Design diagrams for road infrastructure elements: High capacity roads

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Abstract

In this paper, the details for the design of road infrastructure elements, including their reliability are provided. This design is based on travel time, its uncertainty, and associated generalized costs of the road user. The paper presents the methodology developed by Bernard and Axhausen (2007), which deals with this approach. It allows the construction of the design diagrams to represent annual generalized costs of the road user for relevant values of volume and traffic flow compositions. The methodology is evaluated for Swiss motorways in order to examine its applicability for the practical uses. As a result, the scope of the methodology is observed to be limited in the current formulation because of the behavior of schedule delay costs of the road user.

Keywords
Design diagram; Road infrastructure; High capacity roads; Generalized costs of the road users; Value of travel time savings

Preferred citation style
1 Introduction

In Bernard and Axhausen (2007) and Bernard (2008) a highway design concept has been developed, which treats highway cross section capacity and traffic flow as random variables. Capacity and demand are assumed to vary over very short time period. This short term variation is assumed to follow a normal distribution in both the cases. The choice of highway design is based on the travel times, their variabilities, the values of travel time savings, and on the valuations of the travel time reliability. The methodology is suitable for the design of infrastructure elements, for which travel times and delays can be calculated, which in turn are summarized into the generalized costs of the road users, which include both travel time costs and schedule delay costs (early or late delays). The minimum input data requirements are hourly saturation values based on standard demand profiles, capacity estimates, and occupancy rates. To improve the estimates, the share of heavy goods vehicles (trucks, transporters, busses) should be known. If location specific data for any of these items are available, they can be used.

The methodology allows separate calculations of generalized costs for individual motorized traffic and heavy goods traffic. Instead of the previous reliance on a single design volume, say 30th hour, this methodology evaluates the generalized costs encountered across all hours of the year. In this way, the methodology avoids cost underestimates or cost overestimates due to the one selected hour. The difference in generalized costs of the road user between the current conditions and the various alternatives is the design criterion.

The purpose of this paper is to produce design diagrams derived from the annual generalized costs of the road user, which have been calculated for Swiss motorways. These design diagrams will serve as practical aids to assess the difference between generalized costs of the road user on existing infrastructure and the costs involved in investments for construction or modification of road infrastructure elements. The design diagrams will show the characteristics of annual generalized costs of the road user in terms of specified cross section capacity of the motorway and traffic flow observed on the motorway.

This paper is organized as follows: Section 2 provides an overview of the methodology. The necessary parameters for the methodology are currently available only for motorways; thus, subsequent section 3 and 4 analyze it for Swiss motorways (i.e., for 2 lane and 3 lane roadways). Section 5 presents the design diagrams for annual generalized costs. The last section concludes the paper with an evaluation of the methodology.
2 Methodology

The methodology is discussed in the following subsections; the discussion provides the parameters which were estimated for Swiss motorways. The necessary count data were provided by Swiss Federal Roads Authority (ASTRA, 2003); 13 motorway sites were chosen of which 11 sites had a $v_{max} = 120$ kmph and 2 sites a $v_{max} = 100$ kmph. The costs are calculated on a continuous scale in units of Swiss Francs and the system is comparable to a points rationing system (Bernard and Axhausen, 2007).

2.1 Breakdown probability

A traffic breakdown is the transitions from free to congested flow (i.e., from the upper branch to the lower branch of speed-volume fundamental diagram (Transportation Research Board, 2000). The breakdown probability is the product of the distribution of the prevailing traffic flow together with the distribution of the capacity (Bernard and Axhausen, 2007). The breakdown probability for a given saturation rate can be taken from figure [1] or approximated with the following formula:

\[
P_b = \frac{1}{1 + e^{\alpha - \beta a_{60}}}
\]

where,

- $P_b$ = Breakdown Probability
- $a_{60}$ = 60-min saturation rate: $a_{60} = Q_{60}/L_{sv=0}$, hourly demand volume $Q_{60}$ divided by the cross-section capacity $L_{sv=0}$ for zero heavy goods vehicles (see SN 640 018a)
- $\alpha$, $\beta$ = Parameters (see table [1])

Table 1: Parameters for formula [1]:

<table>
<thead>
<tr>
<th>Share of heavy goods vehicles</th>
<th>$\alpha$</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 5%</td>
<td>11.593</td>
<td>8.806</td>
</tr>
<tr>
<td>5 – 15%</td>
<td>11.987</td>
<td>9.361</td>
</tr>
<tr>
<td>15 – 25%</td>
<td>11.481</td>
<td>9.578</td>
</tr>
</tbody>
</table>
The exact breakdown probability can also be calculated with the mean ($\mu_R$) and standard deviation ($\sigma_R$) of the reserve capacity, $R$ (which is defined as $R = C - Q$, where $C$ is Capacity and $Q$ is traffic flow), especially when for $f_c$, $f_s$, or $sd(a)$ values other than those tabulated below are chosen:

$$P_b(\beta) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{-\beta} e^{-\frac{1}{2}x^2} dx$$  \[2\]

where, $\beta$ is defined as reliability index (coefficient of variation) = $\frac{\mu_R}{\sigma_R}$. The mean ($\mu_R$) and the standard deviation ($\sigma_R$) of the reserve capacity are given as:

$$\frac{\mu_R}{L_{sv=0}} = f_c - a_{60}$$  \[3\]

$$\frac{\sigma_R}{L_{sv=0}} = \sqrt{f_s^2 + sd(a)^2}$$  \[4\]
where,

\[ \mu_R = \text{Mean of the reserve capacity in [Fz/h]} \]

\[ \sigma_R = \text{Standard deviation of the reserve capacity in [Fz/h]} \]

\[ f_c, f_s = \text{Parameters (see table [2])} \]

\[ sd(a) = \text{Standard deviation of the saturation rate } a_{60} \text{ can be taken from figure [2] or calculated as:} \]

\[ sd(a) = -0.5166.a_{60}^4 + 1.0046.a_{60}^3 - 0.6864.a_{60}^2 + 0.2561.a_{60} + 0.0125 \quad [5] \]

Please note, that for \( a_{60} < 50\% \) the breakdown probability can be assumed to be zero.

Table 2: Parameters for formulae [3] and [4]:

<table>
<thead>
<tr>
<th>Share of heavy goods vehicles</th>
<th>( f_c )</th>
<th>( f_s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 5%</td>
<td>1.3305</td>
<td>0.1991</td>
</tr>
<tr>
<td>5 – 15%</td>
<td>1.2885</td>
<td>0.1805</td>
</tr>
<tr>
<td>15 – 25%</td>
<td>1.2004</td>
<td>0.1658</td>
</tr>
</tbody>
</table>

Figure 2: Mean standard deviation of the saturation rate \( sd(a) \) given \( a_{60} \)
2.2 Speed without breakdowns

The speed $v_m$ is the expected speed of a vehicle during undisturbed flow for a given volume to capacity ratio. This speed $v_m$ must be distinguished from the free speed $v_0$ which describes the maximum (allowed) speed of a road. To estimate this speed $v_m$ those observed intervals were selected which were not affected by a breakdown (Bernard and Axhausen, 2007). It can either be taken from figure [3] or calculated with the BPR-function of Transportation research Board (2000):

$$v_m = \frac{v_0}{1 + \alpha . a_60^\beta} \quad [6]$$

where,

$$v_m = \text{Mean speed without breakdowns in [km/h]}$$
$$v_0 = \text{Mean free flow speed in [km/h] (see table [3])}$$
$$\alpha, \beta = \text{Parameters (see table [3])}$$

Table 3: Parameters for formula [6]:

<table>
<thead>
<tr>
<th></th>
<th>Motorways with a speed limit of 120 km/h</th>
<th>Motorways with a speed limit of 100 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mIV HGV</td>
<td>mIV HGV</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.194 0.119</td>
<td>0.370 0.236</td>
</tr>
<tr>
<td>$\beta$</td>
<td>3.344 1.700</td>
<td>4.656 4.566</td>
</tr>
<tr>
<td>$v_0$</td>
<td>115.2 96.4</td>
<td>94.4 84.6</td>
</tr>
</tbody>
</table>

2.3 Ratio $f_{mb}$

The driver’s expected speed needs to account for other factors (e.g., traffic volume, weather, and light condition) influencing driver’s behavior. In case of a breakdown, travel time will increase as travel speed will drop down for its duration. The methodology uses ratio $f_{mb}$ to assess the reduced speed during a breakdown ($v_b = f_{mb}.v_m$). Here, $v_b$ represents reduced speed during breakdown (Bernard and Axhausen, 2007). The methodology suggests the calculation of ratio $f_{mb}$ with the figure [4] or with:

$$f_{mb} = c + \delta . a_60 + \frac{\gamma}{1 + e^{\alpha - \beta . a_60}} \quad [7]$$
Figure 3: Mean speed for flow without breakdowns $v_m$ as a function of $\alpha_{60}$ for mIV and HGV on motorways with speed limits of 100 and 120 kmph

where,

$$\alpha, \beta, \gamma, \delta, c = \text{Parameters (see table [4])}$$

Table 4: Parameters for formula [7]:

