Driver schedule efficiency vs. public transport robustness:

A framework to quantify this trade-off based on passive data

Ir. Menno Yap
Dr. ir. Niels van Oort

M.D.Yap@TUDelft.nl

Smart Public Transport Lab
www.smartPTlab.TUDelft.nl

July 24th, 2018
Relevance: complex driver schedules

- Public transport driver schedules increasingly complex:
  - Driver Scheduling Problem (DSP) well-known topic in OR
  - Push for higher efficiency in PT operations
  - More advanced scheduling software (e.g. HASTUS) available

*Single-line single-vehicle*
Duty: 1 line, 1 vehicle

**Fictitious example**
Relevance: complex driver schedules

• Public transport driver schedules increasingly complex:
  o Driver Scheduling Problem (DSP) well-known topic in OR
  o Push for higher efficiency in PT operations
  o More advanced scheduling software (e.g. HASTUS) available

Fictitious example

Single-line multi-vehicle
Duty: 1 line, >1 vehicle

Driver schedule complexity
Relevance: complex driver schedules

- Public transport driver schedules increasingly complex:
  - Driver Scheduling Problem (DSP) well-known topic in OR
  - Push for higher efficiency in PT operations
  - More advanced scheduling software (e.g. HASTUS) available

Multi-line multi-vehicle
Duty: >1 line, >1 vehicle

**Driver schedule complexity**
Study objective

• Problem statement:
  o More complex driver schedule reduces operator costs during undisrupted situations
  o More complex driver schedule increases disruption costs
  o Impact of driver schedule on disruption costs hardly considered

• Development of framework which integrates driver schedule and PT disruption costs:
  o Quantify both components → express in same monetary units
  o Quantify PT disruption costs as function of driver schedule type
Passenger disruption costs (1)

- **In-vehicle time** $\Delta t^{ivt}$:
  - Disrupted link from stop $s_l$ to stop $s_{l+1}$
  - Additional running time compared to schedule for each run $r$
  - Multiplied by passenger flow $q_{rl}$
  
  $$\Delta t^{ivt} = \sum_{r \in R} \left( \left( t_{rl+1}^a - \bar{t}_{rl+1}^a - (t_{rl}^d - \bar{t}_{rl}^d) \right) * q_{rl} \right) * Vot$$

- **Waiting time** $\Delta t^{wtt}$:
  - Use PRDM to express service irregularity (Van Oort & Van Nes 2009)
  - Average waiting time compared to scheduled waiting time
  - For each hour of the day $h$; multiplied by coefficient $\beta_1$
  
  $$\Delta t^{wtt} = \sum_{h \in H} \left( \left( \frac{60}{2 * f_l^h} \right) * \left( 1 + (PRDM^2) \right) - \left( \frac{60}{2 * \bar{f}_l^h} \right) \right) \* \beta_1 \* Vot$$
Passenger disruption costs (2)

- Perceived in-vehicle time due to crowding $\Delta t^{inv,t,p}$:
  - Multiplication of realized in-vehicle time with crowding multiplier
  - Compare between disrupted case $i$ and undisrupted case $j \neq i$

\[
\Delta t^{inv,t,p} = \sum_{r^h \in R^h} \sum_{s_l \in s_{L,l}} ((q_{rs}^i \ast (t_{rs+1}^a - t_{rs}^d) \ast \gamma_{rs}) - (q_{rs}^{j \neq i} \ast (t_{rs+1}^a - t_{rs}^d) \ast \gamma_{rs})) \ast VoT
\]

- Calculation of crowding multiplier $\gamma_{rs}$ (Wardman & Whelan 2010):
  - Based on seat capacity $\varphi_r^s$ and crush capacity $\varphi_r^c$
  - Increases linearly based on corresponding multipliers $\gamma_r^s$ and $\gamma_r^c$

\[
\gamma_{rs} = \begin{cases} 
0.95 & \text{if } q_{rs} \leq 0.5 \ast \varphi_r^s \\
0.95 + \left(\frac{q_{rs} - 0.5 \ast \varphi_r^s}{0.5 \ast \varphi_r^s}\right) \ast (\gamma_r^s - 0.95) & \text{if } 0.5 \ast \varphi_r^s < q_{rs} < \varphi_r^s \\
\gamma_r^s + \left(\frac{q_{rs} - \varphi_r^s}{\varphi_c^r - \varphi_r^s}\right) \ast (\gamma_r^c - \gamma_r^s) & \text{if } q_{rs} > \varphi_r^s
\end{cases}
\]
Operator disruption costs

