Hybrid Data Envelopment Analysis for Large-Scale Smartphone Data Modeling

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Scope

- **Methodological approach** for driving safety efficiency **benchmarking**
  - on a trip basis
  - optimization techniques

- **Smartphone** devices
  - large-scale data
  - naturalistic driving conditions

- Estimation time is **exponentially increased**
  - as more driving data are aggregated
  - improve the existing approach
Background (1/2)

- **Linear programming** for efficiency measurement
  - **Data Envelopment Analysis (DEA)**
    - Banks, Companies, Hospitals, Staff etc.
    - Transport (Systems, Traffic safety etc.)
  - Driving behaviour research

- **Driving behaviour characteristics**
  - Speeding
  - Harsh braking/ acceleration/ cornering
  - Seatbelt use
  - Mobile phone use
Background (2/2)

- **Data collection schemes**
  - Smartphones
  - In-vehicle devices
  - On-board diagnostic devices (e.g. OBD-II)

- **Data sources**
  - Naturalistic driving experiments
  - Driving simulator experiments
  - In-depth accident investigation
Smartphone data collection (1/2)

- A **mobile application** to record user’s driving behaviour (automatic start / stop)

- A variety of **APIs** is used to read mobile phone **sensor data**

- Data is transmitted from the mobile App to the **central database**

- Data are stored in a **sophisticated database** where they are managed and processed
Smartphone data collection (2/2)

- **Indicators** are designed using:
  - machine learning algorithms
  - big data mining techniques

- Data collected for **10,088 trips from 88 drivers** (From July to December 2016)

- The database analyzed was in .csv format
  - Drivers’ trips are stored per row, the characteristics of which are stored in each column’s variables
Data envelopment analysis (1/2)

- **Optimization technique**
  - Performance measurement using DEA
  - Companies, banks, hospitals, staff etc.

- **Significant computation cost**
  - Exact solution
  - Reduced Basis Entry (RBE)
  - Convex Hull (CH)
  - Reduce processing time

- **Decision-Making-Unit (DMU)**
  - Factory, company etc.
  - Trips, drivers
    - variables are continuous and quantitative
    - a driver should reduce the frequency of his driving characteristics for a given mileage
Data envelopment analysis (2/2)

- **Efficiency index** \( \text{Driving\_efficiencyB} \)

- **Input-oriented** DEA
  - minimize inputs (number of HA, HB events etc.) per driving distance

- **Constant-returns-to-scale (CRS)** problem
  - the sum of all inputs changes proportionally to the sum of driving output (distance)

- **Efficient level** of driving characteristics for a trip/ driver
  - inputs
  - outputs

\[
\text{min(Driving\_Efficiency}_B) \\
\text{Subject to the following constraints:} \\
\text{Driving\_Efficiency}_B \cdot x_i - X \cdot \lambda \geq 0 \\
Y \cdot \lambda \geq y_o \\
\lambda_i \geq 0 \forall \lambda_i \in \lambda
\]

\[
\text{Metric}_i = \sum_{j=1}^{m} \lambda_j \cdot \text{Metric}_j \\
\text{dis\_tan\_ce}_{urban} = \text{dis\_tan\_ce}_i / \text{Driving\_Efficiency}_i
\]
Efficiency index parameters

Risk exposure indicators:
- Total distance travelled

Driving behaviour indicators:
- Harsh events
  - Number of harsh braking (longitudinal acceleration) (HA)
  - Number of harsh acceleration (longitudinal acceleration) (HB)
- Speeding (SP)
  - seconds driving over the speed limit
- Mobile phone use distraction (MU)
  - seconds using the mobile phone

Road types:
- Urban road network (signalized or not network, speed limit ≤ 50 km/h)
- Urban express road network (speed limit 50 – 90 km/h)
- Highways (speed limit ≥ 90 km/h)
Driving efficiency analysis using DEA

- **DEA results** 2-D illustration
  - Urban
  - Rural

- **DEA inputs**
  - Number of harsh acceleration events
  - Number of harsh braking events

- **DEA outputs**
  - Trip distance
Data preparation

- Data are **anonymized**
  - user-agnostic approach
  - identify driving behaviors and patterns
  - causality between behaviour and other factors
  - large-scale samples
  - no information on demographics or accident record

- **Python** programming language
  - filter aggregate data
  - retain only necessary information
  - aggregate data
  - data analysis
Trip efficiency analysis (1/3)

- **Convex Hull** technique outperforms

- **Significant time reduction**
  - As the database becomes larger
  - Convex Hull DEA – 5 minutes
  - RBE DEA – 12.6 days
  - Standard DEA – 40.7 days

<table>
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<tr>
<th>No of DMUs</th>
<th>Standard DEA Approach</th>
<th>RBE DEA</th>
<th>Convex Hull DEA</th>
<th>Standard DEA Approach</th>
<th>RBE DEA</th>
<th>CH DEA % computation time improvement over Standard DEA</th>
<th>RBE DEA % computation time improvement over Standard DEA</th>
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</tr>
</tbody>
</table>

* Inputs = [ha\textsubscript{urban}, ha\textsubscript{rural}, ha\textsubscript{highway}], Outputs = [distance\textsubscript{urban}, distance\textsubscript{rural}, distance\textsubscript{highway}]*
Trip efficiency analysis (2/3)

- **Convex Hull DEA**  
  - Linearly increased

- **Standard and RBE DEA**  
  - Exponentially increased
Trip efficiency analysis (3/3)

- **Least efficient** trips
- Efficiency estimation
- **Sort**
  - larger to smaller
- **Percentile**
  - 5%, 10%, 25% etc.
Conclusions

- **Innovative** methodological approach for driving efficiency benchmarking as well as for estimating the efficient level of metrics for each trip.

- The integration of DEA with the convex hull algorithmic approach yielded **significantly better** results than the rest of the approaches tested.
Future research

- Exploit a larger driving sample
- Overcome DEA limitations – zero sum input attributes
- Increase the number of attributes
  - headways
  - lane changing
  - eye movement
  - drowsiness
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