<table>
<thead>
<tr>
<th></th>
<th>Motorways with a speed limit of 120 km/h</th>
<th>Motorways with a speed limit of 100 km/h</th>
<th>Motorways with a speed limit of 100 km/h (Modified Parameters)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mIV</td>
<td>HGV</td>
<td>mIV</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>3.638</td>
<td>3.055</td>
<td>-31.38</td>
</tr>
<tr>
<td>$\beta$</td>
<td>9.223</td>
<td>7.901</td>
<td>-83.61</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>-0.511</td>
<td>-0.596</td>
<td>0.457</td>
</tr>
<tr>
<td>$\delta$</td>
<td>0.415</td>
<td>0.425</td>
<td>0.432</td>
</tr>
<tr>
<td>$c$</td>
<td>0.630</td>
<td>0.762</td>
<td>0.127</td>
</tr>
</tbody>
</table>
Figure 4: Ratio $f_{mb}$ of the speed during a breakdown to the speed without breakdown as a function $a_{60}$ for mIV and HGV on motorways with speed limits of 100 and 120 km/h

The plot for ratio $f_{mb}$ (see figure [4]), which is showing a sharp kink for 100 kmph case, is modified by changing the parameters $\alpha$ and $\beta$ (see table [4] and figure [5]). A parallel analysis of the generalized cost calculations (see section [2.8]) is carried out, but only a very slight difference between previous costs and the newly calculated costs is observed. The analysis shows that the new curve fits well and can replace the previous curve suggested in the original paper (Bernard and Axhausen, 2007). In this paper, the design diagrams (see figures [16] to [21] and appendices [B] and [C]) are produced with modified parameters for $f_{mb}$ (see table [4]).

### 2.4 Mean breakdown duration

In case of a breakdown, the undisturbed travel speed $v_m$ drops down to reduced speed during a breakdown $v_b$, given by a factor $f_{mb}$ (see section [2.3]). The breakdown event is of a certain duration; thus, the duration of breakdown is measured from the instant when a speed drop observed in $v_m$ to the instant when two consecutive 5-minute intervals with average speeds greater than the critical speed are observed (Bernard and Axhausen, 2007). The mean breakdown duration $t_b$ in [h] can be taken from figure [6] or calculated with:
Figure 5: Modified relationship among $f_{mb}$, $a_{60}$, number of lanes, and speed limit:

$$t_b = c + \frac{\gamma}{1 + e^{\alpha - \beta a_{60}}}$$  \[8\]

where,

$\alpha, \beta, \gamma, c = \text{Parameters (see table [5])}$

For saturation rates of $a_{60} \leq 65\%$ on motorways with a speed limit of 120 km/h $t_b$ can be assumed to be 0.707 h and as $t_b = 1.066h$ for those with a speed limit of 100 km/h.

Table 5: Parameters for formula [8]:

<table>
<thead>
<tr>
<th></th>
<th>Motorways with a speed limit of 120 km/h</th>
<th>Motorways with a speed limit of 100 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>12.39</td>
<td>17.95</td>
</tr>
<tr>
<td>$\beta$</td>
<td>34.16</td>
<td>45.37</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.340</td>
<td>0.901</td>
</tr>
<tr>
<td>$c$</td>
<td>0.368</td>
<td>0.165</td>
</tr>
</tbody>
</table>
2.5 Expected speed

The total travel time resulting from both free flow time and congested time is dependent on the distance traveled. Thus, expected speed will be including free travel speed and the expected proportion of congestion. According to Bernard and Axhausen, (2007) with $T_m$ being the total time (over a year) during which flows of a given volume to capacity ratio are not affected by the breakdowns and $T_b$, the sum of all durations of breakdowns for the same traffic volume. The expected speed can be written as:

$$E_v = \frac{T_m}{T_m + T_b} v_m + \frac{T_b}{T_m + T_b} v_b$$  \[9\]

where, $v_m$ denotes the free speed not affected by breakdowns and $v_b$ the reduced speed during breakdowns. If times $T_m$ and $T_b$ can be written as $T_m = n_m \Delta t$ and $T_b = n'_b t_b$ and if $n_m$ is the number of observed 5-minutes intervals ($\Delta t = 5$ min) with a free traffic flow and $n'_b$ the number of observed breakdowns with the duration $t_b$, then the breakdown probability can be written as $P_b = n'_b / n_m$ which results in the expression for expected speed:

$$E_v = \frac{1}{1 + P_b \frac{t_b}{\Delta t}} v_m + \frac{P_b \frac{t_b}{\Delta t}}{1 + P_b \frac{t_b}{\Delta t}} v_b$$  \[10\]
or with $f_{mb} = v_b/v_m$ it can be calculated as:

$$E_v = \frac{\Delta t + P_b t_b f_{mb}}{\Delta t + P_b t_b} \cdot v_m$$ \[11\]

where,

- $E_v$ = Expected speed in [km/h];
- $\Delta t = \frac{1}{12}$ h; interval length for the estimate of $P_b$ in [h]

### 2.6 Planned for mean speed

The planned for mean speed $v_p$, in contrast to $E_v$, incorporates the willingness to pay:

$$v_p = \frac{k_{früh} + k_{spät} \cdot P_b \cdot \frac{t_b}{\Delta t} \cdot f_{mb}}{k_{früh} + k_{spät} \cdot P_b \cdot \frac{t_b}{\Delta t}} \cdot v_m$$ \[12\]

where,

- $k_{früh}$ = Value of early delays in [CHF/Pers-h] (based on SN 641 825)
- $k_{spät}$ = Value of late delays in [CHF/Pers-h] (based on SN 641 825)
- $P_b$ = Probability of breakdown (see section [2.1])
- $v_p$ = Planned for speed of the traveler in [km/h]
- $v_m$ = Mean speed without breakdown in [km/h] (see section [2.2])
- $f_{mb}$ = Ratio of mean speed with breakdown to mean speed without breakdowns (see section [2.3])
- $t_b$ = Mean breakdown duration in [h] (see section [2.4])
- $\Delta t = \frac{1}{12}$ h; interval length for the estimate of $P_b$ in [h]

### 2.7 Generalized costs of travel

The methodology adopts the concept of willingness to pay for reduction in travel time to measure its benefit. This reduction in travel time is multiplied with the value of travel time savings for each user of the infrastructure element to compute the extra benefit. This approach is extended. It includes that a higher willingness to pay exists to reduce late arrivals (e.g., due to congestion) than to reduce travel time (Bernard and Axhausen, 2007). Thus, the generalized costs of travel of a person are calculated as the weighted sum of element specific travel times, early, and late delays:

$$K_p = k_E \cdot t_E + (1 - P_b) \cdot k_{früh} \cdot t_{früh} + P_b \cdot k_{spät} \cdot t_{spät}$$ \[13\]
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where,

\[ K_p = \text{Generalized cost of travel of a person [CHF]} \]

\[ k_E = \text{Value of travel time of the expected travel time [CHF/Pers. h] (based on SN 641 822, SN 641 823, SN 641 827)} \]

\[ k_{früh} = \text{Value of early delays in [CHF/Pers-h] (based on SN 641 825)} \]

\[ k_{spät} = \text{Value of late delays in [CHF/Pers-h] (based on SN 641 825)} \]

\[ t_E = \text{Expected travel time [h]} \]

\[ t_{früh} = \text{Early delay in [h] (= Expected travel time - Travel time without breakdowns)} \]

\[ t_{spät} = \text{Late delays in [h] (= Travel time with breakdowns - Expected travel time)} \]

\[ P_b = \text{Probability of breakdown (see section [2.1])} \]

The ratio of \( k_{früh} : k_E : k_{spät} \) is 1:2:3 as stipulated in SN 641 825.

### 2.8 Assessments of links of high capacity roads

The assessment is based on all hours of the year and all user of a link. The generalized costs of travel per unit length are:

\[
\frac{K_{p,h}}{I} = k_E \cdot \frac{1}{E_v} + \frac{\Delta t}{t_{früh}} k_{früh} \left( \frac{1}{v_p} - \frac{1}{v_m} \right) + \frac{P_b t_b}{t_{spät}} k_{spät} \left( \frac{1}{f_{mb} \cdot v_m} - \frac{1}{v_p} \right) \tag{14}
\]

where,

\[ K_{p,h} = \text{Generalized cost per person-h [CHF]} \]

\[ I = \text{Link length in [km]} \]

\[ E_v = \text{Expected speed in [km/h] (see section 2.5)} \]

\[ v_p = \text{Planned for speed of the traveler in [km/h] (see section 2.6)} \]

\[ v_m = \text{Mean speed without breakdown in [km/h] (see section 2.2)} \]

\[ f_{mb} = \text{Ratio of mean speed with breakdown to mean speed without breakdowns (see section 2.3)} \]

\[ t_b = \text{Mean breakdown duration in [h] (see section 2.4)} \]

\[ \Delta t = \frac{1}{12} \text{ h; interval length for the estimate of } P_b \text{ in [h]} \]

If there are data, respectively assumptions available for the share of heavy goods vehicles, then \( K_{p,h} \) have to be calculated separately for individual traffic and heavy goods traffic. Assume one person per heavy goods vehicle.

