Optimizing Vehicle Transmission Control Strategy for Improved Fuel Economy

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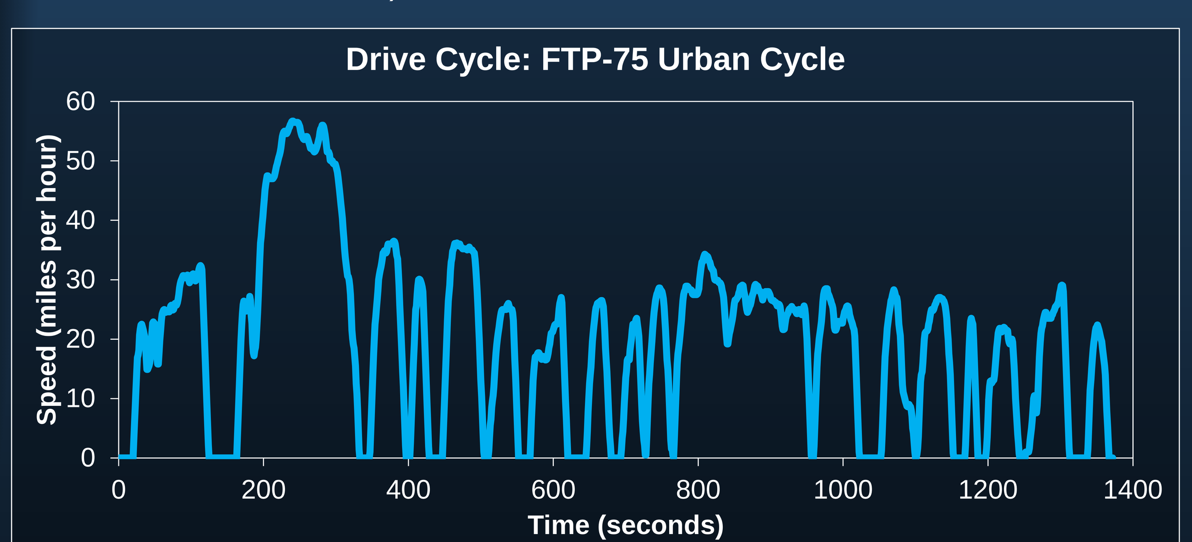
Motivation

- Car companies desire more efficient, greener vehicles
- Vehicle simulation helps predict real-world performance and reduces production development time
  - Helps companies choose vehicle component specifications:
    - Engine Size
    - Battery Capacity
    - Electric Motor Power
  - Facilitates comparison of different vehicle designs
- Existing simulation tools require the user to input the control strategy but the optimal control strategy is hardware and drive cycle dependent
- The goal is to create a optimization algorithm which finds the optimal control strategy while simulating a vehicle given a specified drive cycle

