection, storage, and analysis using high-performance computing (HPC) systems, ensuring data security and accessibility.
- **Literature reviews**: conduct a comprehensive literature review upon the background summary of the proposal to establish the base and success for the development of the research.
- **Report delivery and implementation**: deliver a performance measures report involving process improvements, and data analysis for the research and potential implementation.
- **Technology transfer**: Ensure proper protection, commercialization, and dissemination of the research among the research team of WTI and MDT.
- **Project presentation**: Provide an overview of the project with detailed discussions on the findings and recommendations. This presentation will include strong technical components and in-depth discussions focusing primarily on research and implementation.

Task 1: Use the WTI Safety Sensor to collect both micro-texture and macro-texture data

Different pavements on mainline highways or local roads in Montana will be selected to be the potential data collection sites to be investigated for the research. The types of pavement surface data to be potentially collected in Montana may include:

- Chip seal

- Asphalt pavements (e.g., hot mix asphalt (HMA), micro-surfacing, and high friction surface treatment (HFST))
- Concrete pavements (e.g., transverse tinning, longitudinal grooves, and longitudinal diamond grinding)

The final pavement surface types to be studied in the project should be determined through meetings or consultation with the MDT Technical Panel. For successful analysis, the research team anticipates the basic yet important information about the selected pavement surfaces and sites from the MDT Technical Panel, including the following key information:

- The locations and lengths of the pavement sites incorporating surface types to be investigated.
- The construction date of the selected pavements or surface treatments.
- The pavement sites with the same type of pavement surfaces or surface treatments should vary in the number of years they have been in use, which reflect varying degrees of wear (e.g., newly constructed, heavily worn, and intermediate conditions).
- The daily or average annual traffic volume of the selected pavements or surface treatments.
- Information about the material compositions of selected pavement surfaces or surface treatments.

After completion of collection site selection, the new 3D Safety Sensor at WTI will be used to collect 0.1-mm 3D surface texture data at highway speed along the wheel path on the selected sites. The 0.1 mm 3D Safety Sensor, as shown in Figure 2, scans an 18.5-inch-wide area of 3D data along the wheel path in a continuous and non-contact manner. The horizontal and vertical resolutions of the 2D/3D images obtained from the 3D Safety Sensor are 0.1 mm and 0.04 mm, respectively. In addition to texture data, the new WTI data vehicle can also collect 9-K resolution HDR images of the right of way (ROW), which can help the research team better identify or validate the general conditions of roadway and surrounding areas. The research team plans to conduct data collection each year on the selected pavement sites in the proposed two-year project period.

Figure 2 0.1 mm 3D Safety Sensor in the laboratory (left) and field (right) environments

In the 3D Safety Sensor, an AI-powered super-resolution model (Figure 3) (Wang et al., 2023a; 2023b), which was developed in previous research to reconstruct 0.1 mm high-resolution texture from low-resolution texture data collected at high-way speed, will be used to enable the highway-speed texture data collection. The research team will utilize one other previously developed AI-powered friction model (Wang et al., 2025, under review) to estimate the friction characteristics on the selected pavement sites using the texture data acquired with an AI-powered super-resolution model, as shown in Figure 4. This AI friction model, which has been validated with data sets in other sites in previous studies, will be applied to process the field texture data sets collected from Montana in this study to estimate friction along the wheel path, simulating conditions similar to those measured with a contact- and water-based friction tester, which operates near the critical slip point of an anti-lock braking system (ABS) at highway speeds. The model will replicate the ability to measure friction at 40 mph under the condition of a constant water film thickness.