The annual sum of the generalized costs is:

\[
\frac{K_{tot,a}}{I} = \sum_{h=1}^{8760} Q_{60,h} \left( (1 - SV A_h) BG_h \frac{K_{p,h}^{miv}}{I} + SV A_h \frac{K_{p,h}^{SV}}{I} \right) \tag{15}
\]
where,

\[
\begin{align*}
K_{\text{tot,a}} &= \text{Total annual link generalized costs of travel [CHF]} \\
Q_{60,h} &= \text{Demand volume of the } h^{th} \text{ hour of the year} \\
SV A_h &= \text{Share of heavy good vehicles in } h^{th} \text{ hour [Pers/veh]} \\
BG_h &= \text{Occupancy ratio for the } h^{th} \text{ hour [Pers/veh]} \\
K_{\text{miv},h} &= \text{Generalized costs of travel of a person in } h^{th} \text{ hour [CHF]} \\
K_{\text{SV},h} &= \text{Generalized costs of travel of a heavy goods vehicle in } h^{th} \text{ hour [CHF]}
\end{align*}
\]
3 Input data

The methodology presented above is evaluated for Swiss motorways. The data are supplied by Swiss Association of Road and Transport Experts [SN 640 005b]. This standard presents 7 weekly (168 hours) and 5 annual (12 months) demand profiles. The profiles are presented as relative profiles (in terms of percent). The weekly profile is presented in percent of average weekday traffic (AWT); the annual profile as percent of the average month. The weekly and annual profiles are integrated to obtain the traffic flow data for the whole year (8,760 hours). The integration is done on the assumption that the weekly traffic flow will be same for all the weeks of a particular month. The year is assumed to start from Monday i.e., 1st day of January. For all other weeks which contain the days of a different month, the traffic flow is weighed accordingly on the basis of number of days falling in each month. These profiles obtained are used as input to the methodology. The traffic flow data are then sorted in descending order. Unsorted annual traffic flow profile is shown in figure [7] and sorted annual traffic flow profile is shown in figure [8].

Figure 7: Example showing hourly flow variation for whole year - weekly profile 1 and annual profile 1:

The average weekday traffic (AWT) is assumed to vary from 5,000 to 120,000. The high
range of average weekday traffic is observed in some locations in Switzerland (e.g., Muttenz, Hard (AB) and Baden, Bareggtunnel (AB)) (ASTRA, 2008). The 2 lane and 3 lane cases are evaluated separately. The separate cases for speed limits of 120 kmph and speed limit of 100 kmph are considered. The three types of share of heavy goods vehicles are considered in the analysis: 0 – 5%, 5 – 15%, and 15 – 25%. For calculations, the lower bound of the share of heavy goods vehicles is used as $SV_{A_h}$. The cross section capacity for motorways are assumed as 1500, 1750, 2000, 2250, and 2500 [veh/lane/h]. The occupancy ratio for the $h^{th}$ hour ($BG_{h}$) is considered as 1.1. The willingness to pay figures are (see SN 641 825, SN 641 822, SN 641 823 and SN 641 827):

\[
mIV : \quad k_E = 19.74, \quad k_{früh} = 9.87, \quad \text{and} \quad k_{spät} = 29.61 \,[\text{CHF/h-Pers}] \\
HGV : \quad k_E = 53.72, \quad k_{früh} = 23.86, \quad \text{and} \quad k_{spät} = 80.58 \,[\text{CHF/h-Fz}] 
\]

The HGV values incorporate both the willingness to pay of the senders (SN 641 823) and the operating costs of vehicle (SN 641 827). The hourly generalized costs are calculated for each hour of the year and then summed up for all hours of the year to obtain annual generalized costs. MATLAB is used to perform all the relevant calculations for annual generalized costs of the road user (MathWorks, 2009).
4 Behavior of travel time costs and schedule delay costs of the road user

The methodology incorporates travel time, schedule delays, and associated costs to produce the assessment of road infrastructure elements in the form of generalized costs of the road user. This section discusses the behavior of schedule delay costs with respect to hourly saturation rate $a_{60}$ as proposed by the methodology. The variables presented in the methodology are the functions of hourly saturation rate $a_{60}$. Using hourly saturation rate $a_{60}$ as the base parameter, we have analyzed the behavior of travel time costs and schedule delay costs. The functions for travel time costs (see formula [16]), early schedule delay costs (see formula [17]), and late schedule delay costs (see formula [18]) are as follows:

$$\frac{K_{t,h}}{I} = k_E \cdot \frac{1}{E_v}$$ \hspace{1cm} [16]

where,

$$K_{t,h} = \text{Costs associated with travel time per person-h [CHF]}$$

and,

$$\frac{K_{e,h}}{I} = \frac{\Delta t}{\Delta t + P_b l_b} k_{früh} \left( \frac{1}{v_p} - \frac{1}{v_m} \right)$$ \hspace{1cm} [17]

where,

$$K_{e,h} = \text{Early schedule delay cost per person-h [CHF]}$$

and,

$$\frac{K_{l,h}}{I} = \frac{P_{b l_b}}{\Delta t + P_b l_b} k_{spät} \left( \frac{1}{f_{mb} v_m} - \frac{1}{v_p} \right)$$ \hspace{1cm} [18]

where,

$$K_{l,h} = \text{Late schedule delay cost per person-h [CHF]}$$

The plots for travel time costs are presented in figures [9] and [10] and travel time costs show expected increasing behavior with respect to hourly saturation rate $a_{60}$. The plots (see figures [12], [13], [14], and [15]) for schedule delay costs show a twist and schedule delay costs begin to decline after a specific value of hourly saturation rate $a_{60}$. As, these above presented costs
functions are the composites of continuous functions; thus, these costs functions will also be continuous. First derivative test and second derivative test are applied to check the possibility of maxima and behavior of the function. Let us consider the early schedule delay costs function for analysis (see formula [17]). The function is tested for 120 kmph speed limit, 0 – 5% share of heavy goods vehicles, individual motorized traffic case, and for all $a_{60} \in (0, 2)$.

$$f(a_{60}) = \frac{\Delta t}{\Delta t + P_b t_b} \cdot k_{fr\ddot{u}h} \left( \frac{1}{v_p} - \frac{1}{v_m} \right)$$

where,

$$P_b(a_{60}) = \frac{1}{1 + e^{11.593 - 8.806 \cdot a_{60}}}$$

$$t_b(a_{60}) = 0.368 + \frac{0.340}{1 + e^{12.39 - 34.16 \cdot a_{60}}}$$

$$v_m(a_{60}) = \frac{115.2}{1 + 0.194 \cdot a_{60}^{3.344}}$$

$$f_{mb}(a_{60}) = 0.630 + 0.415 \cdot a_{60} + \frac{-0.511}{1 + e^{3.638 - 9.223 \cdot a_{60}}}$$
\[ v_p(a_{60}) = \frac{9.87 + 29.61P_b(a_{60}) \cdot \frac{t_s(a_{60})}{\Delta t} \cdot f_{mb}(a_{60})}{9.87 + 29.61P_b(a_{60}) \cdot \frac{t_s(a_{60})}{\Delta t}} \cdot v_m(a_{60}) \]

The derivative of the equation [19] is defined continuously over the interval i.e., at each point of interval the function \( f(a_{60}) \) is continuous and differentiable. According to first derivative test, for a function \( f \) which is differentiable in a neighborhood of \( x \), if there exists a positive number \( r \) such that for every \( y \) such that \( x - r < y < x \), we have \( f'(y) > 0 \), and for every \( y \) such that \( x < y < x + r \), we have \( f'(y) < 0 \), then function \( f \) has a local maximum at \( x \). After applying first derivative test and second derivative test, the results are:

\[ f'(a_{60}) = 0 \Rightarrow a_{60} = 1.0344 \]

\[ f'(1.0343) = 1.1420e - 004 \Rightarrow f'(1.0343) > 0 \]

\[ f'(1.0345) = -7.7604e - 005 \Rightarrow f'(1.0345) < 0 \]

\[ f''(1.0344) = -0.9590 \]