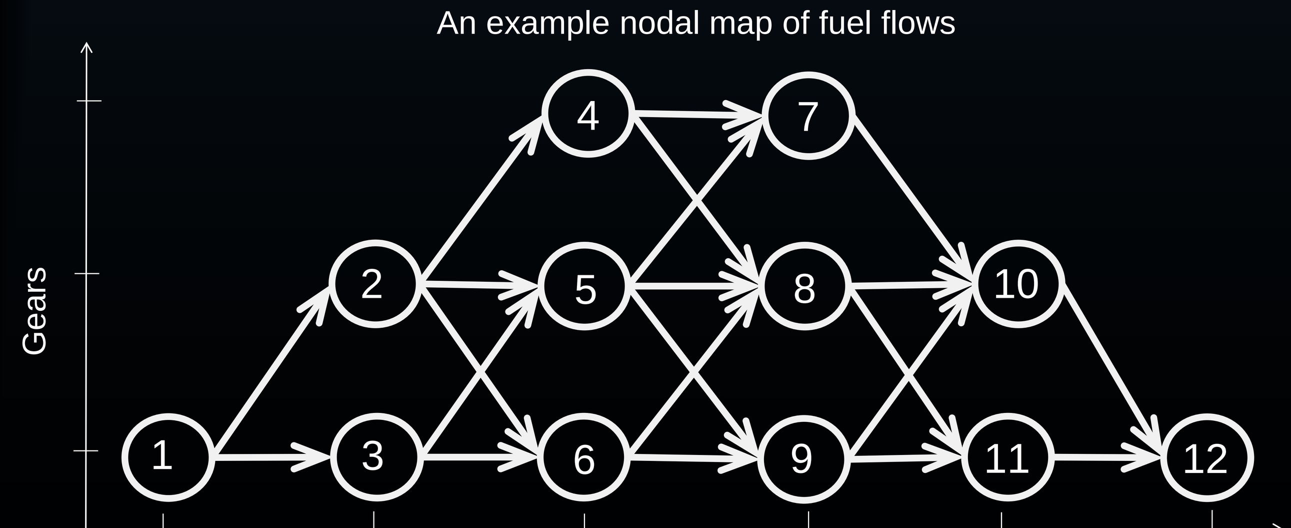
Dynamic Programming

- Given vehicle specifications, the power required to traverse a given drive cycle is determined by vehicle loads (e.g., aerodynamic drag, rolling resistance, and inertia).



- Dynamic Programming is used to optimize the transmission control strategy over a given drive cycle
- Transmission gears are represented as different vehicle states
- Given a map of possible states and fuel flow rates at each state, an optimal path to traverse the drive cycle can be calculated
- The problem is solved recursively by stepping backwards through every state.

