A Hybrid Physics-Based, Data-Driven Approach to Model Damage Accumulation in Corrosion of Polymeric Adhesives

Presenter: Roozbeh Dargazany (MSU)

Collaborating Team:

Emad Poshtan (Bosch)
John Harworth (Bosch)
William V. Mars (Endurica)

2019 U.S. DOE Vehicle Technologies Office Annual Merit Review

Project ID #: MAT152 June 10, 2019

Project Overview

Partners

- Michigan State University (Lead)
- Robert Bosch LLC.
- Endurica LLC.
- JdV Lightweight Strategies, LLC.
- Composite Center at MSU

Budget

Total Project Funding:	$1,442,188
• DOE Share:	$967,662
• Collaborators Share:	$474,526
• Cost Share:	32.9%
• FY 2019 DOE Share:	$308,662

Timeline

Start: January 2019
End: December 2021
Completion: 8%

Barriers*

1. Lack of reliable joining technology for dissimilar materials
2. Lack of cost-effective tests for evaluation of corrosion
3. Lack of constitutive model capable of predicting corrosion
4. Predictive modeling Tools
    - Prediction error <10%
    - Lack of validated test protocols

HPM High Performance Material Group

Read *Light Duty Workshop Final Report and U.S. DRIVE MTT Roadmap, section 5.1.

Relevance & Objectives

Overall Objectives:

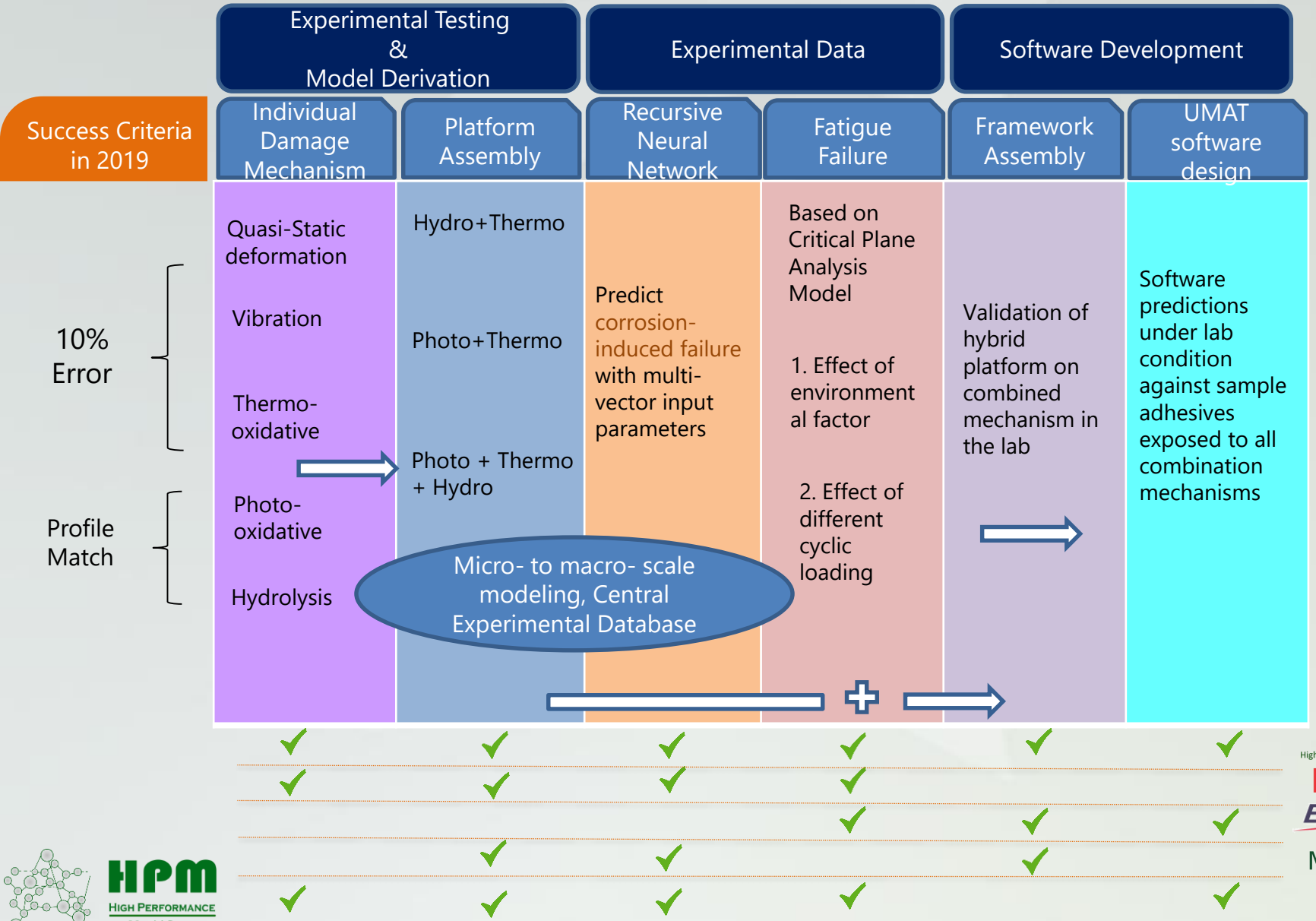
- A software to predict corrosion-induced failure in cross-linked polymeric adhesives with respect to damage accumulation by corrosion and fatigue with a 10% error.
- A theoretical model to describe damage accumulation in constitutive behavior with respect to (1) deformation, (2) vibration, (3) hydrolysis, (4) thermo-oxidation and (5) photo-oxidation.