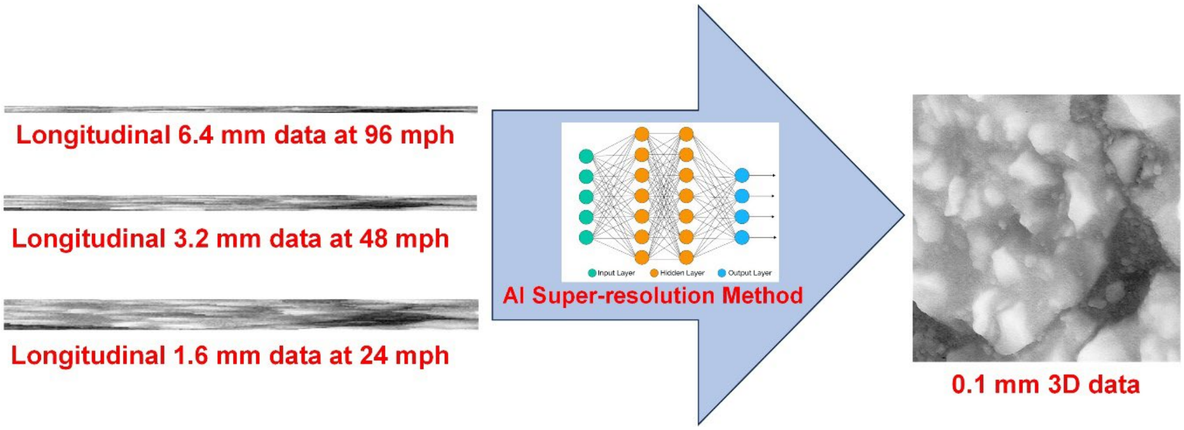


Figure 3 AI super-resolution method for highway-speed 0.1 mm texture data collection

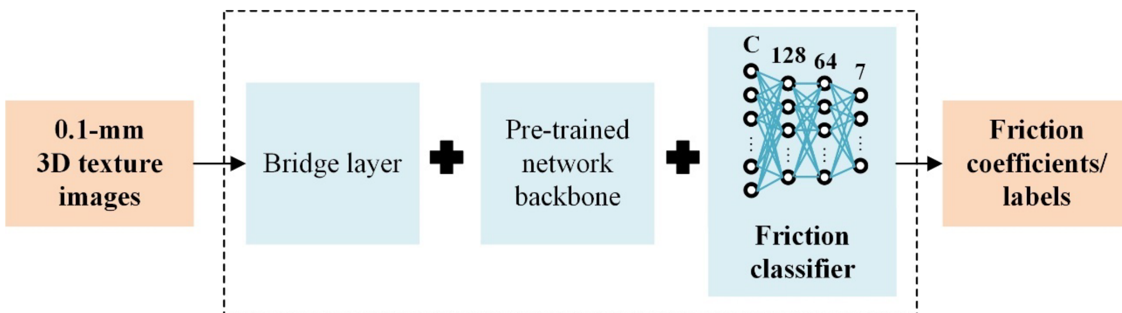


Figure 4 AI friction model for friction label generation using texture data

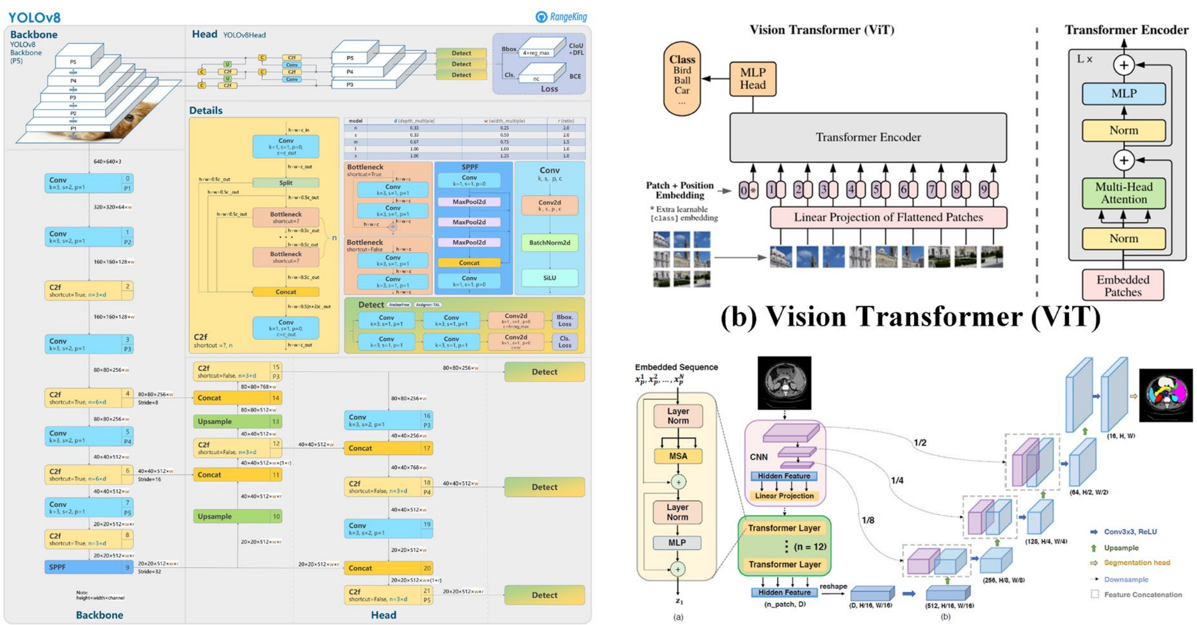
<u>Task 2: Implement data processing and computation methods based on tribology principles</u>

