Exhibit F - UTCRS

UTC Project Information	
Project Title	Optimizing Performance of Railroad Rail through Artificial Wear
University	Texas A&M University (TAMU)
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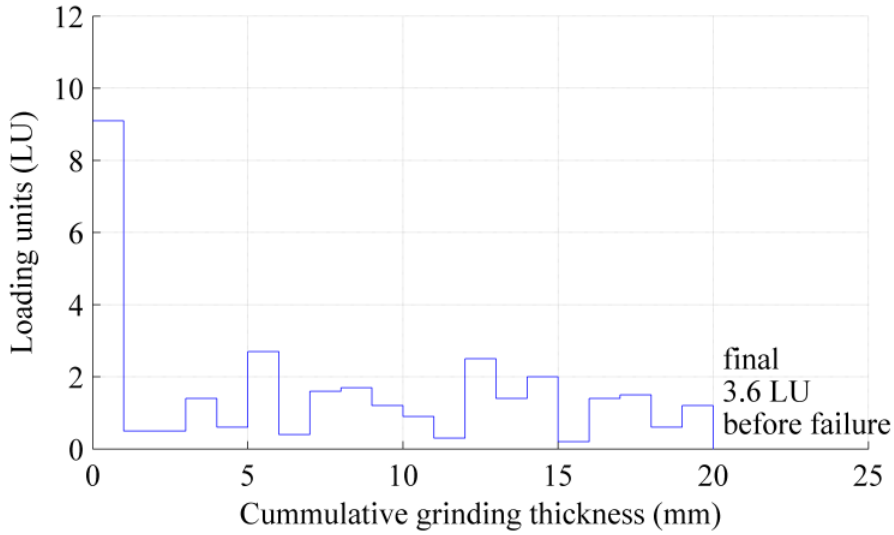
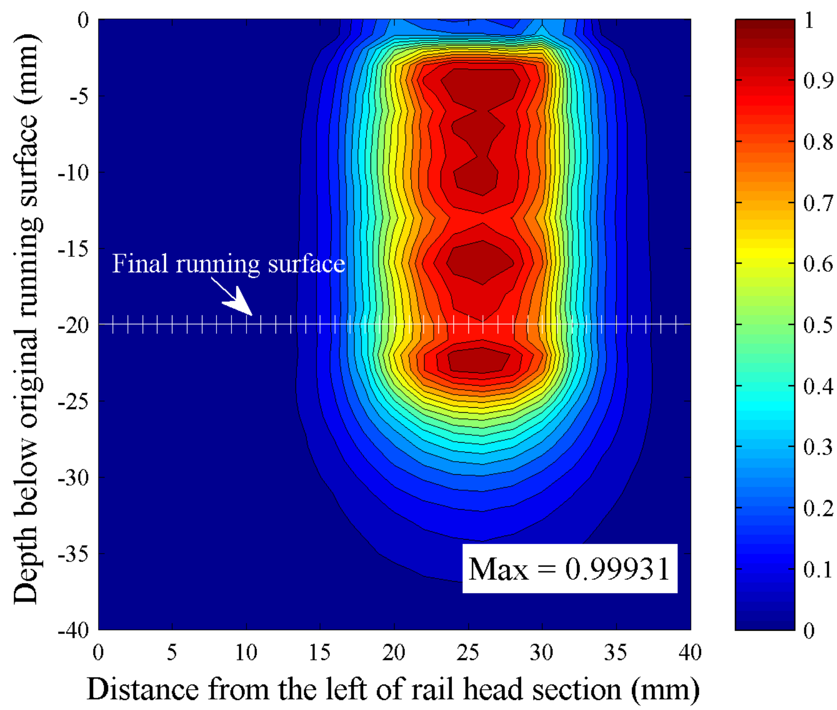
Funding Source(s) and Amounts Provided (by each agency or organization)	Federal Funds (USDOT UTC Program): $100,681 Cost Share Funds (TAMU): $31,039
Total Project Cost	$131,720
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	January 2014 – December 2016
Brief Description of Research Project	Localized plastic deformation from rolling contact and friction at the wheel-rail interface induces a severe multi-axial internal stress state in the rail-head, resulting in both surface and subsurface nucleation of cracks. Catastrophic failure of railroad rail is often caused by such rail-head fatigue defects. The objectives of the proposed project are to reduce the occurrence of fatigue-induced derailments of trains while simultaneously extending the service life of rail. There is worldwide field evidence that rail-head grinding, a form of applying artificial wear to a rail-head, is a cost-effective method to increase the useful life of rails. The current use of rail grinding in the rail industry is to maintain a smooth running surface upon which the wheels of trains roll. Other mechanical effects of rail-head grinding are not fully understood, and thus, the design of grinding schedules

	currently depends upon intuition, prior experience, and historical application. To achieve the goals of this project, wear and fatigue models were developed to simultaneously assess three volumetric regions of the rail-head: surface, near-surface, and subsurface. The proposed wear and fatigue models of this project were integrated into a generalized multi-axial analysis accounting for both natural and artificial wear at the running surface and fatigue crack nucleation within near-surface and subsurface volumetric regions. The multi-axial framework was incorporated into a genetic algorithm (GA) optimization module to help identify meaningful pareto frontiers associated with alternative scenarios of applying artificial wear through rail-head grinding.
Describe Implementation of Research Outcomes (or why not implemented) Place Any Photos Here	A set of representative dynamic wheel loads and corresponding numbers of wheel passages is used in this study. Based on field measurements of a train with nominal 173 kN wheel loads passing at 64 km/h, five representative dynamic wheel loads of 125, 144, 162, 180, and 197 kN, and their corresponding number of wheel passages of 730, 6150, 13820, 8450, and 1390, respectively, were selected. This set defines the *loading unit (LU)* used in this study as a means of comparing the fatigue life outcomes from alternative grinding strategies. Figure 1 presents a schematic and corresponding contour plot of fatigue index accumulation, just before nucleation of the first fatigue crack, for one of the best grinding schedules discovered through the optimization procedure (20 grinding steps with 35.3 LU). As a result, fatigue life increases from 10.16 LU (no-grinding) to 35.4 LU when the grinding schedules developed from an optimization with a genetic algorithm (GA) are applied. This indicates a 248% increase of fatigue life. Nevertheless, the best grinding schedule found in this study is still unlikely to be the global optimum, as the fatigue accumulation contour seems to deviate from the ideal case, where a continuous contour is expected.

	 **(a)**  **(b)** **Figure 1. For the optimal grinding schedule yielding 35.3 LU and 0.99931 maximum fatigue index with 20 grinding steps (from group 1): (a) a schematic of grinding schedule, and (b) a contour of maximum fatigue index accumulation before failure.**

Impacts/Benefits of Implementation (actual, not anticipated)	The proposed optimization framework provides a set of rail grinding schedules that are predicted to improve the safe fatigue life of rail significantly. Specifically, the optimizations with exploratory and local-search genetic algorithm (GA) are able to increase fatigue crack nucleation life of rails by about 240% when compared to no grinding. So far, this project has resulted in three journal manuscripts under revision for submission and a conference paper, which has been accepted for the 2017 *International Heavy Haul Association Conference* to be held in Cape Town, South Africa. • Fry, G., and Tangtragulwong, P., "Analysis of Rail Grinding as a Means to Optimize Rail Head Fatigue Life under Heavy Axle Loads," *Proceedings of the 11th International Heavy Haul Association Conference*, Cape Town, South Africa, September 2-6, 2017.
Web Links • Report • Project Website	http://www.utrgv.edu/railwaysafety/research/infrastructure/railroad-rail-performance/index.htm