Improving Commercial Vehicle Routing with Parking Information

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Introduction
Commercial vehicle driver’s job is challenged by increases in delivery demand, traffic delays, competition for the curb

→ carriers are striving to satisfy demand in an increasingly complex urban environment

Telematics and analytics system can support delivery drivers

- Scheduling: allocation of orders to vehicles
- Routing: optimize order of deliveries considering constraints (e.g. travel time, delivery time windows)
- Live information: traffic conditions, demand changes
How do carriers route?

- Performed interviews with carriers
- Standard model: Capacitated vehicle routing problem with time windows

**Inputs**
- List of orders with delivery addresses
- Travel time matrix
- Number of vehicles with capacity

**Outputs**
- Optimized route / manifest

- Some routing systems use traffic information for time dependent travel times
- Parking occupancy information not used in scheduling/routing
What happens when parking is unavailable?

- Cruising
- Walking
- Re-routing
- Queueing

Dalla Chiara et al. (2021) Understanding urban commercial vehicle driver behaviors and decision making, Transportation research record 2675 (9), 608-619
What can we do with parking occupancy information?

Two options for using data:

- Real-time data
  - Real-time parking information app
- Historic data
  - Improved route planning to reduce cruising delays

Cost and time savings
Objectives

What do we want to contribute?

Evaluate the benefits of using parking occupancy information in urban deliveries

How are we going to achieve this goal?

A lack of parking occupancy information can lead to drive time delays (cruising)

Simulate the effect of incorporating cruising for parking delays into route optimization
Methodology
Overview

**INPUTS**
- Stop data
- Delivery data

1. Cruising time prediction
2. Route optimization (TSP)
3. Route Simulation

**OUTPUTS**
- Route plan
- Driving time/dist
- Cruising delays
Input data (Real world)

Two data sources:

- **Delivery data** (from drivers’ delivery device / delivery management system)
  - Customer, manifest & order details (volume, weight, delivery time window...)
  - Delivery lat/lon & time

- **Stops data** (from in-vehicle GPS system)
  - Stop lat/lon & time
  - Stop dwell time

Were recorded for 2 years, from a beverage distributor’s carrier vehicles, performing deliveries in Seattle

- Approx. 50 drivers, 2k customers, 60k deliveries

**INPUTS**
- Stop data
- Delivery data

**OUTPUTS**
- Route time
- Driving time/dist
- Cruising delays

1. Cruising time prediction
2. Route optimization
3. Route Simulation
Cruising time estimation

Obtain reliable estimates of truck cruising for parking times for different data sources:

<table>
<thead>
<tr>
<th>Stat</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Qu.</td>
<td>0.47</td>
<td>1.08</td>
</tr>
<tr>
<td>Median</td>
<td>2.13</td>
<td>3.27</td>
</tr>
<tr>
<td>Mean</td>
<td>5.43</td>
<td>4.44</td>
</tr>
<tr>
<td>3rd Qu.</td>
<td>7.88</td>
<td>6.46</td>
</tr>
</tbody>
</table>

Dalla Chiara & Goodchild (2020) *Do commercial vehicles cruise for parking?* Transport Policy 97, 26-36
Cruising time prediction

\[ \log(\text{trip time}) = \beta_0 + \beta_{tt} \log(\text{travel time}) + \ldots + \beta_{cvlz} CVLZ + \ldots + \varepsilon \]

“Corrected” travel time matrix with cruising delays

Travel time matrix used as input to “classic” routing models

**INPUTS**
- Stop data
- Delivery data

**OUTPUTS**
- Route time
- Driving time/dist
- Cruising delays
Using cruising information to improve routes

- Update time-dependent travel time matrix with additional cruising estimation
- Show the effect of cruising predictions through two models

**INPUTS**
- List of orders, TWs, nodes
- Time-dependent travel time matrix

**OUTPUTS**
- Route time
- Driving time/dist
- Cruising delays

**TD-TSP-TW with time-dependent travel times only**

Simulate “today” -> Add estimated cruising delays to existing route plan

Difference in route time shows effect of considering historic parking information

**TD-TSP-TW with time-dependent travel and cruising times**

**INPUTS**
- Stop data
- Delivery data
- Time-dependent travel and cruising time matrix

1. Cruising time prediction
2. Route optimization
3. Route Simulation

**OUTPUTS**
- Route time
- Driving time/dist
- Cruising delays
Results
Real World Study

- Route time savings on real world data exist, but are small (mean savings of 1.5% / 1.02 min per route)
- High number of hidden variables influencing the route savings
- Interaction effects with accuracy of cruising time prediction model