Using the data from Task 1, this task is intended to leverage recent development work by the WTI team to implement advanced computational models and procedures using tribology principles for analyzing pavement surface interactions, focusing on better representing the frictional properties of pavement surfaces and improving friction assessments beyond traditional MPD methods. In this task, the literature on principles and theories of tribology will be reviewed and investigated to understand friction, wear, and lubrication in tire-pavement interactions. The significant variables involved in the tire-pavement tribology will include:

- 3D micro-texture data
- 3D macro-texture data

- Pavement friction coefficients

Based on the above significant variables and research work by the WTI team in recent years (Wang et al., 2023a; 2023b; 2025, under review), a non-contact tribology-based procedure representing the frictional properties of pavement surfaces will be developed specifically for MDT. Among development efforts, the most attention and effort will be put into customizing the implementation of data processing and computation methods for MDT based on the AI-powered super-resolution model (Figure 3) and AI-powered tribology-based friction model (Figure 4). Figure 5 illustrates three deep-learning networks that were recently developed by the AI industry, which may be exploited by the WTI research team to implement a computational procedure based on tribology principles to analyze texture data for MDT, if the implementation performance of the previous developed models is less than desirable.



(a) YOLO v8 **(b) Vision Transformer (ViT)** **(c) TransUNet**

Figure 5 Three well-developed deep networks in the AI industry

The development efforts in this task will be based on an advanced software framework and hardware platform for real-time or near real-time data processing speeds in order to match the highway speed data collection of macro- and micro-texture. The latest Graphical Processing Unit (GPU) boards, housed in WTI, will be applied to accelerate the inference of the implemented model solutions. GPUs are architecturally optimized for running thousands of threads or blocks in parallel, delivering superior instruction throughput and memory bandwidth when compared to central processing units (CPUs). The publicly available NVIDIA's CUDA platform, designed for GPU's general-purpose parallel computing to enhance the speed of these operations and provide a C++ environment to ensure efficient high-performance computation, will be capitalized on for model implementation. Built on the publicly available CUDA and WTI-owned GPU boards, the open-source libraries, including TensorFlow and PyTorch, will be tested in this task to allow for real-time implementation of deep learning frictional property models. Both the two software frameworks have been with open-source Python interfaces for designing and customizing deep learning networks and offer users the flexibility to employ multiple GPUs for optimized speed in training and inference processes.

Task 3: Develop PMS-based friction indices for network-level survey

Using the data from Task 1, this task is intended to develop a universal friction index or a combination of friction indices that can be integrated into MDT's Pavement Management System (PMS), enabling network-level identification of road sections with low friction performance. In this task, the significant variables involved in the development of PMS-based friction indices may include the following indices:

- Arithmetic mean deviation
- Root-mean-square deviation
- Mean arithmetic slope
- Root-mean-square slope
- Average wavelength
- Root-mean-square wavelength
- Mean profile depth
- Mean texture depth
- Symmetry
- Skewness
- Kurtosis
- Maximum peak height
- Maximum pit height
- Interfacial area ratio
- Peak density
- Arithmetic mean peak curvature

The above indices will be selectively calculated based on the micro- and macro-texture components of the collected 0.1-mm texture data, on which a universal friction index or a combination of friction indices will be developed separately for micro- and macro-texture components by investigating the statistical significance of these variables on the friction evaluation of pavement surfaces. The practical implication of this proposed friction indices of PMS will be studied in detail in the proposed research, facilitating the understanding of friction, wear, and lubrication in tire-pavement interactions. The proposed friction indices will characterize the friction performance of the pavement surface to monitor specific treatments and help establish thresholds for resurfacing. It will also consider the possibility of the indices in constituting new standards for pavement frictional property evaluation. The finalization of the proposed indices will be made in consultation with the MDT Technical Panel.

The analytical methods include traditional statistical analysis and learning methods based on neural networks. Particularly, significant attention and efforts are planned to be put into developing multi-layer perception models. The principle of multi-layer perception models is to stack the fully connected layers, enabling developers to observe the weight of each of the investigated variables and assess the significance of the input friction-related variables investigated in the friction evaluation. The PMS-based friction indices for both micro- and macro-texture components will group those significant and available indices, such that they can be better employed for the network-level identification of low-friction road sections.

In this Task, MDT may supply the WTI research team with 3rd party macro-texture data collected using the Traffic Speed Deflectometer (TSD) in Montana. The WTI team will collect micro- and macro-texture data on the same pavement sections to conduct comparison studies to assess the effectiveness and applicability of both sets of data on the same pavement sections for pavement management purposes.