Impact/Relevance to DOE

Predicting corrosion failure in joints of dissimilar materials is necessary to

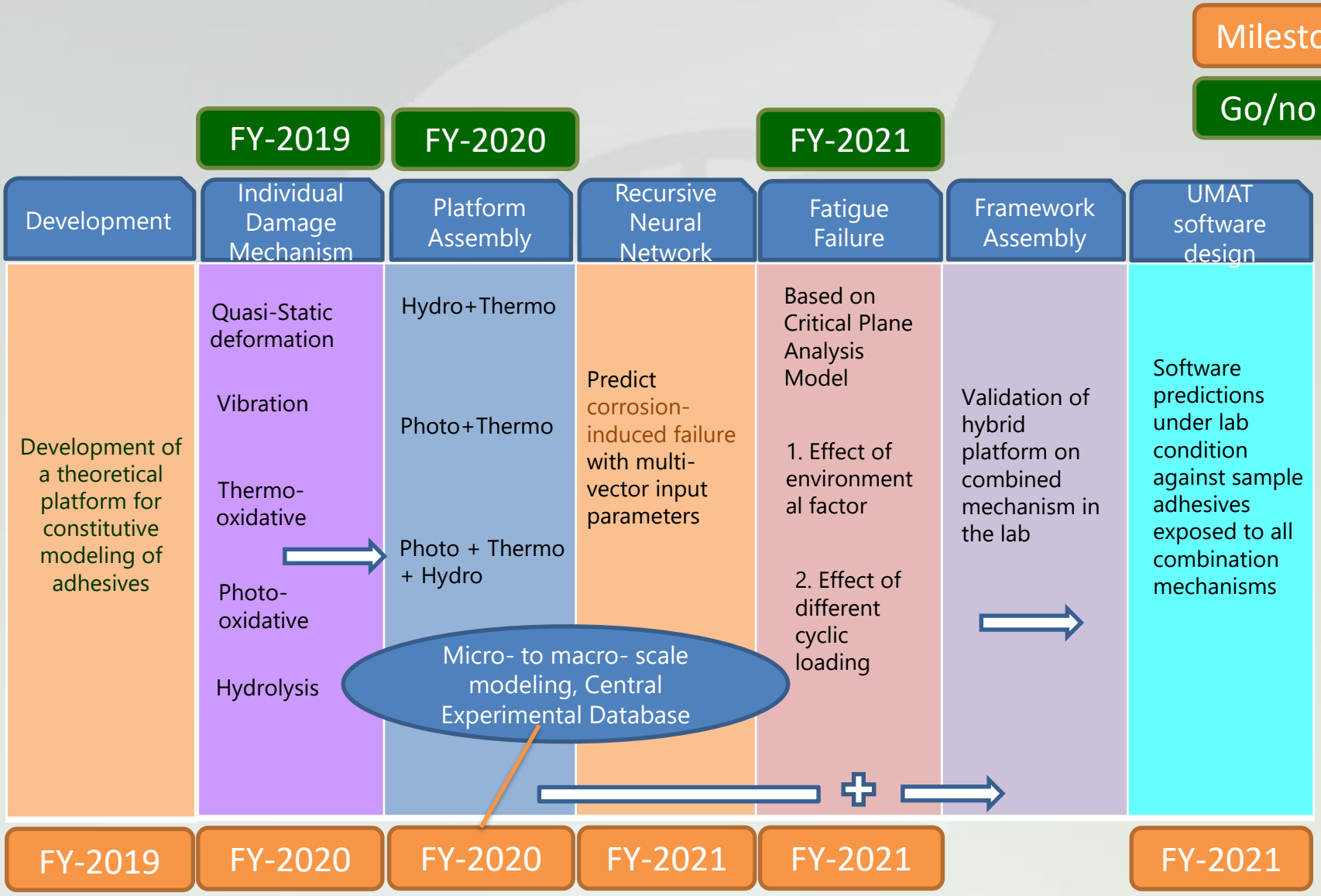
- facilitate use of lightweight material for vehicle mass reduction
- Speed up the application of composites in vehicle structures for lightweighting to address DOE 2030 targets
- reduce time required for testing corrosion failure which makes the use of lightweight materials more attractive for OEM
- Improve CAE prediction capability to achieve a reliable design of joints

