CRII: CPS: A Decentralized and Differentially Private Framework for Sensing, Operations and Respond Logistics in Large-Scale Vehicle Fleets

PI: Murat Yildirim

https://www.nsf.gov/awardsearch/showAward?AWD_ID=2104455

Challenges and Open Questions:

State of the Art → Untapped Potential → Open Questions

- ***State-of-the-art*** in fleet management builds on (periodic) time-based maintenance policies that suffer from:
  - Frequent maintenances and interruptions to operations
  - High number of incidents for asset failures
- Sensor-driven degradation models provide a significant yet ***untapped potential*** for following asset condition insights:
  - Diagnostics and Prognostics
- Translating asset level predictions to fleet management requires us to address the following ***open questions***:
  - How to use sensor-data to model system-level degradation?
  - How to leverage asset-level condition insights for optimal fleet operations?
  - How to address computational and privacy concerns?

Scientific Impact – i.e. Summary of Scientific Contributions

Predictive Analytics → Prescriptive Analytics (Asset Level → Fleet Level)

- Developing ***multi-component degradation models*** incorporating component-to-component degradation interactions
- Building predictive models that harness sensor data to offer accurate ***prognostic predictions for electromechanical systems***
- Building privacy-preserving fleet-level predictive models that leverage distributed sensor-data for ***scalable prognostics***
- Formulating ***a robust optimization model for prognostics-driven fleet management***, which seamlessly integrates the following tasks:
  - Developing a *linear-constraint reformulation* of degradation models
  - Building *sensor-driven uncertainty sets* for uncertainty quantification
  - Formulating *solution algorithms* to ensure computational scalability

Research Products

Predictive Analytics: *Sensing*

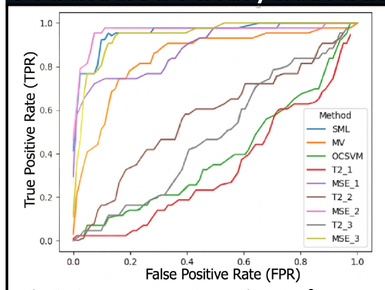


Fig 1. Autonomous Detection Performance for Battery Failure in Vehicular Systems
([1] under review in Int. Journal on Production Research)

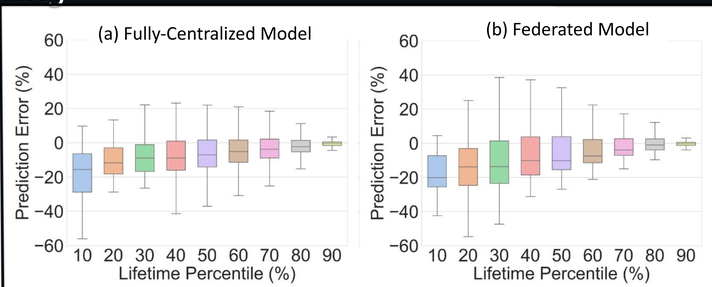
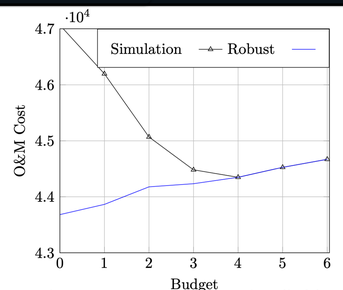


Fig 2. Performance of Remaining Useful Life Prediction for Li-Ion Batteries: (a) Fully-Centralized Prognosis Model, (b) Federated Prognosis Model
([2] under review in Joule)

<u>Prediction</u>: [1] Achieved autonomous monitoring capability using an industrial dataset from an industrial partner. [2] Achieved federated privacy for prognostics with minimal cost in accuracy. Prediction results for the benchmark centralized model has mean absolute percentage error (MAPE) of 17.3, the proposed federated model has a MAPE of 18.5. This is the cost of privacy.

Prescriptive Analytics: *Operations and Respond Logistics*



Deterministic O&M Models	Avg. Sim. O&M Costs
Base	94731
OID	61526
MDI	79902
Comprehensive	47065

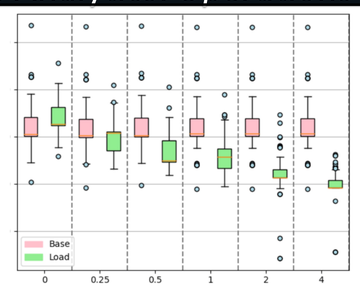


Fig 3. Robust Optimization Results: (left) Comparative results of the proposed vs. benchmark models, showing convergence of simulation and robust optimization results, (right) impact of uncertainty budget on O&M costs.
([3] under review in IISE Transactions)

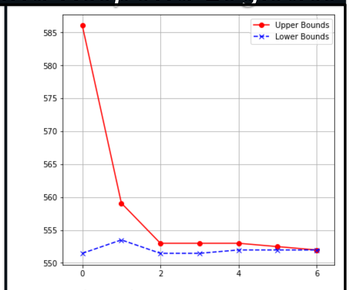


Fig 4. Algorithm Convergence to Joint Vehicle Routing and Maintenance
([4] in preparation for IISE Transactions)

<u>Prescription</u>: [3] Developed novel robust models that adapt to both sensor-driven prognostics and to uncertainty budget (i.e. a measure of willingness to take risks) to provide significant cost savings. When uncertainty budget is 4, cost improvement accounts for 13.1%. [4] Developing a model and a solution algorithm for joint vehicle routing and condition-based maintenance scheduling, with provable upper and lower bounds.

Impact on Human Resources, and DEI

- Training opportunities for 5 PhD students; 3 students from underrepresented groups
- Training and educating the next generation of engineers for an emerging area at the intersection of computer science, electrical engineering, & operations management

Impact on Curriculum Developments

- New course development: *Cyber-Physical Systems* (first course starter in Winter 2023) Course curriculum improvement: *Deterministic Optimization* (Fall 2022, repeated annually)
- Module development: Project development for *REU: Summer Academy in Sustainable Manuf.*

cpsl cyber-physical-systems-lab @ WAYNE STATE UNIVERSITY

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