Task 4: Develop friction evaluation method on surface treatments

Chip seal and other surface treatments offer different textures and surface friction properties than existing in-service pavement surfaces. Using the data from Task 1, this task is intended to develop an evaluation methodology for assessing the texture and friction properties of pavement sections treated with chip seals in Montana. In this task, the research team needs the five pieces of information listed in Task 1 from the MDT Technical Panel, regarding the pavement sites applied with chip seals across the state of Montana. The significant variables involved in this task will include the friction-related texture indices listed in Task 3. The data collection for micro-texture and macro-texture data using the 0.1-mm 3D Safety Sensor is planned to be conducted for the selected chip seal sites every year in the proposed two-year project period. Notably, the friction evaluation method could also be developed universally or specifically for pavement surfaces or surface treatments if the five pieces of information listed in Task 1 are available to the research team.

More frequent data collection may be implemented if needs arise or per request of the MDT Technical Panel. Periodic data collection has the potential to allow the research team to develop an evaluation method by identifying and isolating key friction-related indices that change over time. The developed evaluation method will be able to assess whether the existing chip seal treatments maintain service level standards over time, and characterize the frictional performance of the pavement surface to monitor specific treatments and help establish thresholds for resurfacing. The analytical methods in this task would follow those described in Task 3 but will vary according to the special surface characteristics of the chip seal treatment. An important data collection and analysis activity may involve before and after studies on pavement sites that are being planned to receive chip seals.

Figure 6 displays the proposed four tasks and Task 0 in the research plan and their relationships. Specifically, the data collected in Task 1 will be used as the database to conduct the customized implementation of data processing and computation methods for MDT in Task 2. The results and related data produced in Task 2 along with the collected data in Task 1 will be leveraged to perform Task 3 and Task 4 in the development of PMS-based friction indices for pavement network survey and specific frictional properties evaluation methods for chip-sealed pavements or other surface treatments.

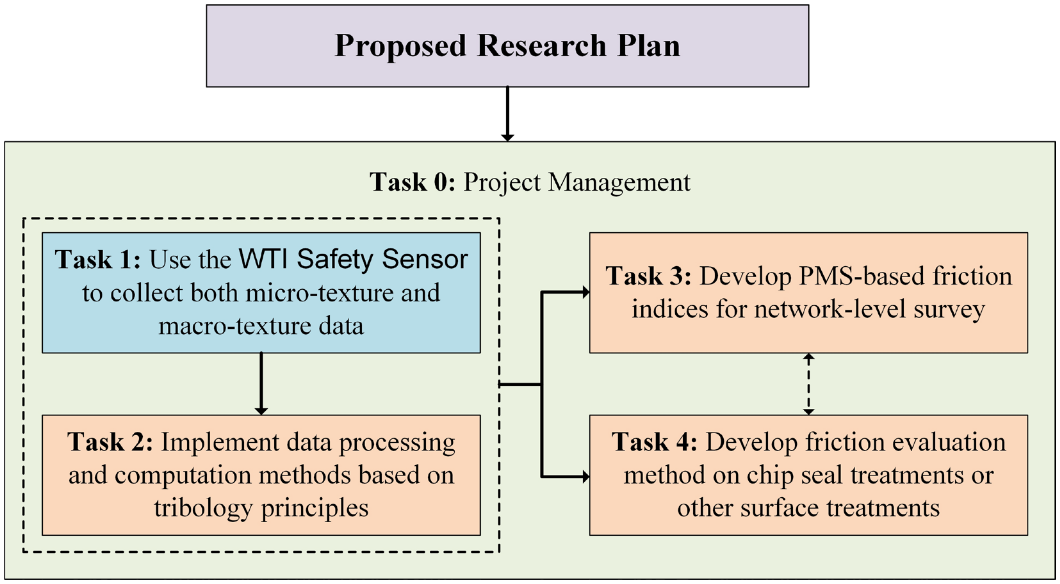


Figure 6 Diagram of the proposed research plan

INTELLECTUAL PROPERTY

The primary IP assets from the proposed research may include:

- **Computational methods and arithmetic models**: The computational models and procedures developed using tribology principles, as described in Tasks 2, 3, and 4, will be major outcomes of this project. These models will provide innovative methods for analyzing pavement surface characteristics and friction property indices.
- **Data collection and processing methods**: The data collection process involving the advanced 0.1-mm 3D resolution Safety Sensor may result in new methodologies or technologies for pavement surface data collection and processing.
- **Evaluation methods and friction indices**: The evaluation methods and the new pavement friction indices developed in Task 3 and Task 4 represent innovative approaches to assessing pavement friction properties at the network level. These outputs will be protected through appropriate IP mechanisms, such as patents or copyrights.
- **Research data and findings**: The raw and processed data collected throughout the project will be managed as intellectual property. While research findings and results may be published in academic journals, access to the underlying data will be governed by institutional policies, with certain datasets potentially restricted for commercial purposes. Any public release of the data will ensure the protection of confidential information and proprietary methods.