Approach & Milestones

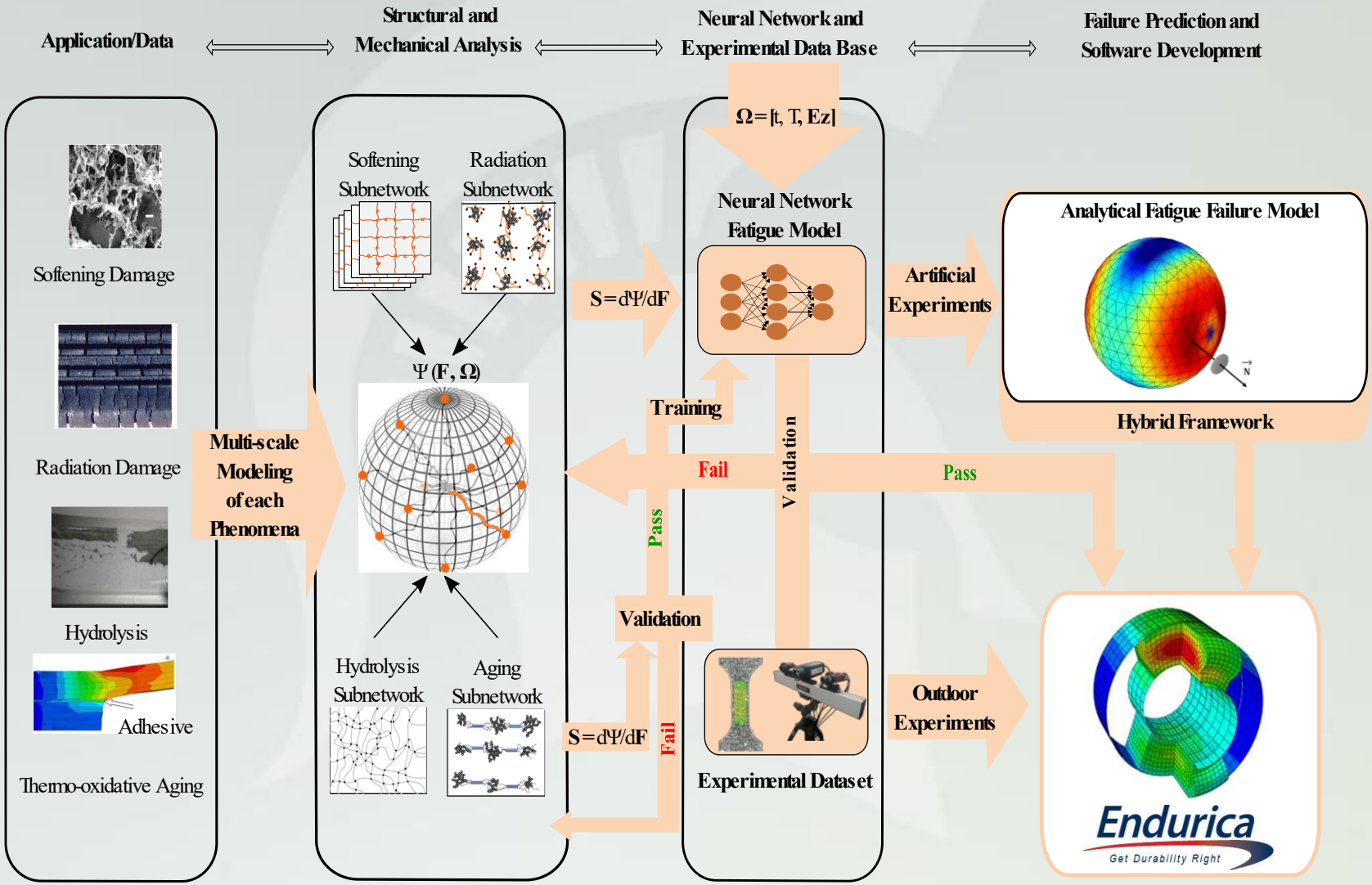


HPM High Performance Material Group
BOSCH
Endurica Get Durability Right
MSU-CMSC
JDV

Approach & Milestones



Approach- Modeling



HPM High Performance Material Group

Technical Accomplishments

Experiment group

- Materials selected:
  - LORD 810 Acylic
  - 3M DP 6310NS Urethane
  - Dow DOWSILTM 7091 (DC)

- Test Conducted:
  - Reliability Test
  - Failure Test for Virgin Material (DC, Urethane, Acrylic)
  - Cyclic Test (DC, Urethan, Acrylic)
  - Failure Test for Aged Material (DC, Urethane)