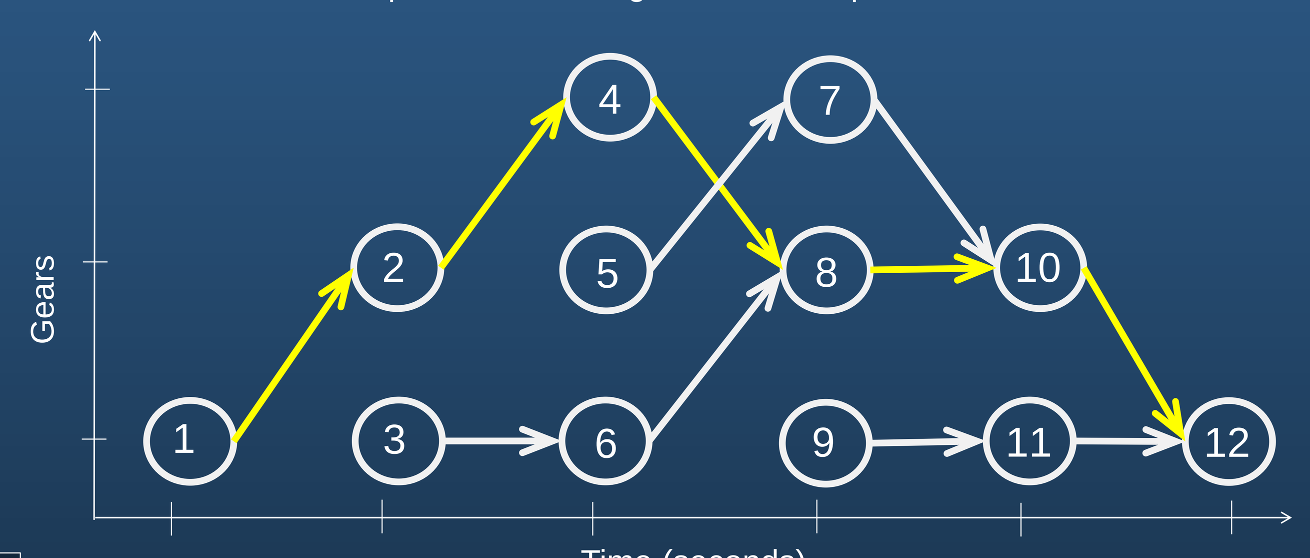
An example nodal map of fuel flows



Dynamic Programming

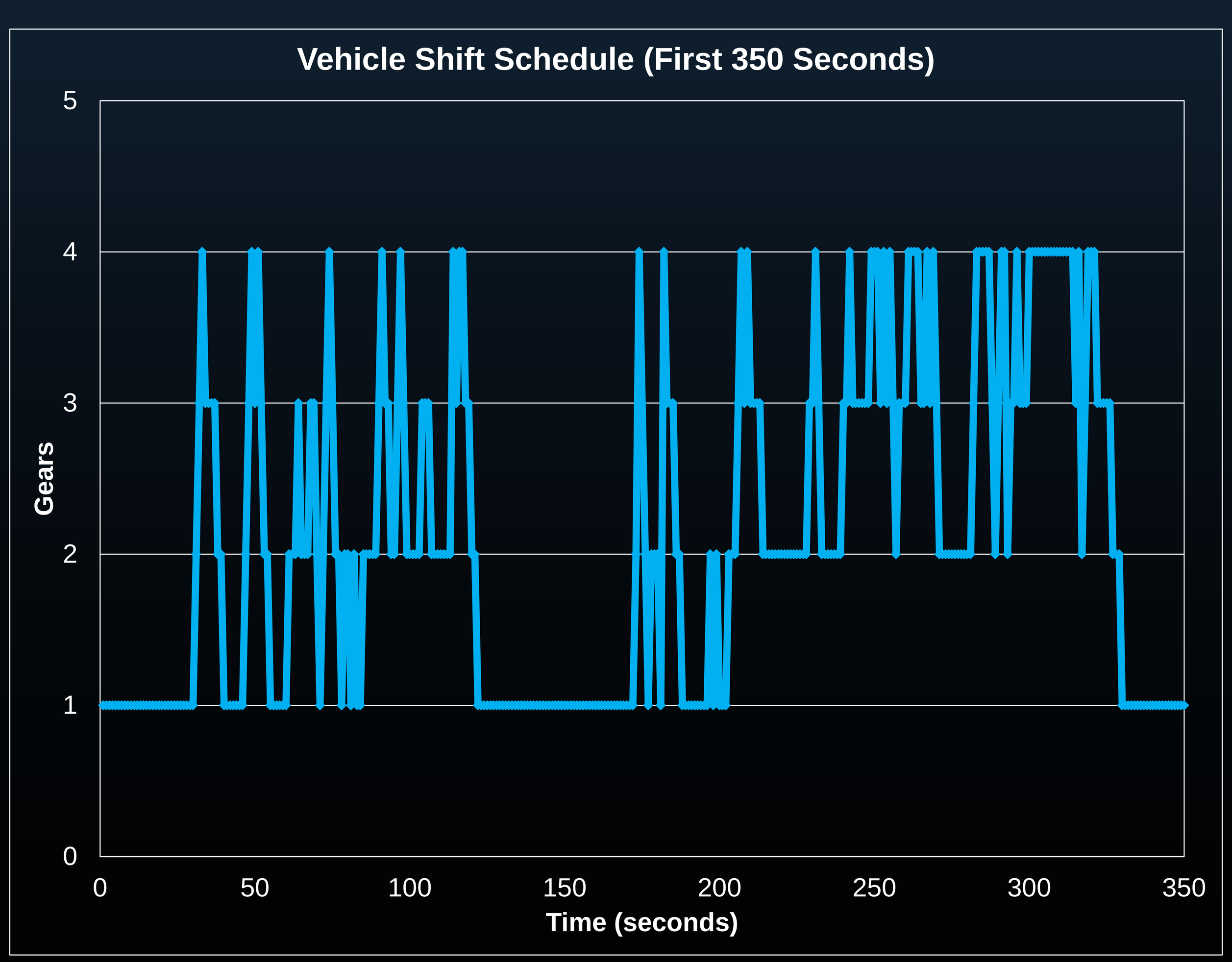
- Given constraints on possible control decisions (e.g. upshift, downshift, no shift) an optimal path and 'cost-to-go' from each state is calculated
- The global optimum shift strategy is the path from the first to last state
  - The solution of the algorithm consists of a map of the optimal path from each and every node to the final node
  - The global optimum path is made up of optimal paths from each node to the last

