Future Goals

The Badger Solar Racing strategy subteam is advancing beyond static optimization toward a dynamic, data-driven framework that integrates optimization theory, statistical learning, and refined physics models. The following future goals outline our trajectory.

Dynamic Optimization Framework

Our current optimization wrapper relies on MATLAB's `fmincon` to determine an optimal operating speed subject to energy and distance constraints. While effective, the existing formulation assumes a constant velocity after the optimization horizon. This simplifying assumption restricts fidelity when conditions (irradiance, slope, or wind) vary over time.

To overcome this limitation, we are reformulating the problem as a *trajectory optimization* task. The decision variables will be a vector of speeds

$$v = \{v_0, v_1, \ldots, v_{N-1}\},$$

discretized across the horizon. The cost functional will minimize race time or maximize distance subject to battery state-of-charge dynamics, aerodynamic drag, rolling resistance, and other physical constraints. In practice, this approach is embedded within a *receding-horizon model predictive control (MPC)* loop: only the first control action is applied, while subsequent actions are recalculated at each update step with new telemetry and forecasts. This structure allows the system to remain adaptive rather than static.

Data Integrity via Machine Learning

High-quality input data is essential for reliable optimization. Current telemetry and forecast signals (e.g., irradiance, velocity, battery current) contain noise, outliers, and occasional sensor faults. To address this, we are building a machine-learning based anomaly detection module. Specifically, we are implementing an *Isolation Forest* algorithm to identify and remove corrupted data points prior to simulation and optimization. This statistical pre-processing step will:

- reduce spurious variation in solar irradiance forecasts,
- ensure physically consistent velocity and power measurements,
- improve solver convergence and solution reliability.

This upgrade enables the optimization program to run on clean, representative datasets, reducing risk of infeasible solutions caused by anomalous inputs.

Enhanced Physics Modeling

The current vehicle model primarily accounts for aerodynamic drag, rolling resistance, and battery dynamics. To more accurately capture real-world conditions, we are extending the model in three dimensions:

1. **Rotational dynamics:** Explicit inclusion of wheel inertia and drivetrain rotational losses to capture transient accelerations and decelerations.
2. **Inclined/declined driving:** Incorporation of gravitational components for road slopes, refining the model for hill climbs and descents.
3. **Cross-subteam integration:** Systematically embedding updates from mechanical, aerodynamics, and electrical subteams (e.g., revised drag coefficients, battery efficiency maps, suspension parameters) directly into the strategy model.

These enhancements increase fidelity and allow the race strategy tool to approximate energy flows under a broader set of real-world scenarios.

Integration and Validation

All proposed upgrades will be validated against experimental data. This includes:

- controlled track tests to benchmark predicted versus observed power consumption,
- regression against laboratory battery cycling data,
- sensitivity analysis of weather scenarios (e.g., cloud cover, wind gusts).

The long-term vision is a unified race-day tool capable of simulating course-scale dynamics with high fidelity, responsive to real-time telemetry, and robust under uncertain forecasts.

Vision

Together, these initiatives shift our strategy platform from a static, open-loop tool into a *dynamic decision system* that synthesizes optimization theory, data science, and physics-based modeling. This evolution ensures that Badger Solar Racing continues to push the frontier of student-led engineering innovation.