- **Long-term loss of ridership** $\Delta q$ (Van Oort et al. 2015):
  - Approach based on simple generalized cost elasticity $E_d$
  - Weighted average generalized costs $\bar{t}^{pi}$ between disrupted time $t^i$ and undisrupted time $T - t^i$

$$\Delta q = \left( E_d \ast \left( \frac{\bar{t}^{pi} \ast t^i + (\bar{t}^{pj\neq i} \ast (T - t^i))}{\bar{t}^{pj\neq i} \ast T} - 1 \right) + 1 \right) \ast \sum_{s_t \in S_i} \sum_{s_j \in S_j} q_{s_i,s_j}$$

- **Components operator costs** $c^i_o$:
  - Revenue loss: $\beta_2 \ast \Delta q$
  - Personnel overtime hours costs: $\beta_3 \ast t$
  - Fine too early, too late and cancelled trips:
    $$\beta_4 \ast \sum_{r \in R} r^e + \beta_5 \ast \sum_{r \in R} r^l + \beta_6 \ast \sum_{r \in R} r^c$$
  - Fine infrastructure unavailability: $\beta_7 \ast t^i$
Case study: disruption

- Case study: urban PT network The Hague, the Netherlands
- Switch failure light rail at Laan van NOI station:
  - 11:22 – 11:26: activation rescheduling procedure
  - 11:26 – 14:33: active rescheduling procedure during disruption
  - 14:33 – 19:38: service recovery after disruption resolved
Case study: driver schedules

- Scenario 1: multi-line multi-vehicle driver schedule:
  - Schedule-based rescheduling
  - Situation as currently applied by PT operator
  - Empirical quantification based on (fusion of) AFC + AVL data

- Scenario 2: single-line multi-vehicle driver schedule:
  - Headway-based rescheduling: no risk on delay propagation
  - Shorter recovery time $\rightarrow$ reduction disruption costs + overtime
  - Quantification based on equal hourly vehicle distribution
    - Same irregularity (PRDM) as during undisrupted case
    - Passenger load equally divided by perceived frequency

- Extrapolation to yearly costs based on disruption log-data
Results: costs per disruption

- Monetised costs per disruption (€):
  - Scenario 1: €29k (operator) + €36k (pax) = €65k (€1.1M yearly)
  - Scenario 2: €17k (operator) + €19k (pax) = €36k (€0.6M yearly)
  - Total disruption costs decrease by 45% in scenario 2
Results: cost-benefit analysis

• Monetised trade-off between disruption costs and driver schedule costs:
  o Implementation of single-line multi-vehicle schedule + regularity
  o Driver schedule costs increase by €300k
  o Operator costs during disruptions decrease by €200k
  o Societal costs (operator + passenger) decrease by €500k
Discussion and conclusions

• Benefits of complex driver schedule are overestimated if increased disruption costs are not considered:
  o Initial cost reduction of €300k
  o However: €200k costs / revenue loss
  o However: €500k total societal costs

• Role PT authority to bridge gap financial vs. societal costs?

• Further research (based on sensitivity analysis) :
  o More detailed study to service recovery time reduction
  o More detailed study to long-term demand elasticity value
Driver schedule efficiency vs. public transport robustness:

A framework to quantify this trade-off based on passive data

Ir. Menno Yap
Dr. ir. Niels van Oort

M.D.Yap@TUDelft.nl

Smart Public Transport Lab
www.smartPTlab.TUDelft.nl

July 24th, 2018
Results: sensitivity analysis

- Results sensitive to reduction service recovery time (50%)
  - Value of 30% (-40%) reduces operator benefits scenario 2 by €100k
Results: sensitivity analysis

- Limited sensitivity to demand elasticity parameter (-0.5)
  - Value -0.3 (-40%) reduces operator benefits scenario 2 by €50k