An example solution to a given nodal map of fuel flows



Results

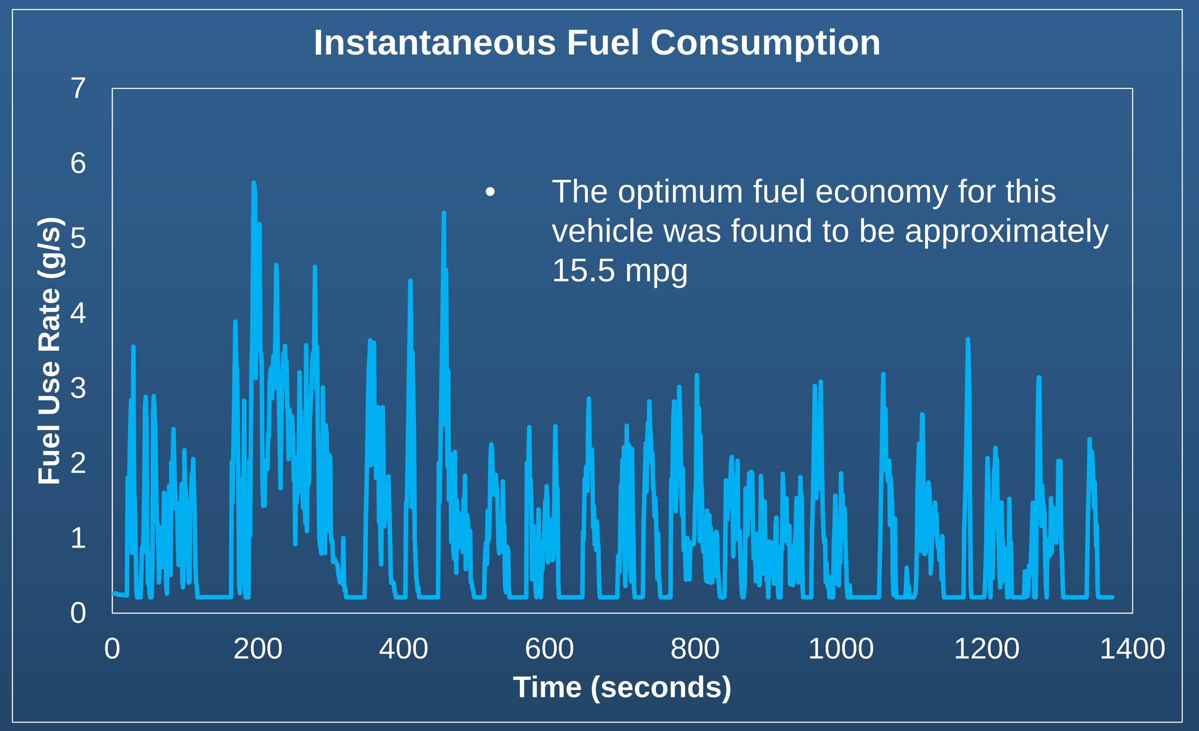
- Given a matrix of fuel flow rates for every state for each second in the drive cycle, a dynamic programming algorithm was used to find the optimal shift schedule.



- Of the 5 gears available, only four are used because the velocities of the drive cycle are never great enough.

Results

- This shift schedule corresponded to fuel flow rates at every second and an overall fuel consumption.



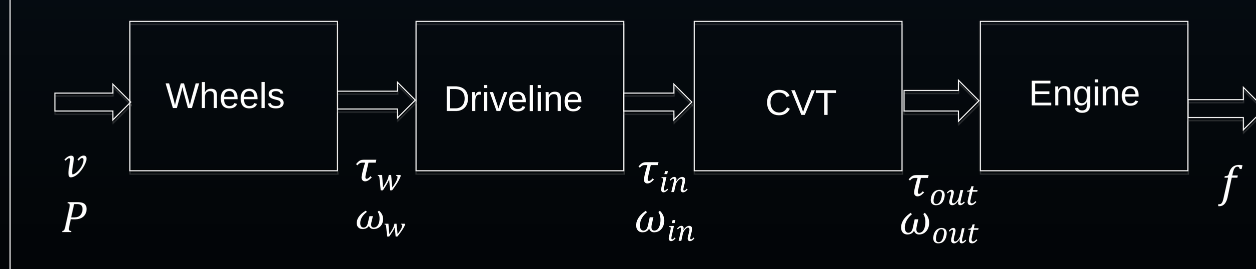
Problem Statement

- Currently Dynamic Programming is used to optimize a conventional 5-speed transmission with fixed gear ratios
- The goal is to optimize more advanced power-trains, such as CVTs, which use a continuous range of gear ratios

Problem Formulation

- An approach to optimizing the fuel economy of a CVT was developed by finding the local optimal fuel flow at a prescribed power and speed
- The power required to propel the vehicle is determined from the prescribed velocity in the drive cycle and the vehicle specifications
- The power and velocity are propagated through the drivetrain to yield a torque and angular velocity that are input to the CVT