**INPUTS**
- Stop data
- Delivery data

**OUTPUTS**
- Route time
- Driving time/dist
- Cruising delays

**PROCESS**
1. Cruising time prediction
2. Route optimization
3. Route Simulation
Synthetic Study

**Goal:** Identify route characteristics that benefit from consideration of cruising delays

**Design:** Full factorial $2^k$ experiment

**Method:** Delivery manifests sampled from coordinates based on varying parameters:

- **INPUTS**
  - Stop data
  - Delivery data

- **1. Cruising time prediction**
- **2. Route optimization**
- **3. Route Simulation**

- **OUTPUTS**
  - Route time
  - Driving time/dist
  - Cruising delays
# Synthetic Study - Parameters of Interest

<table>
<thead>
<tr>
<th>Variable</th>
<th>Low</th>
<th>High</th>
<th>Variable</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of Area ($a$)</td>
<td>1 km²</td>
<td>4 km²</td>
<td>Variance of Cruise Time Delays ($\sigma_{cd}$)</td>
<td>$\sigma = 0.5$</td>
<td>$\sigma = 2$</td>
</tr>
<tr>
<td>Number of Stops ($n$)</td>
<td>5 Stops</td>
<td>15 Stops</td>
<td>Variance of Travel Time Matrix ($\sigma_{tt}$)</td>
<td>$\sigma = 0.35 \cdot \sqrt{a}$</td>
<td>$\sigma = 1.5 \cdot \sqrt{a}$</td>
</tr>
</tbody>
</table>

**INPUTS**
- Stop data
- Delivery data

1. Cruising time prediction
2. Route optimization
3. Route Simulation

**OUTPUTS**
- Route time
- Driving time/dist
- Cruising delays
Synthetic Study - ANOVA

Significant variables:
- Number of stops
- Cruising time variance
- Travel distance variance
- Cruise time Variance *

Number of Stops

Best configuration: Few Stops, Compact Shape, Low Travel Matrix variance, High Cruising delay variance

Mean saving per stop: -3.78 minutes per stop
Synthetic Study - Findings

- Variance of cruise time delays, the number of stops, and shape of the route all play a significant role in how impactful route savings are when cruising delays are considered in route generation.
- Average drive time savings of 21.6% with savings up to 60% for some routes.
- **Few** Stops, **Compact** Shape, **Low** Travel Matrix variance, **High** Cruising delay variance have largest mean drive time savings of 43% and an average of -3.78 minutes per stop.

![Population distribution for drive time savings](image)

**INPUTS**
- Stop data
- Delivery data

**1. Cruising time prediction**

**2. Route optimization**

**3. Route Simulation**

**OUTPUTS**
- Route time
- Driving time/dist
- Cruising delays
Conclusions

● YES, considering parking occupancy information in route planning can generates savings for route planning

● Synthetic Study shows potential for savings of 21.6% in drive time
  ○ Routes with fewer stops, concentrated shape, high cruising time variance show largest savings potential

● This demonstrates that it is beneficial to further push for more transparency on parking occupancy in future research, as it reduces delivery caused stressors of the urban environment.
Questions & Answers
Back-Up
Time dependent TSP with time windows (TD-TSP-TW)

Vu et al. (2018)

\[ z = \text{minimize} \sum_{((i,t),(j,t')) \in A} c_{ij}(t)x_{((i,t),(j,t'))} \]

subject to

\[ \sum_{((i,t),(j,t')) \in A : i \neq j} x_{((i,t),(j,t'))} = 1, \forall j \in N, \quad (1) \]

\[ \sum_{((i,t),(j,t')) \in A} x_{((i,t),(j,t'))} - \sum_{((j,t),(i,t)) \in A} x_{((j,t),(i,t))} = 0, \forall (i, t) \in \mathcal{N}, i \neq 0 \quad (2) \]

\[ x_{((i,t),(j,t'))} \in \{0, 1\}, \forall ((i, t), (j, t')) \in A. \quad (3) \]

\[ t' \leq \|_j \]

\[ t' = \max\{e_j, t + \tau_{ij}(t)\} \]

**INPUTS**
- Stop data
- Delivery data

1. Cruising time prediction
2. Route optimization
3. Route Simulation

**OUTPUTS**
- Route time
- Driving time/dist
- Cruising delays
Explaining cruising time

- Parking buffers centered at trip destinations of 100 meters (330 ft.) rad.
  - Parking allocation & infrastructure
  - Built environment
  - Parking occupancy

- Other variables:
  - Time attributes
  - Activity attributes
  - Vehicle & driver attributes
  - Route attributes
  - ...
Time dependent TSP with time windows (TD-TSP-TW)

**Inputs**
- Stop data
- Delivery data

**Outputs**
- Route time
- Driving time/dist
- Cruising delays

**Diagram**
- Time steps from 1 to 7
- Customer visits and time windows
- Cruising time predictions
- Route optimization
- Route simulation
Recap: How do carriers route?