IP Ownership and Management

Ownership of intellectual property resulting from this project will be shared between WTI and MDT, in accordance with the respective contributions and institutional policies. The team will work closely with the technology transfer office at MSU to ensure proper protection, commercialization, and dissemination of the IP from the project.

MDT AND TECHNICAL PANEL INVOLVEMENT

The Montana Department of Transportation (MDT) and the Technical Panel will play an integral role in overseeing the progress and evaluating the success of the research project, including the confirmations of site selection, data collection, analysis, and evaluation of the developed methodologies.

Task 0: <u>Project Management</u>

- Participate in monthly or quarterly progress meetings to track the status of each task.
- Offer feedback on resource allocation, scheduling, and risk management strategies.
- Ensure compliance with MDT policies and regulations.
- Monitor the overall timeline to ensure that all project milestones are met.
- Review of various task reports.

Task 1: <u>Use the WTI Safety Sensor to collect both micro- and macro-texture data</u>

- Provide as-built information for the selection of candidate data collection locations as well as other important information, including the data collection sites' construction date, traffic volume, and material components. Note that, although the Safety Sensor can achieve network-level pavement data surveys at highway speeds, the research team does not anticipate long-distance data collection for each road section, considering the limited research budget and the fact that processing the very large 0.1-mm 3D texture data with AI models is both time-consuming and costly.
- Evaluate the quality and completeness of the collected micro- and macro-texture data to ensure it meets MDT's expectations for pavement assessment.
- Review data summary report and provide interpretations on the performance of the WTI Safety Sensor and related solutions, ensuring the system produces actionable data.

Task 2: <u>Implement data processing and computation methods based on tribology principles</u>

- Review the task report and provide comments on the report and results.
- Evaluate the proposed models and procedures, ensuring alignment with MDT's needs for friction properties assessment and decision-making.

Task 3: <u>Develop PMS-based friction indices for network-level survey</u>

- Review the task report and provide interpretations on the proposed indices. MDT will work closely with the research team to assess the possibility of integrating the proposed indices into PMS.
- Provide interpretations on the results of the evaluation and help define how the methodology can be applied to pavement networks across the state.
- If possible, provide existing MDT macro-texture data sets collected with 3rd party devices, such as the Traffic Speed Deflectometer (TSD), for comparison studies by the WTI team.

Task 4: <u>Develop friction evaluation method on chip seal treatments</u>

- Provide as-built information for the selection of the chip seal sites (or other surface treatment sites) as well as other important information, including the data collection sites' construction date, traffic volume, and material components.

- Review the task report and provide interpretations on the results of the evaluation and help define how the methodology can be applied to future chip seal projects across the state.

Throughout the project, the MDT Technical Panel will provide basic and important information about the data collection sites and continuous guidance to ensure the research aligns with the department’s goals and technical standards through scheduled meetings, interim reports, and review sessions. MDT’s involvement will ensure that the outcomes of this research, particularly the data collection methods, friction indices, and chip seal evaluation methodology, are both practical and implementable within the department’s ongoing pavement management strategies.

OTHER COLLABORATORS, PARTNERS, AND STAKEHOLDERS

At this time, no additional collaborators, partners, or stakeholders are to be involved in this project. The research will be conducted by the Western Transportation Institute (WTI) in collaboration with the Montana Department of Transportation (MDT), and these two entities manage all aspects of the project, including research design, data collection, analysis, and implementation.

PRODUCTS

In the proposed research, the four tasks will deliver specific products or outcomes. (1) For Task 1, the deliverables include a full dataset of micro and macro-texture data for the selected pavement sites and a relevant data summary report detailing the data collection conditions, data quality, and relevant additional information, such as photos of filed data collection. (2) For Task 2, the deliverables include a set of tribology-based models that enhance pavement surface friction assessments and a comparative analysis report relevant to traditional MPD methods. (3) For Task 3, the deliverables include a new PMS-based friction index or indices that can provide a reliable means of identifying pavement sections with poor friction performance issues and a validation report demonstrating the accuracy and utility of the friction indices in network-level assessments. A comparison analysis will be submitted on existing 3rd party data sets of pavement macro-texture that were collected using Traffic Speed Deflectometer (TSD) truck with the data sets from the Safety Sensor. (4) For Task 4, the deliverables include a comprehensive evaluation method for assessing the texture and friction properties of chip-sealed or other surface pavements and reports with findings on the effectiveness of chip seal treatments, including recommendations for future applications and maintenance strategies. These deliverables will be presented as appropriate in the following forms:

- Progress Reports
- Task Reports
- Final Report, including recommendations, an implementation plan, and performance measures, as applicable
- Data Management Plan
- Project Summary Report
- Implementation Meeting and Report
- Performance Measures Report
- Poster
- Final Presentation

Note that the budget of this project is not planned to purchase any GPU-equipment computing devices. Instead, WTI will offer the necessary GPU-equipment computing devices to complete the research project. It is not anticipated that MDT would receive any hardware such as GPU-equipped computing devices from the deliverables. The developed solutions and software programs can be installed onto regular Windows computers for use.

RISKS

The proposed research project involves a number of potential risks as below.

1. Model Validation and Accuracy

- **Risk**: The tribology-based models or friction indices may not perform as expected.
    - **Impact**: Medium – leading to inaccuracies, reducing the project's value.
    - **Probability**: Medium
    - **Forewarning indicators**: Early discrepancies between model predictions and field data, or negative feedback from MDT and the Technical Panel.
- **Mitigation measures**:
    - Develop models iteratively, with frequent validation using real-world data.
    - Benchmark new models against current methods to ensure performance.
- **Contingency plan**: Refine models based on feedback and additional data collection.

2. Schedule Delays

- **Risk**: Technical difficulties, field access issues, or prolonged model validation.
    - **Impact**: High – Delays in key tasks could push back the final deliverables.
    - **Probability**: Low
    - **Forewarning indicators**: Missed deadlines or delayed data collection
- **Mitigation measures**:
    - Build buffer periods into the project timeline to account for potential delays.
    - Regularly review progress with the Technical Panel to identify any delays early.
- **Contingency plan**: Re-prioritize critical tasks if necessary.

Risk Monitoring and Management

The presented risks are not anticipated to occur during the execution of the project. However, each identified risk will be closely monitored. Risk management will be maintained to track forewarning indicators and implement mitigation strategies in a timely manner in close collaboration with MDT and the Technical Panel, allowing for proactive responses to any emerging risks, therefore minimizing any negative impact of the risks.

IMPLEMENTATION

The key deliverables will include **Technical Reports and Data**. The findings of this research will be accessible and usable by MDT personnel for possible implementations after this research is conducted. The implementation work listed below will not be included in this proposed research.

Application of Research Results

- The research results will primarily be applied by MDT. Agencies such as AASHTO and FHWA may find the methodologies and models useful for updating standards.

Standards and Practices Affected

- **MDT's pavement management specifications, and related policies and procedures in relation to pavement texture and friction properties evaluation**.
- **AASHTO specifications**: The results may contribute to updates in AASHTO's national standards for pavement surface texture measurement and friction evaluation.

Implementation Plan and Performance Measures

- **The implementation of this research could be carried out in three phases in the future research:**
  - Phase 1: Testing; Phase 2: Integration; Phase 3: Long-Term Monitoring

Necessary Activities for Successful Implementation

- **Training**: MDT engineers and staff will require training on the proposed methods
- **System integration into MDT PMS**
- **Stakeholder acceptance**: Continuous engagement with MDT leadership, pavement engineers, and field staff for final solution acceptance.

Criteria for Judging Implementation Progress

- **Accuracy**: The solutions accurately evaluate real-world pavement frictional properties
- **Adoption**: The rate at which MDT engineers adopt the new methods into their workflow
- **Impact**: A measurable reduction in pavement-related friction-related crashes.
- **Efficiency**: Improvements in the efficiency of pavement texture data collection and analysis

Long-Term Implementation Activities

- **System maintenance and data collection**

Barriers to Implementation and Solutions

- **Barrier 1: Integration challenges with existing systems. Solution**: Involve MDT's PMS Consultant Department early in the process to ensure smooth integration of the tools into PMS.
- **Barrier 2: Budget constraints. Solution**: Prioritize low-cost aspects of the project for immediate implementation and seek external funding for larger integration efforts.

Future Steps

Further field testing: Conduct additional field trials to validate the model across different pavement types and environmental conditions.

SCHEDULE

The proposed research project is planned for two years, from March 2025 to February 2027. The time schedule for proposed major tasks is shown below. Task 0 (Project Management) is assumed to run through the entire project period.