Technical Accomplishments

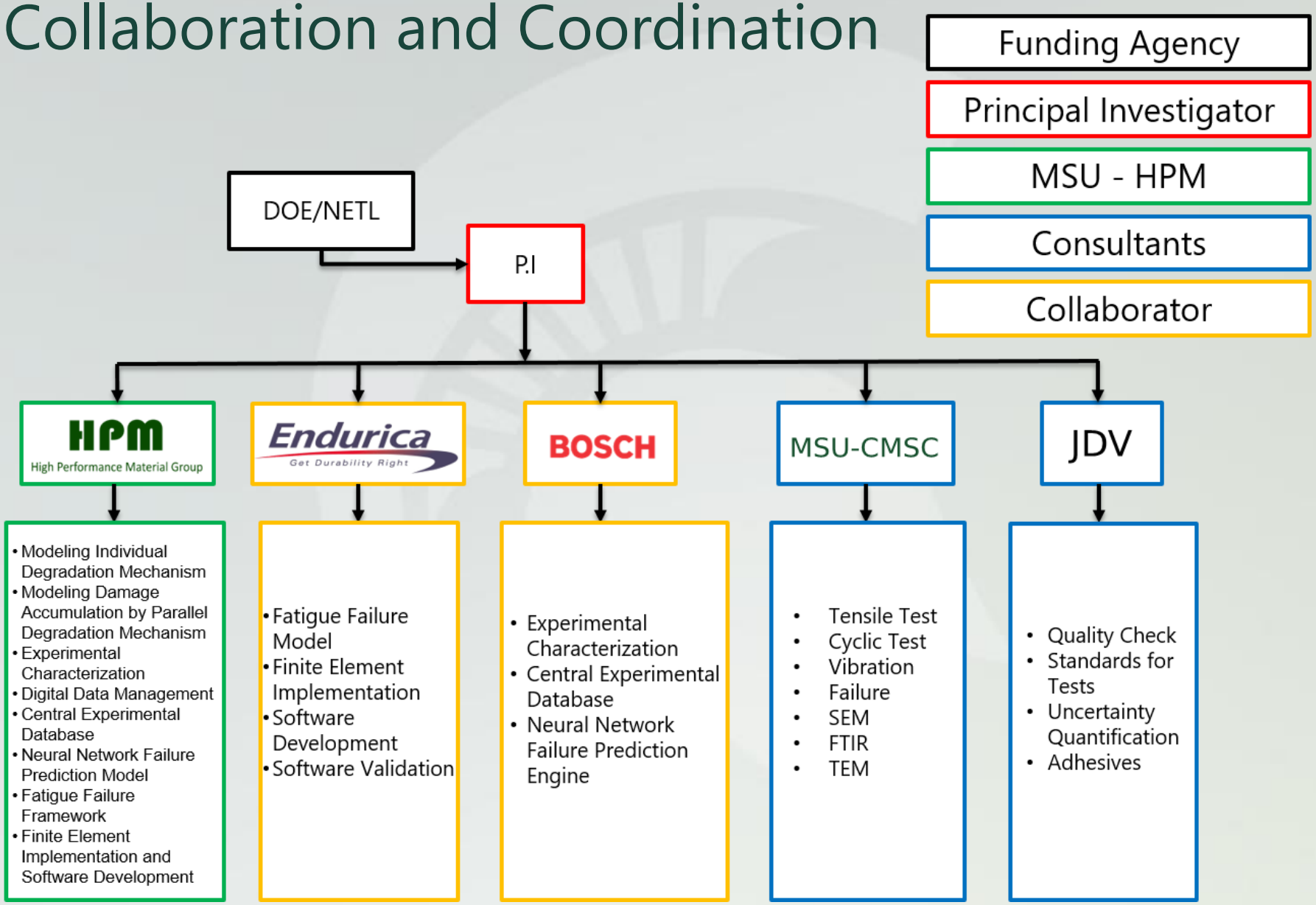
Modeling group

- Modular platform
  - Development of *NET v1.0* as a framework to simulate the permeant damage in elastomeric adhesives (available online on HPM website and SoftwareX journal)
- Improvement accuracy of current statistical polymer elasticity theory
  - Accepted for the publication in journal of Phys. Rev. E
- Current progress
  - Enhancement of quasi-static model (Implemented on interpenetrating polymer networks, will be presented in ECCMR 2019)
  - Utilize non-uniform partial fatigue theory to consider progressive damage due to vibration (will be presented in ASME-AMECE2019)
  - Develop fading-generating networks theory to consider aging mechanisms (thermo-induced aging will be presented in ECCMR 2019 and the water-induced aging will be presented in ASME-AMECE2019)
  - Investigate the effect of decay functions on constitutive model of aged material

Response to Previous Year Review Comments

This project was not reviewed at the previous 2018 VTO Annual Merit Review.

Collaboration and Coordination



Remaining Challenges and Barriers

Modeling	Experiment
Various nonlinear behaviors with specific features for different adhesives	The cost and complexity of corrosion mechanisms aging to achieve isolation of single mechanism
Optimize number of fitting parameters	Impurities (compound, and curing) can expedite corrosion-induced failure of bulk samples
Non-uniform damage mechanism in the material	The need for accelerated and validated test protocols for the evaluation of corrosion of adhesive components under a variety of operating conditions.
Complicated and inseparable sources of degradations mechanism	
Inconsistency between accelerated and normal aging tests results	

Proposed Future Research

Ongoing	FY19	Derivation & Validation of the quasi-static model
		Derivation & Validation of the vibration induced damage model
		Derivation of the Hydrolysis model
		Prediction of constitutive behavior of adhesives subjected to Thermo-oxidation
Proposed	FY20	Validation of Hydrolysis model
		Derivation & Validation of photo-oxidation model within