Second derivative test confirms that maxima exists at \( a_{60} = 1.0344 \) and

\[ f(1.0344) = 0.023 \Rightarrow f(1.0344) \geq f(a_{60}) \forall a_{60} \in (0, 2) \]

the above analysis shows that function \( f(a_{60}) \) (see equation [19]) will have global maximum at \( a_{60} = 1.0344 \). The critical values of hourly saturation rate \( a_{60} \), for which the schedule delay costs showing a twist pattern (occurrence of maxima), are estimated for different cases using MATLAB (MathWorks, 2009) and tabulated in tables [6] and [7]:

Table 6: Critical values of hourly saturation rate \( a_{60} \) for motorways with a speed limit of 120 kmph:

<table>
<thead>
<tr>
<th></th>
<th>mIV</th>
<th></th>
<th>HGV</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Early delay</td>
<td>Late delay</td>
<td>Early delay</td>
<td>Late delay</td>
</tr>
<tr>
<td>0 – 5%</td>
<td>1.034</td>
<td>1.014</td>
<td>1.009</td>
<td>0.9912</td>
</tr>
<tr>
<td>5 – 15%</td>
<td>1.017</td>
<td>0.9988</td>
<td>0.9938</td>
<td>0.9784</td>
</tr>
<tr>
<td>15 – 25%</td>
<td>0.9448</td>
<td>0.9272</td>
<td>0.9248</td>
<td>0.9106</td>
</tr>
</tbody>
</table>

However, the annual generalized costs seem to increase (see figure [11]) with respect to average weekday traffic because the travel time costs are always observed in an increasing fashion and the area under the graph of schedule delay costs is also increasing; therefore, it will incorporate positive changes in the annual generalized costs pattern. The behavior of schedule delay costs restricts the applicability of the methodology beyond a definite value of hourly saturation rate \( a_{60} \). In this paper, the methodology is applied for Swiss motorways within the above mentioned
limits (see tables [6] and [7]) and design diagrams (see next section [5]) are produced after making these considerations.

Table 7: Critical values of hourly saturation rate $a_{60}$ for motorways with a speed limit of 100 kmph:

<table>
<thead>
<tr>
<th></th>
<th>mIV</th>
<th>HGV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Early delay</td>
<td>Late delay</td>
</tr>
<tr>
<td>0 – 5%</td>
<td>1.001</td>
<td>0.9786</td>
</tr>
<tr>
<td>5 – 15%</td>
<td>0.9834</td>
<td>0.9638</td>
</tr>
<tr>
<td>15 – 25%</td>
<td>0.9076</td>
<td>0.8883</td>
</tr>
</tbody>
</table>

Figure 10: Example showing behavior of travel time costs with respect to hourly saturation rate $a_{60}$ for 100 kmph speed limit, 15 – 25% share of heavy goods vehicles, heavy goods traffic case:
Figure 11: Example showing design diagram without considering the behavior of schedule delay costs of the road user for weekly profile 1, annual profile 1, speed limit 100 km/h, and number of lanes 3:
Figure 12: Example showing behavior of early schedule delay costs with respect to hourly saturation rate $a_{60}$ for 100 kmph speed limit, 15 – 25% share of heavy goods vehicles, individual traffic case:
Figure 13: Example showing behavior of early schedule delay costs with respect to hourly saturation rate $a_{60}$ for 100 kmph speed limit, 15 – 25% share of heavy goods vehicles, heavy goods traffic case:
Figure 14: Example showing behavior of late schedule delay costs with respect to hourly saturation rate $a_{60}$ for 100 kmph speed limit, 15 – 25% share of heavy goods vehicles, individual traffic case:
Figure 15: Example showing behavior of late schedule delay costs with respect to hourly saturation rate $a_{60}$ for 100 kmph speed limit, 15 – 25% share of heavy goods vehicles, heavy goods traffic case:
5 Design diagrams

To assess the differences in the generalized costs of current conditions and various alternatives, the plots of annual generalized costs and average weekday traffic (AWT) are produced in two manners; first, the plots for specified speed limit and number of lanes, and second, for specified share of heavy goods vehicles and cross section capacity per lane. The cross section capacity per lane considered for both the cases are: 1500, 1750, 2000, 2250, and 2500 [veh/lane/h].

Figures [16] to [19] represent three different sets of lines. Each set represents one specified share of heavy goods vehicles. The topmost set of lines represents 15 - 25% share of heavy goods vehicles, the middle set represents 5 - 15% share of heavy goods vehicles, and the bottom set represents 0 - 5% share of heavy goods vehicles. Each set consists of 5 different lines; each line represents annual cost for specified cross section capacity per lane. In each set of lines, the topmost line represents 1500 [veh/lane/h] and the bottommost line represents 2500 [veh/lane/h]. Figures [20] and [21] contain a set of 4 lines. Each line represents specific share of heavy goods vehicles, cross section capacity per lane, speed limit, and number of lanes.

The actual design diagrams are produced for average weekday traffic varying from 0 to 120,000. In order to provide more clear visualization, we have presented them in this paper considering the variation of average weekday traffic from 0 to 70,000.
Figure 16: Example showing design diagram for weekly profile 4, annual profile 1, speed limit 120 km/h, and number of lanes 2:
Figure 17: Example showing design diagram for weekly profile 4, annual profile 1, speed limit 120 km/h, and number of lanes 3:
Figure 18: Example showing design diagram for weekly profile 4, annual profile 1, speed limit 100 km/h, and number of lanes 2:
Figure 19: Example showing design diagram for weekly profile 4, annual profile 1, speed limit 100 km/h, and number of lanes 3:
Figure 20: Example showing design diagram for weekly profile 4, annual profile 1, share of heavy goods vehicles 0%, cross section capacity 1750 [veh/lane/h]:

![Design Diagram](image-url)
Figure 21: Example showing design diagram for weekly profile 4, annual profile 1, share of heavy goods vehicles 0%, cross section capacity 2000 [veh/lane/h]:
6 Conclusions

We have presented design diagrams based on the methodology for Swiss motorways. The methodology offers a way to integrate travel speed and random delays in to a cost benefit analysis. It also provides a detailed description of effects that influence travel speed in contrast to existing design concept for motorways (Bernard and Axhausen, 2007). The design diagrams provide an outlook to assess the differences between current conditions and various possible alternatives.

A modification for the functional parameters of ratio $f_{mb}$ is proposed; it is observed that this modification has unnoticeable influence on the annual generalized costs of the road users. The limitations of the methodology have also come to notice. The behavior of schedule delay costs narrows the applicability of the methodology for practical considerations. The limits are calculated and presented for which the methodology works best and these limits are dependent on various factors: the type of traffic demand profile being input and resulting hourly saturation rate $a_{60}$ of considered motorway. The next step will be to reestimate these schedule delay cost curves so that they remain valid across the relevant range of $a_{60}$ between zero and two.
7 Acknowledgements

The authors would like to thank Bundesamt für Strassen, Bern for providing average daily traffic and average weekday traffic data for the analysis.

The first author would like to express his deep sense of gratitude to Prof. Axhausen for providing him an opportunity to work on interesting subject of highway design concept and guiding him throughout the project.
8 References


9 Appendix A: Annual traffic demand profiles

This section contains all annual traffic demand profiles derived from the integration of weekly and annual profiles supplied by the standard (see section [3]).
Figure 22: Ranked hourly flow variation for weekly profile 1 and annual profile 1:

![Graph showing ranked hourly flow variation for weekly profile 1 and annual profile 1.]

Figure 23: Ranked hourly flow variation for weekly profile 1 and annual profile 2:

![Graph showing ranked hourly flow variation for weekly profile 1 and annual profile 2.]

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Figure 24: Ranked hourly flow variation for weekly profile 1 and annual profile 3:

![Figure 24: Ranked hourly flow variation for weekly profile 1 and annual profile 3.](image1)

Figure 25: Ranked hourly flow variation for weekly profile 1 and annual profile 4:

![Figure 25: Ranked hourly flow variation for weekly profile 1 and annual profile 4.](image2)
Figure 26: Ranked hourly flow variation for weekly profile 1 and annual profile 5:

![Graph showing ranked hourly flow variation for weekly profile 1 and annual profile 5.]

Figure 27: Ranked hourly flow variation for weekly profile 2 and annual profile 1:

![Graph showing ranked hourly flow variation for weekly profile 2 and annual profile 1.]

Figure 28: Ranked hourly flow variation for weekly profile 2 and annual profile 2:

![Graph showing ranked hourly flow variation for weekly profile 2 and annual profile 2.]

Figure 29: Ranked hourly flow variation for weekly profile 2 and annual profile 3:

![Graph showing ranked hourly flow variation for weekly profile 2 and annual profile 3.]

Figure 30: Ranked hourly flow variation for weekly profile 2 and annual profile 4:

Figure 31: Ranked hourly flow variation for weekly profile 2 and annual profile 5:
Figure 32: Ranked hourly flow variation for weekly profile 3 and annual profile 1:

![Graph showing ranked hourly flow variation for weekly profile 3 and annual profile 1.]