Table 1: Project Time Schedule

Project Work Task	Dates	2025											2026												2027		
		2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
Kick-off meeting, literature review, coding preparation	Jul 25																										
1 – Data collection																											
Task 1 Report	Nov 25,Oct 26																										
Decision Point Meeting	Nov, 25																										
2 – Implement Data Processing and Computation																											
Task 2 Report	Jan 26,Dec 26																										
Decision Point Meeting	Jan 26																										
3 – Developing PMS-based Friction Indices																											
Task 3 Report	May 26,Dec 26																										
Decision Point Meeting	May 26																										
4 – Developing Method for Surface Treatments																											
Task 4 Report	Dec 26																										
Decision Point Meeting	Dec 26																										
5 – Final Reporting																											
5a – Draft Final Report	Jan 27																										
5b – Project Summary Report	Feb 27																										
5c – Final Report	Feb 27																										
5d – Final Presentation	Feb 27																										

◆ Quarterly Progress Reports

⬆ Deliverable Due Dates

Decision Point Meetings will be held between the MDT Technical Panel and the WTI research team at milestones indicated in the schedule chart (Table 1), when the research team would receive feedback and directions from the Technical Panel for the next tasks or technical activities.

BUDGET

Project budget can be found in Table 2.

Table 2: Detailed Project Budget

Table 2- Detailed Project Budget											
Labor Expenses											
Person	Role	Task 1	Task 2	Task 3	Task 4	Total Hours		Total Wages		Total Benefits	Total Cost
Kelvin Wang	PI	80	160	160	160	560		$ 51,335.20		$ 19,784.80	$ 71,120.00
Steven Wang	Researcher	190	340	340	340	1210		$ 43,003.40		$ 21,598.50	$ 64,601.90
Kate Koller	Project Management	20	30	30	30	110		$ 3,602.50		$ 1,854.60	$ 5,457.10
Dana May	Communications	10	20	20	20	70		$ 2,982.70		$ 1,402.80	$ 4,385.50
Neil Hetherington	Visual Comms	10	20	20	20	70		$ 2,503.90		$ 1,243.90	$ 3,747.80
Sameer Gautum (25% FTE)	Grad Student/Researcher	120	280	280	280	960		$ 17,616.00		$ 3,878.40	$ 21,494.40
Clayton Donally (25% FTE)	Grad Student/Researcher	120	280	280	280	960		$ 17,616.00		$ 3,878.40	$ 21,494.40
Terry Tracy	Researcher	60	140	140	140	480		$ 15,950.40		$ 11,347.20	$ 27,297.60
	Total	**610**	**1,270**	**1,270**	**1,270**	**4,420**		**$ 154,610.10**		**$ 64,988.60**	**$ 219,598.70**

Total Labor Direct Costs	$	219,598.70
Labor Indirect Cost @ 25%	$	54,899.68
Total Labor Cost	$	274,498.38

Non-Labor Direct Expenses		
In State Travel	$	4,980.00
Out of State Travel	$	-
Expendable Supplies	$	421.00
Equipment Use Fee	$	15,000.00
Total Non Labor Direct Expenses	$	20,401.00
Non-Labor Indirect Cost @ 25%	$	5,100.25
Total Non-Labor Expenses	$	25,501.25

Totals		
Total Direct Expenses	$	239,999.70
Total Indirect Expenses @ 25%	$	59,999.93
Total	$	299,999.63

Table 3: Travel Budget

Table 3- Travel Budget			
Assumption	Number	Unit Cost	Total
Estimated 15 total days of data collection for two (2) people; assuming overnight trips until more info about trips is available. **Using 2024 GSA rates			
Airfare	-	$ -	$ -
Hotel: 15 days of overnight travel for two people	30	$ 110.00	$ 3,300.00
Rental Car	-	$ -	$ -
Meals: 15 full days of overnight travel for two people	30	$ 56.00	$ 1,680.00
		Total	$ 4,980.00

Travel expenses include an estimated 15 total days of data collection for two (2) people with the assumption of overnight accommodation until more information about the data collection efforts are available.

Table 4: Task, Meeting, and Deliverable Budget

Table 4- Task Budget					
Item	Labor (Salaries + Benefits)	Supplies	Equipment	Travel	Total
Task 1	$ 31,244.00	$ 421.00	$ 15,000.00	$ 4,980.00	$ 51,645.00
Task 2	$ 62,784.90				$ 62,784.90
Task 3	$ 62,784.90				$ 62,784.90
Task 4	$ 62,784.90				$ 62,784.90
Total Direct Costs	$ 219,598.70	$ 421.00	$ 15,000.00	$ 4,980.00	**$ 239,999.70**

