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Design loads for road infrastructures: A new approach

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Context

- PhD dissertation M. Bernard
- Sponsor: ASTRA research funding of VSS projects
- Purpose: Update of current Swiss design load norm
Confusion in application

Link (Levels of service):

• $n^{th}$ hour
• AADT (symmetric matrix)
• Average peak hour (asymmetric matrix)

Intersections (waiting time):

• $4 \times$ peak quarter hour
• $1.2 \times$ peak hour
30th Hour: the original measurements

Hempsey and Teply (1999)
Why not the 200th hour? (Canadian measurements)
Ideal approach

Covers:

• Complete demand profile especially peak loads (remember we are dealing with queues!)

• Consistent across all elements of the road system

• Consistent with cost-benefit analysis

• (Reasonably) simple in application
Candidate?

Concept of

distribution of the instantaneous reserve capacity R

As difference between

momentarily available capacity C and current demand Q
Why instantaneous C and Q?
Why randomly distributed C and Q?
Micro-variance of flow q

Question:

How large is the variance of the flow (5 min intervals) for the hourly values forecast?
Measurement of the micro-variance

Data:

- 13 Swiss motorway cross-sections
- Between 180’000 and 330’000 5-min intervals
- Standardised relative with the current norm capacities (estimated for each cross-section)
Normal distributed flows given hourly $q$

$r_{60} = 30\%$

$(\Delta r = 1.25\%)$
Normal distributed flows given hourly $q$

$r_{60} = 90\%$

$(\Delta r = 1.25\%)$
Micro-variance and hourly flows (Norm LOS)

\[ r_{60} = Q_{60}/C_{VSS} \]

\[ sd(r_{5}) = sd(q_{5})/C_{VSS} \]
Capacity as a random variable
“HCM” - approach

Counting station: 023
Direction: 0
Number of intervals: 326055
Breakdown as the indicator of capacity
Breakdown probabilities and aggregation intervals

Matt and Elefteriadou (2001)
Estimation via reserve capacity $R$

Assume $C \sim N(\mu_C, \sigma_C)$ and $Q \sim N(\mu_Q, \sigma_Q)$

Reserve capacity $R$ is then:

$$R := C - Q$$

from which

$$P_b = P(C \leq Q) = P(C - Q \leq 0)$$
$$P_b = P(R \leq 0)$$

with $R \sim N(\mu_R, \sigma_R)$

$$\mu_R = \mu_C - \mu_Q$$
$$\sigma_R = \sqrt{\sigma_C^2 + \sigma_Q^2}$$
Breakdown probability

- $C \sim N(3600, 220)$
- $Q \sim N(3000, 310)$
- $R \sim N(600, 380)$

Probability of breakdown (right axis)
Breakdown probability Maatstetten
Breakdown probability as a function of flow Q

\[ r_{60} = \frac{Q_{60}}{C_{VSS}} \]
<table>
<thead>
<tr>
<th>Heavy Vehicle percentage</th>
<th>Median of mean capacities</th>
<th>Median of standard deviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 5%</td>
<td>$1.327 , C_{VSS,0-5%}$</td>
<td>$0.197 , C_{VSS,0-5%}$</td>
</tr>
<tr>
<td>5 – 15%</td>
<td>$1.294 , C_{VSS,0-5%}$</td>
<td>$0.180 , C_{VSS,0-5%}$</td>
</tr>
<tr>
<td>15 – 25%</td>
<td>$1.206 , C_{VSS,0-5%}$</td>
<td>$0.164 , C_{VSS,0-5%}$</td>
</tr>
</tbody>
</table>
Costs of a breakdown
Duration $t_b$ of low speed

Zählstelle Mattstetten, A1, Richtung Zürich
Speed reduction relative to free flow speed $v_m$

Heavy goods vehicles 0 – 5 %

$r_{60} = q_{60}/C_{VSS}$

$f_{mb} = V_b/V_m$
Speed reduction cars and heavy goods vehicles

\[ f_{mb} = \frac{V_b}{V_m} \]

\[ r_{60} = \frac{q_{60}}{C_{VSS}} \]
Breakdown duration

$\frac{Q_{60}}{C_{\text{VSS}}}$ vs. $t_b$ in min
Speed with and without breakdowns

\[ r_{60} = \frac{Q_{60}}{C_{VSS}} \]
Speed (including breakdowns) by speed limit

\[ r_{60} = \frac{Q_{60}}{C_{VSS}} \]

E(v) in km/h

- 120 km/h: 0 - 5%
- 120 km/h: 5 - 15%
- 120 km/h: 15 - 25%
- 100 km/h: 0 - 5%
- 100 km/h: 5 - 15%
- 100 km/h: 15 - 25%
Approximation of the user costs

Users N (with car occupancy \( o_o \)):
\[ N = o_o \cdot Q_{60} \]

Value of travel time savings (VTTS):
\[ COST_{tot} = N \cdot (VTTS_m \cdot t_m + (VTTS_m + VTTS_b) \cdot \Delta t_b) \]

or for a km:
\[ \frac{COST_{tot}}{s} = o_o \cdot Q_{60} \cdot \frac{1}{v_m} \left( VTTS_m + (VTTS_m + VTTS_b) \left( \frac{1 - f_{mb}}{\Delta t/P_b t_b + f_{mb}} \right) \right) \]

with function:
\[ v_m = \frac{v_0}{1 + \alpha r_{60}^\beta} \]

and
\[ \frac{\Delta t_b}{t_m} = \left( \frac{1 - f_{mb}}{\Delta t/P_b t_b + f_{mb}} \right) \]
Share of breakdown times (costs)

\[ r_{60} = \frac{Q_{60}}{C_{VSS}} \]

\[ \Delta \frac{t_b}{t_m} \]
What has been achieved?

• Detailed analysis of micro-variance
• Estimates of capacity as a random variable

• Reserve capacity as design tool for links

• Estimates of reserve capacities as random variables

• Cost estimates of breakdowns as a function of
  • Flow
  • Car occupancy
  • Breakdown probability
  • Breakdown duration
  • Share of heavy vehicles
  • Willingness to pay
What is missing? - Outlook

- Standard demand profiles
- Link between peak hour and AADT
- Integration over the demand profile
- Non-linear penalty for lateness and unreliability