Figure 33: Ranked hourly flow variation for weekly profile 3 and annual profile 2:

![Graph showing ranked hourly flow variation for weekly profile 3 and annual profile 2.]


Figure 34: Ranked hourly flow variation for weekly profile 3 and annual profile 3:

Figure 35: Ranked hourly flow variation for weekly profile 3 and annual profile 4:
Figure 36: Ranked hourly flow variation for weekly profile 3 and annual profile 5:

![Graph showing ranked hourly flow variation for weekly profile 3 and annual profile 5.]

Figure 37: Ranked hourly flow variation for weekly profile 4 and annual profile 1:

![Graph showing ranked hourly flow variation for weekly profile 4 and annual profile 1.]

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Figure 38: Ranked hourly flow variation for weekly profile 4 and annual profile 2:

![Graph showing ranked hourly flow variation for weekly profile 4 and annual profile 2.]

Figure 39: Ranked hourly flow variation for weekly profile 4 and annual profile 3:

![Graph showing ranked hourly flow variation for weekly profile 4 and annual profile 3.]

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Figure 40: Ranked hourly flow variation for weekly profile 4 and annual profile 4:

![Graph](image1)

Figure 41: Ranked hourly flow variation for weekly profile 4 and annual profile 5:

![Graph](image2)
Figure 42: Ranked hourly flow variation for weekly profile 5 and annual profile 1:

![Graph showing ranked hourly flow variation for weekly profile 5 and annual profile 1.]

Figure 43: Ranked hourly flow variation for weekly profile 5 and annual profile 2:

![Graph showing ranked hourly flow variation for weekly profile 5 and annual profile 2.]


Figure 44: Ranked hourly flow variation for weekly profile 5 and annual profile 3:

![Graph showing ranked hourly flow variation for weekly profile 5 and annual profile 3.]

Figure 45: Ranked hourly flow variation for weekly profile 5 and annual profile 4:

![Graph showing ranked hourly flow variation for weekly profile 5 and annual profile 4.]

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Figure 46: Ranked hourly flow variation for weekly profile 5 and annual profile 5:

![Graph](image1)

Figure 47: Ranked hourly flow variation for weekly profile 6 and annual profile 1:

![Graph](image2)
Figure 48: Ranked hourly flow variation for weekly profile 6 and annual profile 2:

Figure 49: Ranked hourly flow variation for weekly profile 6 and annual profile 3:
Figure 50: Ranked hourly flow variation for weekly profile 6 and annual profile 4:

![Ranked hourly flow variation for weekly profile 6 and annual profile 4](image1)

Figure 51: Ranked hourly flow variation for weekly profile 6 and annual profile 5:

![Ranked hourly flow variation for weekly profile 6 and annual profile 5](image2)
Figure 52: Ranked hourly flow variation for weekly profile 7 and annual profile 1:

![Ranked hourly flow variation for weekly profile 7 and annual profile 1](image1)

Figure 53: Ranked hourly flow variation for weekly profile 7 and annual profile 2:

![Ranked hourly flow variation for weekly profile 7 and annual profile 2](image2)
Figure 54: Ranked hourly flow variation for weekly profile 7 and annual profile 3:

![Diagram showing ranked hourly flow variation for weekly profile 7 and annual profile 3.](image)

Figure 55: Ranked hourly flow variation for weekly profile 7 and annual profile 4:

![Diagram showing ranked hourly flow variation for weekly profile 7 and annual profile 4.](image)
Figure 56: Ranked hourly flow variation for weekly profile 7 and annual profile 5:

![Ranked hourly flow variation graph](image-url)
10 Appendix B: Design diagrams set 1

This section contains the design diagram produced for particular speed limit and number of lanes. Average weekday traffic is considered from 0 to 70,000 in order to have more clear visualization. On each page, the design diagrams are arranged for 2 lane and 3 lane at a specified speed limit.
10.1 Speed Limit 120 kmph

Figure 57: Design diagram for weekly profile 1, annual profile 1, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 1, annual profile 1, speed limit 120 km/h, and number of lanes 2](image)

Figure 58: Design diagram for weekly profile 1, annual profile 1, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 1, annual profile 1, speed limit 120 km/h, and number of lanes 3](image)
Figure 59: Design diagram for weekly profile 1, annual profile 2, speed limit 120 km/h, and number of lanes 2:

Figure 60: Design diagram for weekly profile 1, annual profile 2, speed limit 120 km/h, and number of lanes 3:
Figure 61: Design diagram for weekly profile 1, annual profile 3, speed limit 120 km/h, and number of lanes 2:

![Design diagram](image1)

Figure 62: Design diagram for weekly profile 1, annual profile 3, speed limit 120 km/h, and number of lanes 3:

![Design diagram](image2)
Figure 63: Design diagram for weekly profile 1, annual profile 4, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 1, annual profile 4, speed limit 120 km/h, and number of lanes 2](image1)

Figure 64: Design diagram for weekly profile 1, annual profile 4, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 1, annual profile 4, speed limit 120 km/h, and number of lanes 3](image2)
Figure 65: Design diagram for weekly profile 1, annual profile 5, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 1, annual profile 5, speed limit 120 km/h, and number of lanes 2](image)

Figure 66: Design diagram for weekly profile 1, annual profile 5, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 1, annual profile 5, speed limit 120 km/h, and number of lanes 3](image)
Figure 67: Design diagram for weekly profile 2, annual profile 1, speed limit 120 km/h, and number of lanes 2:

![Graph showing design diagram for weekly profile 2, annual profile 1, speed limit 120 km/h, and number of lanes 2.](image)

Figure 68: Design diagram for weekly profile 2, annual profile 1, speed limit 120 km/h, and number of lanes 3:

![Graph showing design diagram for weekly profile 2, annual profile 1, speed limit 120 km/h, and number of lanes 3.](image)
Figure 69: Design diagram for weekly profile 2, annual profile 2, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 2, annual profile 2, speed limit 120 km/h, and number of lanes 2](image)

Figure 70: Design diagram for weekly profile 2, annual profile 2, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 2, annual profile 2, speed limit 120 km/h, and number of lanes 3](image)
Figure 71: Design diagram for weekly profile 2, annual profile 3, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 2, annual profile 3, speed limit 120 km/h, and number of lanes 2](image)

Figure 72: Design diagram for weekly profile 2, annual profile 3, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 2, annual profile 3, speed limit 120 km/h, and number of lanes 3](image)
Figure 73: Design diagram for weekly profile 2, annual profile 4, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 2, annual profile 4, speed limit 120 km/h, and number of lanes 2](image)

Figure 74: Design diagram for weekly profile 2, annual profile 4, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 2, annual profile 4, speed limit 120 km/h, and number of lanes 3](image)
Figure 75: Design diagram for weekly profile 2, annual profile 5, speed limit 120 km/h, and number of lanes 2:

Figure 76: Design diagram for weekly profile 2, annual profile 5, speed limit 120 km/h, and number of lanes 3:
Figure 77: Design diagram for weekly profile 3, annual profile 1, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 3, annual profile 1, speed limit 120 km/h, and number of lanes 2](image)

Figure 78: Design diagram for weekly profile 3, annual profile 1, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 3, annual profile 1, speed limit 120 km/h, and number of lanes 3](image)
Figure 79: Design diagram for weekly profile 3, annual profile 2, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 3, annual profile 2, speed limit 120 km/h, and number of lanes 2](image1)

Figure 80: Design diagram for weekly profile 3, annual profile 2, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 3, annual profile 2, speed limit 120 km/h, and number of lanes 3](image2)
Figure 81: Design diagram for weekly profile 3, annual profile 3, speed limit 120 km/h, and number of lanes 2:

Figure 82: Design diagram for weekly profile 3, annual profile 3, speed limit 120 km/h, and number of lanes 3:
Figure 83: Design diagram for weekly profile 3, annual profile 4, speed limit 120 km/h, and number of lanes 2:

![Design Diagram for Weekly Profile 3, Annual Profile 4, Speed Limit 120 km/h, and Number of Lanes 2](image)

Figure 84: Design diagram for weekly profile 3, annual profile 4, speed limit 120 km/h, and number of lanes 3:

![Design Diagram for Weekly Profile 3, Annual Profile 4, Speed Limit 120 km/h, and Number of Lanes 3](image)
Figure 85: Design diagram for weekly profile 3, annual profile 5, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 3, annual profile 5, speed limit 120 km/h, and number of lanes 2.](chart1)

Figure 86: Design diagram for weekly profile 3, annual profile 5, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 3, annual profile 5, speed limit 120 km/h, and number of lanes 3.](chart2)
Figure 87: Design diagram for weekly profile 4, annual profile 1, speed limit 120 km/h, and number of lanes 2:

Figure 88: Design diagram for weekly profile 4, annual profile 1, speed limit 120 km/h, and number of lanes 3:
Figure 89: Design diagram for weekly profile 4, annual profile 2, speed limit 120 km/h, and number of lanes 2:

