Optimizing Traffic Signal Timings to Reduce Fuel Consumption

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Sustainable Transportation

- Moves people, goods and information in ways that reduce its impact on the environment, the economy, and society.
- Promotes non-traditional ways of transport such as public transport, cycling and walking facilities.
- Advocates reduction in fuel consumption and use of cleaner fuels and technologies.
Challenges of Sustainable Traffic Control

- Improve Pedestrian Operations
- Reduce Vehicular Emissions
- Provide Priority for Transit
- Improve Traffic Flow
Objectives for Minimal Fuel Consumption

- Minimal delay (waiting time)
- No stops
- Uniform speed ~ 35-45 mph
Signal Timing Parameters

- **Cycle length**
- **Split (A phase)**
- **Offset**
Fuel Consumption & Traffic Signals

- **Cycle Lengths**
  - Higher CL provide more capacity but cause more delays per each vehicle in the network (+ FC)
  - Very low CL cause extreme delays (++) FC

- **Splits**
  Should be equivalent to the demand for each movement (phase) – if inappropriate cause cycle failure – a vehicle needs to wait for one more cycle (+ FC)

- **Offsets**
  Impact progression (# of stops) of the major traffic movements between intersections – the most important parameter to reduce FC
Do we have right objectives and policies?

No, sustainable policies to consider – transit, emissions, person-based costs, etc.

Do we (always) know what performance measures to use?

No, we use surrogate performance measures (in lieu of emission-related metrics)

Can current models support our goals?

No, we need better models and better interface between models and field operations

Early Research on Minimizing FC


• Concept of Performance Index – $PI = Delay + W^* Stops$
• Lowest FC achieved when a stop is worth 40 seconds of waiting time (delay) (Robertson et al.)
• Signal timings optimized (in TRANSYT 8) to minimize fuel consumption
• Benefits of such signal timings may decrease fuel consumption by up to 3%
• FC estimated from its linear relationship with delay, stops, and average speed
FC Estimation in Current Tools

Exhaustive Search Processes

Analytical Models of Traffic

Optimization Process (PI, Delay, etc.)

Traffic Metrics:
Travel mileage, average speed, # of stops, delay

FC = Total Travel * k1 + Total Delay * k2 + Stops * k3

FC Evaluation Process

FC Estimation Process
Current Practice

- Tools: SYNCHRO & TRANSYT-7F (and similar)
- Macroscopic and analytical tools (no individual driving behavior)
- FC not used as an objective function in optimization
- Very simplistic relationships between overall traffic activity in the area and fuel consumption
- FC not based on cyclical engine loads
- No ability to account for various vehicular technologies (new vs old) and different vehicle types (heavy, diesel, ...)

...
Current Practice - Fuel Consumption

- \( FC = Total\ Travel \ast k1 + Total\ Delay \ast k2 + Stops \ast k3 \)

- \( k1 = 0.075283 - 0.0015892 \ast Speed + 0.000015066 \ast Speed^2 \)
- \( k2 = 0.7329 \)
- \( k3 = 0.0000061411 \ast Speed \ast 2 \)

- FC= Fuel Consumption [gal]
- Speed = Cruise speed [mph]
- Total Travel = Vehicle-miles traveled [veh-mil]
- Total Delay = Total signal delay [hours]
- Stops = Total stops [veh/hour]
VISSIM-CMEM-VISGAOST Integration

VISSIM

- VISSIM Input
  - SignalGroup[8]: [1.0, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9]
  - SignalPhase[8]: [[1.0, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9], [0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.2], [0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.2, 0.3], [0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.2, 0.3, 0.4], [0.5, 0.6, 0.7, 0.8, 0.9, 0.2, 0.3, 0.4, 0.5], [0.6, 0.7, 0.8, 0.9, 0.2, 0.3, 0.4, 0.5, 0.6], [0.7, 0.8, 0.9, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7], [0.8, 0.9, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8], [0.9, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9]]
  - LeadPhase[8]: [[0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9], [0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.2], [0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.2, 0.3], [0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.2, 0.3, 0.4], [0.5, 0.6, 0.7, 0.8, 0.9, 0.2, 0.3, 0.4, 0.5], [0.6, 0.7, 0.8, 0.9, 0.2, 0.3, 0.4, 0.5, 0.6], [0.7, 0.8, 0.9, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7], [0.8, 0.9, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8], [0.9, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9]]
  - CycleLength[1]: [66.0]
  - Offset[1]: [30.0]