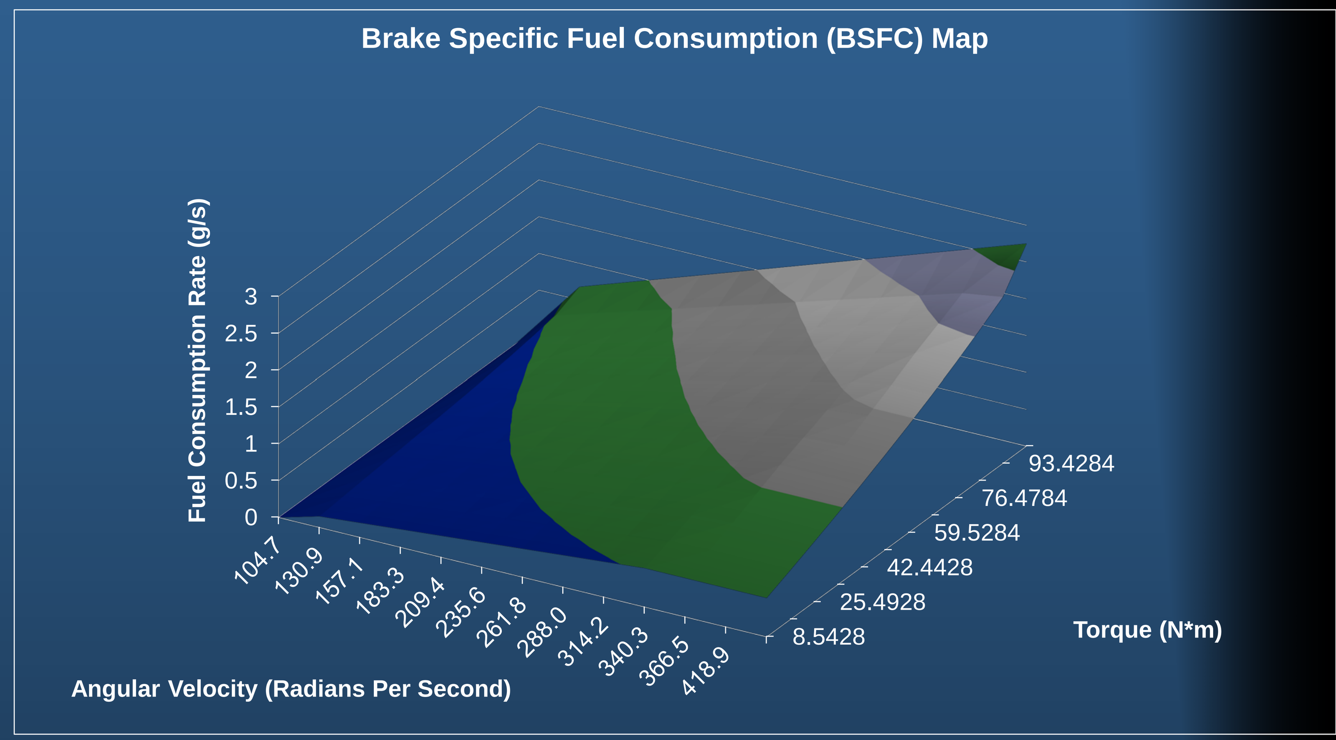
Vehicle Drivetrain Model with CVT Transmission



- There are a range of possible gear ratios to achieve the required driving power
  - The algorithm determines the optimal gear to drive the vehicle at each second
- The chosen gear determines the torque and angular velocity demanded by the engine

Problem Formulation

- Instantaneous fuel consumption rate is a function of torque and angular velocity
  - This data is given in the Brake Specific Fuel Consumption map below
    - Consists of Experimental Data:



- In order to interpolate points on the BSFC map
  - Fit BSFC surface with analytic function (quadratic) of both torque and angular velocity:

$$f(\tau,\omega) = a_{11}\tau^2 + (a_{12}+a_{21})\tau\omega + a_{22}\omega^2 + b_1\tau + b_2\omega + const.$$

- Fuel use as a function of the gear ratio is the objective function
- The main constraint is on the range of the possible gears at each second, which depend on the chosen gear at the previous time and the physical range of the CVT.
- The local minimum fuel use at each second is calculated, but the global minimum is not attained.
  - For the global minimum to be attained, a more complicated and stringent optimization procedure is required.

Summary/Future Work

- Dynamic Programming was used to optimize fuel efficiency for a 5-speed conventional transmission vehicle
- An approach to optimizing the fuel efficiency of the CVT was designed
  - The local optimum fuel flow is found given a prescribed power and speed
- Future work is to find the global minimum fuel efficiency of a drive cycle by solving a more constrained problem.

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