![Design diagram](image1)

Figure 90: Design diagram for weekly profile 4, annual profile 2, speed limit 120 km/h, and number of lanes 3:

![Design diagram](image2)
Figure 91: Design diagram for weekly profile 4, annual profile 3, speed limit 120 km/h, and number of lanes 2:

Figure 92: Design diagram for weekly profile 4, annual profile 3, speed limit 120 km/h, and number of lanes 3:
Figure 93: Design diagram for weekly profile 4, annual profile 4, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 4, annual profile 4, speed limit 120 km/h, and number of lanes 2](image)

Figure 94: Design diagram for weekly profile 4, annual profile 4, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 4, annual profile 4, speed limit 120 km/h, and number of lanes 3](image)
Figure 95: Design diagram for weekly profile 4, annual profile 5, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 4, annual profile 5, speed limit 120 km/h, and number of lanes 2](image)

Figure 96: Design diagram for weekly profile 4, annual profile 5, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 4, annual profile 5, speed limit 120 km/h, and number of lanes 3](image)
Figure 97: Design diagram for weekly profile 5, annual profile 1, speed limit 120 km/h, and number of lanes 2:

![Design Diagram for Weekly Profile 5, Annual Profile 1, Speed Limit 120 km/h, and Number of Lanes 2](image)

Figure 98: Design diagram for weekly profile 5, annual profile 1, speed limit 120 km/h, and number of lanes 3:

![Design Diagram for Weekly Profile 5, Annual Profile 1, Speed Limit 120 km/h, and Number of Lanes 3](image)
Figure 99: Design diagram for weekly profile 5, annual profile 2, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 5, annual profile 2, speed limit 120 km/h, and number of lanes 2.](image)

Figure 100: Design diagram for weekly profile 5, annual profile 2, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 5, annual profile 2, speed limit 120 km/h, and number of lanes 3.](image)
Figure 101: Design diagram for weekly profile 5, annual profile 3, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 5, annual profile 3, speed limit 120 km/h, and number of lanes 2.]

Figure 102: Design diagram for weekly profile 5, annual profile 3, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 5, annual profile 3, speed limit 120 km/h, and number of lanes 3.]

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Figure 103: Design diagram for weekly profile 5, annual profile 4, speed limit 120 km/h, and number of lanes 2:

![Design Diagram](image1)

Figure 104: Design diagram for weekly profile 5, annual profile 4, speed limit 120 km/h, and number of lanes 3:

![Design Diagram](image2)
Figure 105: Design diagram for weekly profile 5, annual profile 5, speed limit 120 km/h, and number of lanes 2:

Figure 106: Design diagram for weekly profile 5, annual profile 5, speed limit 120 km/h, and number of lanes 3:
Figure 107: Design diagram for weekly profile 6, annual profile 1, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 6, annual profile 1, speed limit 120 km/h, and number of lanes 2](image)

Figure 108: Design diagram for weekly profile 6, annual profile 1, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 6, annual profile 1, speed limit 120 km/h, and number of lanes 3](image)
Figure 109: Design diagram for weekly profile 6, annual profile 2, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 6, annual profile 2, speed limit 120 km/h, and number of lanes 2.]

Figure 110: Design diagram for weekly profile 6, annual profile 2, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 6, annual profile 2, speed limit 120 km/h, and number of lanes 3.]

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Figure 111: Design diagram for weekly profile 6, annual profile 3, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 6, annual profile 3, speed limit 120 km/h, and number of lanes 2](image1)

Figure 112: Design diagram for weekly profile 6, annual profile 3, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 6, annual profile 3, speed limit 120 km/h, and number of lanes 3](image2)
Figure 113: Design diagram for weekly profile 6, annual profile 4, speed limit 120 km/h, and number of lanes 2:

Figure 114: Design diagram for weekly profile 6, annual profile 4, speed limit 120 km/h, and number of lanes 3:
Figure 115: Design diagram for weekly profile 6, annual profile 5, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 6, annual profile 5, speed limit 120 km/h, and number of lanes 2](image)

Figure 116: Design diagram for weekly profile 6, annual profile 5, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 6, annual profile 5, speed limit 120 km/h, and number of lanes 3](image)
Figure 117: Design diagram for weekly profile 7, annual profile 1, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 7, annual profile 1, speed limit 120 km/h, and number of lanes 2]

Figure 118: Design diagram for weekly profile 7, annual profile 1, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 7, annual profile 1, speed limit 120 km/h, and number of lanes 3]
Figure 119: Design diagram for weekly profile 7, annual profile 2, speed limit 120 km/h, and number of lanes 2:

Figure 120: Design diagram for weekly profile 7, annual profile 2, speed limit 120 km/h, and number of lanes 3:
Figure 121: Design diagram for weekly profile 7, annual profile 3, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 7, annual profile 3, speed limit 120 km/h, and number of lanes 2](image)

Figure 122: Design diagram for weekly profile 7, annual profile 3, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 7, annual profile 3, speed limit 120 km/h, and number of lanes 3](image)
Figure 123: Design diagram for weekly profile 7, annual profile 4, speed limit 120 km/h, and number of lanes 2:

Figure 124: Design diagram for weekly profile 7, annual profile 4, speed limit 120 km/h, and number of lanes 3:
Figure 125: Design diagram for weekly profile 7, annual profile 5, speed limit 120 km/h, and number of lanes 2:

![Design diagram for weekly profile 7, annual profile 5, speed limit 120 km/h, and number of lanes 2](image)

Figure 126: Design diagram for weekly profile 7, annual profile 5, speed limit 120 km/h, and number of lanes 3:

![Design diagram for weekly profile 7, annual profile 5, speed limit 120 km/h, and number of lanes 3](image)
10.2 Speed Limit 100 km/h

Figure 127: Design diagram for weekly profile 1, annual profile 1, speed limit 100 km/h, and number of lanes 2:

![Design diagram for weekly profile 1, annual profile 1, speed limit 100 km/h, and number of lanes 2](image1)

Figure 128: Design diagram for weekly profile 1, annual profile 1, speed limit 100 km/h, and number of lanes 3:

![Design diagram for weekly profile 1, annual profile 1, speed limit 100 km/h, and number of lanes 3](image2)
Figure 129: Design diagram for weekly profile 1, annual profile 2, speed limit 100 km/h, and number of lanes 2:

![Design diagram for weekly profile 1, annual profile 2, speed limit 100 km/h, and number of lanes 2](image1)

Figure 130: Design diagram for weekly profile 1, annual profile 2, speed limit 100 km/h, and number of lanes 3:

![Design diagram for weekly profile 1, annual profile 2, speed limit 100 km/h, and number of lanes 3](image2)
Figure 131: Design diagram for weekly profile 1, annual profile 3, speed limit 100 km/h, and number of lanes 2:

![Design diagram for weekly profile 1, annual profile 3, speed limit 100 km/h, and number of lanes 2]

Figure 132: Design diagram for weekly profile 1, annual profile 3, speed limit 100 km/h, and number of lanes 3:

![Design diagram for weekly profile 1, annual profile 3, speed limit 100 km/h, and number of lanes 3]
Figure 133: Design diagram for weekly profile 1, annual profile 4, speed limit 100 km/h, and number of lanes 2:

![Diagram](image1)

Figure 134: Design diagram for weekly profile 1, annual profile 4, speed limit 100 km/h, and number of lanes 3:

![Diagram](image2)
Figure 135: Design diagram for weekly profile 1, annual profile 5, speed limit 100 km/h, and number of lanes 2:

Figure 136: Design diagram for weekly profile 1, annual profile 5, speed limit 100 km/h, and number of lanes 3:
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Figure 137: Design diagram for weekly profile 2, annual profile 1, speed limit 100 km/h, and number of lanes 2:

![Design diagram for weekly profile 2, annual profile 1, speed limit 100 km/h, and number of lanes 2](image)

Figure 138: Design diagram for weekly profile 2, annual profile 1, speed limit 100 km/h, and number of lanes 3:

![Design diagram for weekly profile 2, annual profile 1, speed limit 100 km/h, and number of lanes 3](image)
Figure 139: Design diagram for weekly profile 2, annual profile 2, speed limit 100 km/h, and number of lanes 2:

![Design diagram for weekly profile 2, annual profile 2, speed limit 100 km/h, and number of lanes 2:]

Figure 140: Design diagram for weekly profile 2, annual profile 2, speed limit 100 km/h, and number of lanes 3:

![Design diagram for weekly profile 2, annual profile 2, speed limit 100 km/h, and number of lanes 3:]
Figure 141: Design diagram for weekly profile 2, annual profile 3, speed limit 100 km/h, and number of lanes 2:

![Design diagram for weekly profile 2, annual profile 3, speed limit 100 km/h, and number of lanes 2.](image)

Figure 142: Design diagram for weekly profile 2, annual profile 3, speed limit 100 km/h, and number of lanes 3:

![Design diagram for weekly profile 2, annual profile 3, speed limit 100 km/h, and number of lanes 3.](image)
Figure 143: Design diagram for weekly profile 2, annual profile 4, speed limit 100 km/h, and number of lanes 2:

Figure 144: Design diagram for weekly profile 2, annual profile 4, speed limit 100 km/h, and number of lanes 3:
Figure 145: Design diagram for weekly profile 2, annual profile 5, speed limit 100 km/h, and number of lanes 2:

![Design diagram for weekly profile 2, annual profile 5, speed limit 100 km/h, and number of lanes 2](image)

Figure 146: Design diagram for weekly profile 2, annual profile 5, speed limit 100 km/h, and number of lanes 3:

![Design diagram for weekly profile 2, annual profile 5, speed limit 100 km/h, and number of lanes 3](image)
Figure 147: Design diagram for weekly profile 3, annual profile 1, speed limit 100 km/h, and number of lanes 2:

![Design diagram for weekly profile 3, annual profile 1, speed limit 100 km/h, and number of lanes 2](image)

Figure 148: Design diagram for weekly profile 3, annual profile 1, speed limit 100 km/h, and number of lanes 3:

![Design diagram for weekly profile 3, annual profile 1, speed limit 100 km/h, and number of lanes 3](image)
Figure 149: Design diagram for weekly profile 3, annual profile 2, speed limit 100 km/h, and number of lanes 2:

Figure 150: Design diagram for weekly profile 3, annual profile 2, speed limit 100 km/h, and number of lanes 3:
Figure 151: Design diagram for weekly profile 3, annual profile 3, speed limit 100 km/h, and number of lanes 2:

Figure 152: Design diagram for weekly profile 3, annual profile 3, speed limit 100 km/h, and number of lanes 3:
Figure 153: Design diagram for weekly profile 3, annual profile 4, speed limit 100 km/h, and number of lanes 2:

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![Design diagram for weekly profile 3, annual profile 5, speed limit 100 km/h, and number of lanes 2](image)

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![Design diagram for weekly profile 4, annual profile 3, speed limit 100 km/h, and number of lanes 2.](image1)

Figure 162: Design diagram for weekly profile 4, annual profile 3, speed limit 100 km/h, and number of lanes 3:

![Design diagram for weekly profile 4, annual profile 3, speed limit 100 km/h, and number of lanes 3.](image2)
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![Design diagram for weekly profile 4, annual profile 4, speed limit 100 km/h, and number of lanes 2](image)

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![Design diagram for weekly profile 4, annual profile 4, speed limit 100 km/h, and number of lanes 3](image)
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![Design diagram for weekly profile 5, annual profile 5, speed limit 100 km/h, and number of lanes 2](image)

Figure 176: Design diagram for weekly profile 5, annual profile 5, speed limit 100 km/h, and number of lanes 3:

![Design diagram for weekly profile 5, annual profile 5, speed limit 100 km/h, and number of lanes 3](image)
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Figure 178: Design diagram for weekly profile 6, annual profile 1, speed limit 100 km/h, and number of lanes 3:
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![Design diagram for weekly profile 6, annual profile 2, speed limit 100 km/h, and number of lanes 2](image)

Figure 180: Design diagram for weekly profile 6, annual profile 2, speed limit 100 km/h, and number of lanes 3:

![Design diagram for weekly profile 6, annual profile 2, speed limit 100 km/h, and number of lanes 3](image)
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Figure 182: Design diagram for weekly profile 6, annual profile 3, speed limit 100 km/h, and number of lanes 3:
Figure 183: Design diagram for weekly profile 6, annual profile 4, speed limit 100 km/h, and number of lanes 2:

Figure 184: Design diagram for weekly profile 6, annual profile 4, speed limit 100 km/h, and number of lanes 3:
Figure 185: Design diagram for weekly profile 6, annual profile 5, speed limit 100 km/h, and number of lanes 2:

![Design Diagram for Weekly Profile 6, Annual Profile 5, Speed Limit 100 km/h, and Number of Lanes 2](image)

Figure 186: Design diagram for weekly profile 6, annual profile 5, speed limit 100 km/h, and number of lanes 3:

![Design Diagram for Weekly Profile 6, Annual Profile 5, Speed Limit 100 km/h, and Number of Lanes 3](image)
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![Design diagram for weekly profile 7, annual profile 1, speed limit 100 km/h, and number of lanes 2.](image)

Figure 188: Design diagram for weekly profile 7, annual profile 1, speed limit 100 km/h, and number of lanes 3:

![Design diagram for weekly profile 7, annual profile 1, speed limit 100 km/h, and number of lanes 3.](image)
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![Design Diagram for Weekly Profile 7, Annual Profile 2, Speed Limit 100 km/h, and Number of Lanes 2]

Figure 190: Design diagram for weekly profile 7, annual profile 2, speed limit 100 km/h, and number of lanes 3:

![Design Diagram for Weekly Profile 7, Annual Profile 2, Speed Limit 100 km/h, and Number of Lanes 3]
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![Design diagram for weekly profile 7, annual profile 4, speed limit 100 km/h, and number of lanes 2](image1)

Figure 194: Design diagram for weekly profile 7, annual profile 4, speed limit 100 km/h, and number of lanes 3:

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![Design Diagram for Weekly Profile 7, Annual Profile 5, Speed Limit 100 km/h, and Number of Lanes 2]

Figure 196: Design diagram for weekly profile 7, annual profile 5, speed limit 100 km/h, and number of lanes 3:

![Design Diagram for Weekly Profile 7, Annual Profile 5, Speed Limit 100 km/h, and Number of Lanes 3]
11 Appendix C: Design diagrams set 2

This section contains the design diagram produced for specified share of heavy goods vehicles and cross section capacity per lane of the considered motorway. The design diagrams are arranged in 15 subsections. Each subsection represents design diagrams for specific value of share of heavy goods vehicles and cross section capacity per lane.
11.1 Cross section capacity: 1500 [veh/lane/h] and share of heavy goods vehicles: 0 – 5%

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Figure 198: Design diagram for weekly profile 1, annual profile 2, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]:

Figure 199: Design diagram for weekly profile 1, annual profile 3, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 1, annual profile 3, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]](image)

Figure 200: Design diagram for weekly profile 1, annual profile 4, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 1, annual profile 4, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]](image)
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![Design diagram](image1)

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![Graph showing the relationship between average weekday traffic and annual cost for different road configurations.]

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![Graph showing the relationship between average weekday traffic and annual cost for different road configurations.]
Figure 207: Design diagram for weekly profile 3, annual profile 1, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]:

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Figure 209: Design diagram for weekly profile 3, annual profile 3, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]:

![Design Diagram](image1)

Figure 210: Design diagram for weekly profile 3, annual profile 4, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]:

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![Design diagram for weekly profile 3, annual profile 5](image1)

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Figure 212: Design diagram for weekly profile 4, annual profile 1, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 4, annual profile 1](image2)
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![Design diagram for weekly profile 4, annual profile 2, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]](image1)

Figure 214: Design diagram for weekly profile 4, annual profile 3, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 4, annual profile 3, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]](image2)
Figure 215: Design diagram for weekly profile 4, annual profile 4, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 4, annual profile 4, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]](image)

Figure 216: Design diagram for weekly profile 4, annual profile 5, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 4, annual profile 5, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]](image)
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![Design diagram for weekly profile 5, annual profile 1, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]](image1)

Figure 218: Design diagram for weekly profile 5, annual profile 2, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 5, annual profile 2, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]](image2)
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![Design diagram for weekly profile 5, annual profile 3, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]](image)

Figure 220: Design diagram for weekly profile 5, annual profile 4, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 5, annual profile 4, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]](image)
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![Design diagram for weekly profile 5, annual profile 5, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]](image1)

Figure 222: Design diagram for weekly profile 6, annual profile 1, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 6, annual profile 1, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]](image2)
Figure 223: Design diagram for weekly profile 6, annual profile 2, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]:

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![Design diagram for weekly profile 6, annual profile 4, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]](image)

Figure 226: Design diagram for weekly profile 6, annual profile 5, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 6, annual profile 5, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]](image)
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![Design diagram for weekly profile 7, annual profile 1](image1)

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![Design diagram for weekly profile 7, annual profile 2](image2)
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![Design diagram for weekly profile 7, annual profile 3](image)

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![Design diagram for weekly profile 7, annual profile 4](image)
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![Design diagram for weekly profile 7, annual profile 5, share of heavy goods vehicles 0%, cross section capacity 1500 [veh/lane/h]](image-url)
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Figure 232: Design diagram for weekly profile 1, annual profile 1, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]:

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Figure 235: Design diagram for weekly profile 1, annual profile 4, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]:
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Figure 237: Design diagram for weekly profile 2, annual profile 1, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]:

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Figure 239: Design diagram for weekly profile 2, annual profile 3, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]:

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Figure 241: Design diagram for weekly profile 2, annual profile 5, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]:

![Design Diagram](image2)
Figure 242: Design diagram for weekly profile 3, annual profile 1, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 3, annual profile 1](image1)

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![Design diagram for weekly profile 3, annual profile 2](image2)
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![Design diagram for weekly profile 3, annual profile 3, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]](image)

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![Design diagram for weekly profile 3, annual profile 4, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]](image)
Figure 246: Design diagram for weekly profile 3, annual profile 5, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 3, annual profile 5, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]](image1)

Figure 247: Design diagram for weekly profile 4, annual profile 1, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 4, annual profile 1, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]](image2)
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![Design Diagram](image1)

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![Design Diagram](image2)
Figure 250: Design diagram for weekly profile 4, annual profile 4, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 4, annual profile 4, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h].]