- Optimized Signal Settings

- Measures of Effectiveness

VISSIM Output

- Vehicle Record
  - Veh Type: 1.0.2: 1001: 23.18, 0.88; 1.0.1: 1001: 25.75, 0.69; 1.0.4: 1001: 24.60, 0.80; 1.0.3: 1001: 24.35, 0.82; 2.0.5: 1001: 23.80, 0.59; 2.0.4: 1001: 24.60, 0.80; 2.0.2: 1001: 23.76, 0.86

VISSAOST

- Network Performance Simulation Time: 4200
- Parameter: Value
  - Total travel time (s): 833.8
  - Total delay time (s): 199.2
  - Number of stops: 21828
  - Stopped delay (s): 84.2

Summed Estimations
- CO2: 1.241697E7
- CO: 1.459775E5
- HC: 2.54E6
- NOx: 29045.52
- Fuel: 31437.79
- Dist: 20699.89

VISSIM-CMEM-VISGAOST Interface

- CMEM Output
  - Control File: veh.
  - Activity File: veh.
  - Distance Traveled: 0.35 mi
  - Fuel Use: 17.05 gal
  - CO2 = 17.846 (grams)
  - CO = 7.522 (grams)
  - HC = 0.0954 (grams)
  - NOx = 0.0931 (grams)

- LDV
- HDD
- Lookup Table
Comprehensive Modal Emission Model

University of California - Riverside
FC & Emission Scenarios in CMEM

- Stoichiometric Cruise Section
- Constant Power Section
- Constant Acceleration Section
- Air Conditioning Hill Section
- Repeat Hill Cruise Section
VISGAOOST - Basic Steps

1. Encode Timing Plans
2. Initialize First Population
3. Run VISSIM & Evaluate Population
4. End Criteria Satisfied?
   - yes: Return Best Timing Plan
   - no: Create Next Generation of Population

Diagram:
- Encode Timing Plans
- Initialize First Population
- Run VISSIM & Evaluate Population
- End Criteria Satisfied?
  - yes: Return Best Timing Plan
  - no: Create Next Generation of Population
Test-bed Network
Why 2-intersection Network?

- Simplest coordinated operations
- Low number of signal timings to optimize
  - Short computational time - increased chances to find an ‘optimum’ (local or global)
  - Ability to understand what is going on after an optimal solution is found
- Properly calibrated and validated network
- Relatively heavy side-street traffic
- Different speeds on main & side streets
FC Change during PI Optimization

Optimization of Performance Index

- Fuel Consumption
- Performance Index

Number of Generations

Fuel Consumption [gr]

Performance Index
Optimizing FC in Delay & Stops Space
PIs with various weights for stops

\[ PI = D + 10*S \]

\[ PI = D + 20*S \]

\[ PI = D + 80*S \]
Delay & Stops for Synchro’s Solution

\[ PI = D + 10S \]
\[ PI = D + 20S \]
\[ PI = D + 80S \]

Total Delay [h]
Number of Stops
Various Objective Functions - Minimize FC

Fuel Consumptions per Mile during Various Optimizations

- Fuel Consumption per Mile
- Performance Index
- Throughput
- Delay
- All Stops
- Stops for Main Street

9%
Conclusions

• FC can be reduced 5-10% when FC is minimized (used as an objective function) instead of minimizing surrogate performance measures

• FC for each case might be unique, and depends on:
  • Side-street and main street: traffic volumes and speed limits
  • % of heavy vehicles, terrain, AC usage, ...

• FC optimizations very time consuming

• Need to investigate if there is a better surrogate performance measure

• Interest to reduce FC in traffic community still low
The End

Questions & Comments?