		Validation of Fatigue Failure model on samples with no degradation
		Prediction of constitutive behavior of adhesives subjected to individual hydrolysis, photo-oxidation and thermal-oxidative degradation
		Prediction of constitutive behavior of adhesives subjected to dual combined hydrolysis, photo-oxidation and thermal-oxidative degradation
Planned	FY20\21	Validation of Neural network engine on samples with different types of degradation
		Validation of hybrid platform on combined degradation mechanisms, lab and outdoor
		Software predictions against sample adhesives exposed to all combination mechanisms for all degradation mechanisms

HPM
HIGH PERFORMANCE
Material Group

Any proposed future work is subject to change based on funding levels.

Technology Transfer and Proposed Future Work

Technology Transfer

- Results of this project will be disseminated through scientific journal publications, conference presentations, releasable codes, and discussions with industry
- Promising technologies will be further pursued through development agreements with industry

Research Outlook

- Generalize the model to other polymeric adhesives, especially for those with brittle behavior
- Further consideration of the effect of interface adhered and the joint morphology or failure-fracture mechanism
- Investigate the effect of dynamic aging

Summary

Accomplishments

- Established the core process required for adhesive characterization
- Identified and addressed the problems involved with testing and validation
- Selected the adhesive compounds, and associated testing technologies to be investigated in FY19 and 20
- Established the modeling concept for three mechanisms: Quasi-static, Thermo-oxidative and Hygro-thermal
- Initiated the concept development for photo-oxidation and vibration-induced damage mechanisms

Future Research

- Further chemical, mechanical and physical characterization of bulk adhesives at different stages of corrosion
- Development of standardized tests for quantification of corrosion for specific damage mechanisms
- Understand the inelastic mechanisms that may occur in parallel with our subject aging mechanism, such as bio-degradation, and diffusion limited oxidation