**INPUTS**
- List of orders with delivery addresses
- Travel time matrix
- Number of vehicles with capacity

**OUTPUTS**
- Optimized route / manifest

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**Standard Vehicle Routing Problem (VRP)**

Find the routes with shortest total driving and stopping time

**INPUTS**
- Stop data
- Delivery data

**OUTPUTS**
- Route time
- Driving time/dist
- Cruising delays

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1. Cruising time prediction
2. Route optimization
3. Route Simulation
Simplification from VRP to TSP with time windows

What does the VRP with time windows do?
- VRP performs order allocation and routing simultaneously for optimal routes
- VRP with and without cruising time estimates changes travel time matrix
  - This may result in completely different order allocations and route plans

Why is that a problem?
- Difficult to isolate the effect of cruising estimates on routing

What is our solution?
- Isolate effect of cruising estimates through simplifying to TSP with time windows
  - TSP is a single-vehicle VRP and takes list of orders for a single vehicle as input and optimizes routes
TSP with time windows

**INPUTS**
- List of orders with delivery addresses and time windows
- Travel time matrix

**OUTPUTS**
- Optimized route / manifest

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**TSP with time windows**

**Base line:**
TSP with time windows:
Every delivery has to take place in a certain time window

**OUTPUTS**
Route time
Driving time/dist
Cruising delays

**INPUTS**
Stop data
Delivery data

1. Cruising time prediction
2. Route optimization
3. Route Simulation

**OUTPUTS**
- Optimized route / manifest

---

**Travelling Salesman Problem (TSP)**

Find the route with shortest total driving and stopping time
Time dependent TSP with time windows (TD-TSP TW)

In addition: Considers different travel times during different hours of the day

INPUTS
- List of orders with delivery addresses and time windows
- Time dependent travel time matrix

OUTPUTS
- Optimized route / manifest

In each step:
1. Cruising time prediction
2. Route optimization
3. Route Simulation

OUTPUTS
- Route time
- Driving time/dist
- Cruising delays
MP-BRKGA for TD-TSP-TW

- MP-BRKGA (Andrade et al., 2021) heuristic implicitly represents solution

  ![Solution provided by Genetic Algorithm](image1)

  ![Solution re-ordered in increasing order](image2)

  ![Solution translated into route plan](image3)

  ![Fitness evaluated by objective function](image4)

- Decoder tailored to TW constraints
- Demonstrated strong performance for small instances that could be compared with commercial solvers

INPUTS
- Stop data
- Delivery data

OUTPUTS
- Route time
- Driving time/dist
- Cruising delays

1. Cruising time prediction
2. Route optimization
3. Route Simulation
Varying Number of Stops

**Observation:** Lower number of Stops lead to better average savings per stop

**Takeaways:**
- Total drive time savings are still larger under the high stop scenarios. Standardization creates an inverse relationship.
- Increased complexity from tripling number of stops requires significant runtime increase to reach optimal values in BRKGA.

**INPUTS**
- Stop data
- Delivery data

**OUTPUTS**
- Route time
- Driving time/dist
- Cruising delays

1. Cruising time prediction
2. Route optimization
3. Route Simulation
Drive Time Savings

Best performing Config:
Low Stops, Low Area, Low
Travel distance variance, High
Cruise time variance

Average Percent Savings: 43%

Every configuration with a low travel matrix variance and a high cruise time variance was above the population average.

Acronyms:
S – Stops, A – Area
TV – Travel matrix Variance
CV – Cruise time Variance

INPUTS
Stop data
Delivery data

1. Cruising time prediction
2. Route optimization
3. Route Simulation

OUTPUTS
Route time
Driving time/dist
Cruising delays
With parking information during route planning

No parking information during route planning

Optimize route with TD-TSP-TW without cruising info

Use TSP route and simulate true route times with cruising delays

Predict true travel time including cruising delays

Difference in route time represents impact of parking information

Optimize route with TD-TSP-TW with cruising info

Use TSP route according to model results

With parking information during route planning

Model Structure

Data
- Delivery manifest
- Stop data

External tools
- Google Maps API

Models
- Cruising time prediction model
- VRP Time Windows time dependent travel distances
- TSP Time Windows time dependent travel distance
Detailed Simulation Structure

1. Cruising time prediction model
   - Estimation of “true” travel times, considering experienced cruising times
   - Time-dependent “true” travel time matrix updated by considering cruising times

2. TD-TSP-TW route optimization (MP-BRKG)
   - Route optimization considering cruising delays
   - Route optimization not considering cruising time

3. Simulation of “true” travel times experienced for routes optimized without cruising time consideration

4. Difference analysis
   - Route time savings from considering cruising times
   - Route optimized not considering cruising time; post-processed with “true” travel times considering cruising

GPS data from real-world deliveries

Time-dependent travel time matrix as per Google Maps API (not considering cruising times)

Route manifest including:
- No. of stops
- Delivery addresses
- Time windows
Interaction Effect