**COMMENT 1**

***There is a need for a clear vision to be presented by the project team on the look, feel and application of the final product. Consider the experience with the MEPDG model and address those limitations, i.e. high cost of AAHTO maintenance and hosting. This is not meant to be a criticism of this project, rather a note that past negative experiences may be avoided with proactive actions.***

The final product of the project will be a standalone and self-contained tool that can be used by FHWA and state DOTs to estimate pavement response to tire loading. That tool will also provide an adjustment factor to the pavement responses obtained from AASHTOWare Pavement ME Design. The adjusted pavement responses will be used as input in the transfer functions to estimate pavement damage.

***Analysis Tool***

The final outcome of the project will be a tire-pavement impact estimator tool. This tool will allow user to select loading and pavement configuration to predict the impact of tire on pavement. User will be able to select different tire types (wide-base or dual), tire pressure, and applied load. Pavement configuration module will include number of layers, pavement layer thicknesses, and layer moduli or material properties. The responses at any given temperature may be determined using temperature model to adjust responses obtained at base temperature (21oC).

The output of the tool will be pavement responses at critical locations including, but not limited to, tensile strain/stress at bottom of AC, and vertical strain/stress on top of subgrade. Output can be displayed on the tool or saved in user defined location. The engine of the tool will be artificial neural networks that will be running in the background. Pavement responses will be calculated based on real tire-pavement interaction condition; actual non-uniform contact stresses pattern and pavement viscoelastic properties. ANN model training is the most crucial step and will be based on extensive numerical modeling and field/APT test results. The developed tool is not be a design tool.

**COMMENT 2**

***Clearly define the relationship of the product to current performance and pavement design practices; how it does or does not relate and how it may be complimentary.***

The objective of this research was to estimate pavement damage due to new generation wide-base tires as compared to conventional dual tire assemblies. Therefore, the scope of the numerical and field experiments was designed to isolate the effect of tire type, load magnitude, and inflation pressure on pavement response. As a consequence, the product of the original proposal cannot be used as a design tool for pavements, but can provide insight on the behavior of pavements under various tire types and vehicle loads. The analysis method adopted in this research to estimate pavement response is different than that used in the existing Pavement ME Design. Three-dimensional finite element simulations utilizing non-uniform tire-pavement contact stresses allows the introduction of tire type as an impact factor for pavement damage which may not be considered in the current version of Pavement ME Design.

The output from the developed tool are initial pavement responses, whereas Pavement ME Design takes into account the evolution of the responses due to traffic spectra throughout the design period considering seasonal variations.

Hence, an ad-hoc approach will be used that allows coupling the outcome of advanced vehicular loading simulations with the Pavement ME Design if needed. This may require additional simulations and analysis to integrate the outcome of this research to the existing Pavement ME Design. If the panel agrees on the modification of the work plan to implement the research outcome in the design guide, researchers can prepare a tentative plan. It is anticipated that the analysis tool, the final product of this project, will calculate an adjustment factor for the most relevant pavement responses. In order to do so, the research team will obtain the pavement responses using the same assumptions of the Pavement ME Design. Adjustment factor or family of adjustment factors may be determined based on neural network to find a link between Pavement ME Design structural responses and those of the 3-D FEM. The adjustment factors will be incorporated in the distress-prediction transfer functions. Figure 1 summarizes the procedure. If such approach is acceptable, it can be added to the project.

**COMMENT 3**

***There is insufficient time devoted to the LCA portion of the project. Please consider recent reports from Quebec and Ontario for reference.***

Preliminary and general LCA analysis will be provided based on time and data-availability constraints. The first preliminary phase of the LCA work was completed by UC-Davis researchers and currently being reviewed by the PI. It is important to note that LCA is a very data intensive method and the type of data needed (rolling resistance, fuel consumption, impact of tire-pavement interaction on fuel consumption, etc.) to perform a comprehensive LCA for this research is not readily available in the literature. The input from pooled fund partners is critical for some of the data that may be needed to perform LCA. If time and additional resources is allocated, LCA work can be extended and improved.