Figure 251: Design diagram for weekly profile 4, annual profile 5, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 4, annual profile 5, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h].]
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![Diagram 254]

Figure 255: Design diagram for weekly profile 5, annual profile 4, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]:

![Diagram 255]
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![Design diagram for weekly profile 5, annual profile 5, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h].]

Figure 257: Design diagram for weekly profile 6, annual profile 1, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 6, annual profile 1, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h].]
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![Design diagram for weekly profile 6, annual profile 2, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h].]

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![Design diagram for weekly profile 6, annual profile 3, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h].]
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![Graph 1](image1)

Figure 261: Design diagram for weekly profile 6, annual profile 5, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]:

![Graph 2](image2)
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Figure 263: Design diagram for weekly profile 7, annual profile 2, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]:
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![Design diagram for weekly profile 7, annual profile 3, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]](image)

Figure 265: Design diagram for weekly profile 7, annual profile 4, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 7, annual profile 4, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]](image)
Figure 266: Design diagram for weekly profile 7, annual profile 5, share of heavy goods vehicles 5%, cross section capacity 1500 [veh/lane/h]:
11.3 Cross section capacity: 1500 [veh/lane/h] and share of heavy goods vehicles: 15 – 25%

Figure 267: Design diagram for weekly profile 1, annual profile 1, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

Figure 268: Design diagram for weekly profile 1, annual profile 2, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

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Figure 272: Design diagram for weekly profile 2, annual profile 1, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:
Figure 273: Design diagram for weekly profile 2, annual profile 2, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 2, annual profile 2, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]](image)

Figure 274: Design diagram for weekly profile 2, annual profile 3, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 2, annual profile 3, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]](image)
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![Diagram for weekly profile 2, annual profile 4](image1)

Figure 276: Design diagram for weekly profile 2, annual profile 5, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Diagram for weekly profile 2, annual profile 5](image2)
Figure 277: Design diagram for weekly profile 3, annual profile 1, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 3, annual profile 1, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]](image1)

Figure 278: Design diagram for weekly profile 3, annual profile 2, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 3, annual profile 2, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]](image2)
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![Diagram](image)

Figure 280: Design diagram for weekly profile 3, annual profile 4, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Diagram](image)
Figure 281: Design diagram for weekly profile 3, annual profile 5, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 3, annual profile 5, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]](image)

Figure 282: Design diagram for weekly profile 4, annual profile 1, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 4, annual profile 1, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]](image)
Figure 283: Design diagram for weekly profile 4, annual profile 2, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Graph showing design diagram for weekly profile 4, annual profile 2, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h].]

Figure 284: Design diagram for weekly profile 4, annual profile 3, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Graph showing design diagram for weekly profile 4, annual profile 3, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h].]
Figure 285: Design diagram for weekly profile 4, annual profile 4, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 4, annual profile 4, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h].](image)

Figure 286: Design diagram for weekly profile 4, annual profile 5, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 4, annual profile 5, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h].](image)
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Figure 288: Design diagram for weekly profile 5, annual profile 2, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:
Figure 289: Design diagram for weekly profile 5, annual profile 3, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

Figure 290: Design diagram for weekly profile 5, annual profile 4, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:
Figure 291: Design diagram for weekly profile 5, annual profile 5, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 5, annual profile 5, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]](image)

Figure 292: Design diagram for weekly profile 6, annual profile 1, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 6, annual profile 1, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]](image)
Figure 293: Design diagram for weekly profile 6, annual profile 2, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 6, annual profile 2, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]](image)

Figure 294: Design diagram for weekly profile 6, annual profile 3, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 6, annual profile 3, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]](image)
Figure 295: Design diagram for weekly profile 6, annual profile 4, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 6, annual profile 4, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]](image)

Figure 296: Design diagram for weekly profile 6, annual profile 5, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Design diagram for weekly profile 6, annual profile 5, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]](image)
Figure 297: Design diagram for weekly profile 7, annual profile 1, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

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Figure 299: Design diagram for weekly profile 7, annual profile 3, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Design diagram](image)

Figure 300: Design diagram for weekly profile 7, annual profile 4, share of heavy goods vehicles 15%, cross section capacity 1500 [veh/lane/h]:

![Design diagram](image)
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![Design diagram for road infrastructure elements: High capacity roads](image-url)
11.4 Cross section capacity: 1750 [veh/lane/h] and share of heavy goods vehicles: 0 – 5%

Figure 302: Design diagram for weekly profile 1, annual profile 1, share of heavy goods vehicles 0%, cross section capacity 1750 [veh/lane/h]:

![Design diagram for weekly profile 1, annual profile 1, share of heavy goods vehicles 0%, cross section capacity 1750 [veh/lane/h]](image1)

Figure 303: Design diagram for weekly profile 1, annual profile 2, share of heavy goods vehicles 0%, cross section capacity 1750 [veh/lane/h]:

![Design diagram for weekly profile 1, annual profile 2, share of heavy goods vehicles 0%, cross section capacity 1750 [veh/lane/h]](image2)
Figure 304: Design diagram for weekly profile 1, annual profile 3, share of heavy goods vehicles 0%, cross section capacity 1750 [veh/lane/h]:

![Graph](image1)

Figure 305: Design diagram for weekly profile 1, annual profile 4, share of heavy goods vehicles 0%, cross section capacity 1750 [veh/lane/h]:

![Graph](image2)
Figure 306: Design diagram for weekly profile 1, annual profile 5, share of heavy goods vehicles 0%, cross section capacity 1750 [veh/lane/h]:

![Design diagram for weekly profile 1, annual profile 5](image1)

Figure 307: Design diagram for weekly profile 2, annual profile 1, share of heavy goods vehicles 0%, cross section capacity 1750 [veh/lane/h]:

![Design diagram for weekly profile 2, annual profile 1](image2)
Figure 308: Design diagram for weekly profile 2, annual profile 2, share of heavy goods vehicles 0%, cross section capacity 1750 [veh/lane/h]:

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- 2Lane 100kmph
- 3Lane 100kmph
- 2Lane 120kmph
- 3Lane 120kmph

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- 2Lane 100kmph
- 3Lane 100kmph
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![Design diagram for weekly profile 2, annual profile 3, share of heavy goods vehicles 5%, cross section capacity 1750 [veh/lane/h]]
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\[
\begin{align*}
\text{Average Weekday Traffic (AWT) } & \times 10^4 \\
\text{Annual Cost (CHF/km)} & \times 10^4 \\
\end{align*}
\]

- 2Lane 100kmph
- 3Lane 100kmph
- 2Lane 120kmph
- 3Lane 120kmph

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\[
\begin{align*}
\text{Average Weekday Traffic (AWT) } & \times 10^4 \\
\text{Annual Cost (CHF/km)} & \times 10^4 \\
\end{align*}
\]

- 2Lane 100kmph
- 3Lane 100kmph
- 2Lane 120kmph
- 3Lane 120kmph
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**Average Weekday Traffic (AWT)**

- 2Lane 100kmph
- 3Lane 100kmph
- 2Lane 120kmph
- 3Lane 120kmph

**Annual Cost (CHF/km):**

- 2Lane 100kmph
- 3Lane 100kmph
- 2Lane 120kmph
- 3Lane 120kmph
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Figure 534: Design diagram for weekly profile 5, annual profile 3, share of heavy goods vehicles 0%, cross section capacity 2250 [veh/lane/h]:
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Figure 535: Design diagram for weekly profile 5, annual profile 4, share of heavy goods vehicles 0%, cross section capacity 2250 [veh/lane/h]:

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Figure 535: Design diagram for weekly profile 5, annual profile 4, share of heavy goods vehicles 0%, cross section capacity 2250 [veh/lane/h]:
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\[
\text{Annual Cost (CHF/km)}
\]

\[
\begin{align*}
\text{Average Weekday Traffic (AWT)} & \quad \times 10^4 \\
\text{2Lane 100kmph} & \quad \text{3Lane 100kmph} \\
\text{2Lane 120kmph} & \quad \text{3Lane 120kmph}
\end{align*}
\]
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