Table 5: State Fiscal Year (SFY) (7/1 – 6/30) Breakdown

Table 5- State Fiscal Year Breakdown				
	State Fiscal Year			
Item	2025	2026	2027	Total
Salaries	$ 32,468	$ 77,305	$ 44,837	$ 154,610
Benefits	$ 13,648	$ 32,494	$ 18,847	$ 64,989
In State Travel	$ 1,046	$ 2,490	$ 1,444	$ 4,980
Out of State Travel	$ -	$ -	$ -	$ -
Equipment Use Fee	$ 3,150	$ 7,500	$ 4,350	$ 15,000
Expendable Supplies	$ 88	$ 211	$ 122	$ 421
Total Direct Costs	$ 50,400	$ 120,000	$ 69,599	$ 240,000
Indirect Costs - 25%	$ 12,600	$ 30,000	$ 17,400	$ 60,000
Total Project Cost	$ 63,000	$ 150,000	$ 86,999	$ 300,000

STAFFING

The proposed project will be led by Dr. Kelvin C.P. Wang, the project's Principal Investigator (PI) at WTI. The PI is the general manager of the project. Dr. Steven GL Wang, research associate at WTI, will assist the PI as a Co-PI and manage the day-to-day operation of the technical work and coordinate with other research staff and graduate students to meet the requirements of MDT. The PI has 30 years' experience in leading research in pavement evaluation with advanced sensor and software tools. Dr. Steven Wang completed his PhD in 2023 on the topic of non-contact 3D pavement friction evaluation with AI tools. The PI and Co-PI will spend about 6hr per week and 13hr per week on the project respectively.

The project has two graduate research assistants who are each paid about ¼ or quarter time (0.25FTE) to assist the data collection and proposed data analysis work. Mr. Terry Tracy, research associate at WTI with over 10 years' experience of sensor development, will provide support to the data collection and analysis from the perspective of 3D hardware and software angles at 10% of his time from the project. WTI support staff, Dana May, Neil Hetherington, and Kate Koller will spend about 2% of their time during the project duration on project administration, communication, and accounting management respectively.

Other commitments of the team members include the PI being the WTI director and PI of a FHWA research project on AI for pavement evaluation. The Co-PI is a key researcher for the same FHWA project. Mr. Tracy provides technical support to the same FHWA project. The three WTI staff also have minor roles in a sub-award from Oklahoma DOT (ODOT) on pavement and bridge evaluation.

Table 6 provides the number of person-hours devoted to each task by research team members, as including the principal investigators and other key professionals who will be involved.

Table 6: Project Staffing

Table 6- Project Staffing								Percent of Time vs. Total Project Hours (total hrs./person/total project hrs.)	Percent of Time - Annual Basis (total hours/ person/ 2080 hr.)
		Tasks							
Staff Name	Role in Project	Task 1	Task 2	Task 3	Task 4	Total			
Kelvin Wang	PI	80	160	160	160	560		13%	27%
Steven Wang	Researcher	190	340	340	340	1210		27%	58%
Kate Koller	Project Management	20	30	30	30	110		2%	5%
Dana May	Communications	10	20	20	20	70		2%	3%
Neil Hetherington	Visual Comms	10	20	20	20	70		2%	3%
Sameer Gautum (25% FTE)	Grad Student/Researcher	120	280	280	280	960		22%	46%
Clayton Donally (25% FTE)	Grad Student/Researcher	120	280	280	280	960		22%	46%
Terry Tracy	Researcher	60	140	140	140	480		11%	23%
	Total	**610**	**1,270**	**1,270**	**1,270**	**4,420**			

FACILITIES

The research project will be conducted at the Western Transportation Institute (WTI) at Montana State University, which is well-equipped with the necessary resources and facilities to carry out advanced pavement texture analysis, data processing, and solution development. The following facilities and equipment will be utilized for the successful execution of this project:

1. 3D Safety Sensor and 3D Truck

The WTI lab has a newly built 3D data collection truck equipped with a high-resolution 3D Safety Sensor capable of capturing 0.1-mm texture measurements, and other instruments for pavement evaluation. The facilities will be used to collect macro-texture and micro-texture data from selected pavement sites, enabling precise and detailed analysis of the pavement surface.

2. Computing and Data Processing Facilities

WTI has access to high-performance computers with the latest GPUs that support large-scale data processing and the execution of complex procedures. This computational power is essential for developing and running complex models on the collected texture data, as well as conducting statistical analyses for texture deterioration trends. Also, the research team will have access to advanced software tools, including Python, TensorFlow, PyTorch, and MATLAB, to facilitate the development of computational models, statistical analyses, and friction-related algorithms. These tools will be crucial for implementing and testing the proposed models and ensuring accurate texture data analysis.

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