 **Proposal Addendum for LCA:**

LCA of pavements and tires are influenced by their interaction as well as the amount of input and output that is consumed for raw materials and during their production. Vehicles’ fuel consumption is one of the components contributing to pavements and tires life-cycle individually. Since pavements and tires are considered to be long-lived products, their use-phase (service life) is usually expected to be the dominant contributor to their life-cycle. This study will aim at identifying pavement-vehicle interaction models to calculate fuel consumption influenced by tires and pavements and compiling a combined LCA for pavement and tires together. The combined LCA will include various life cycle stages of each product (pavement and tires) including material acquisition, production, construction, use-phase and end-of-life. The study, for example, will focus on evaluating the overall environmental impact of vehicles equipped with certain fraction of wide-base or dual tires traveling on a network of different pavement structures at varying smoothness levels. The outcome will include the effects of tires on damage levels of a road network, maintenance/rehabilitation needed to maintain overall condition of a road network due to tire damage, and environmental impact of tire production, maintenance, and disposal.

Pavement-vehicle interaction plays a significant role on the fuel consumption of all classes of vehicles including light and heavy duty vehicles. The components of pavement-vehicle interaction are composed of tire geometry and material properties and pavement surface roughness and structural characteristics. It was shown in some of the recent studies that that pavement surface properties (texture and roughness) and stiffness can change fuel consumption by 1-5% for different class of vehicles (Zaabar and Chatti, 2011[[1]](#footnote-1), Chupin et al. 2013[[2]](#footnote-2)). The hypotheses that led to the conclusion reported in these studies are related to the fact that pavement can have an additional impact on the rolling resistance of tires and this impact varies depending on the smoothness and surface deflection of pavement structures. The impact of roughness is relatively well understood due to field measurements; however, effect of pavement characteristics on fuel consumption is a current area of research. In general, none of these studies attempted to quantify the impact of tire type on the fuel consumption. The current study shows that tire type (i.e. wide-base vs. dual) can make significant differences on pavement response which may also influence the effect of pavements on fuel consumption. Therefore, there is certainly a need to improve the existing and emerging models in the literature to incorporate tire type and geometry. This study could be an ideal platform to accomplish this objective since supporting data from the extensive simulations are readily available.

The following figure describes the methodology to calculate fuel consumption of vehicles including the effects of pavement.



Figure 1. Summary of approach to calculate fuel consumption changing with pavement-vehicle interaction (PVI)

The work plan and methodology is outlined as follows:

Task 1 – Review of existing models for PVI and its consequences on fuel consumption

Task 2 – Definition of LCA’s goals and scope

Task 3 – Inventory data collection for pavements and tires (this task will require some data collection from tire manufacturers)

Task 4 – Development of fuel consumption models for PVI

Task 5 – Perform combined LCA for tires and pavements

Task 6 – Report

The expected increase in budget for this part of the work is $210,000 to support one graduate student and part-time research associate for two years.

**DTA *Pavement ME Design***

* **Linear elastic materials**
* **Vertical and uniform contact stresses**
* **Circular tire-pavement contact area**
* **Static load**
* **Fully-bonded layers**

**DTA *Full FEA***

* **Linear viscoelastic, nonlinear stress dependent, and linear elastic materials**
* **3D nonuniform contact stresses**
* **Accurate contact area**
* **Continuously moving load**
* **Friction between layers**

**WBT *Full FEA***

* **Linear viscoelastic, nonlinear stress dependent, and linear elastic materials**
* **3D nonuniform contact stresses**
* **Accurate contact area**
* **Continuously moving load**
* **Friction between layers**

**ADJUSTMENT FACTOR 1**

**(AF1)**

**Factor accounting for model complexity** $AF1=\frac{DTA Full FEA}{DTA Pavement ME Design}$

**ADJUSTMENT FACTOR 2**

**(AF2)**

**Factor accounting WBT tire effect**

$$AF2=\frac{WBT Full FEA}{DTA Full FEA}$$

$$WBT Full FEA=AF1\*AF2\*DTA Pavement ME Design$$

**Fatigue Cracking** $N\_{f}=f\left(E, ε\_{t}^{'}\right);ε\_{t}^{'}=AF1\_{t}\*AF2\_{t}\*ε\_{t}$

**Permanent Deformation** $N\_{f}=f\left(T, ε\_{v}^{'}\right);ε\_{v}^{'}=AF1\_{v}\*AF2\_{v}\*ε\_{v}$

Figure 1. Summary of adjustment factor procedure

1. Chatti, K., and I. Zaabar, “Estimating the Effects of Pavement Condition on Vehicle Operating Costs.” NCHRP Report 720 (2011). [↑](#footnote-ref-1)
2. #  Chupin, O., J.-M. Piau, and A. Chabot. Evaluation of the structure-induced rolling resistance (SRR) for pavements including viscoelastic material layers. Materials and Structures.Vol. 46 (4) (2013).

 [↑](#footnote-ref-2)