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Mechanical Engineering - Posters

THE PARAMETER ESTIMATION OF THE LINK PERFORMANCE FUNCTIONS

József Osztényi[1*], Rafael Alvarez Gil[2], Kálmán Bolla[2], Edit Csizmás[2], Csaba Fábián[2], Lóránt Kovács[2], Tamás Kovács[2], Krisztián Medgyes[2] and Tibor Vajnai[2]

[1]Department of Natural Sciences and Engineering,
[2] Department of Information Technologies,
Faculty of Mechanical Engineering and Automation, Kecskemét College, Hungary

* Corresponding author e-mail: osztenyi.jozsef@gamf.kefo.hu

Abstract
The link performance function is a mathematical representation of the relation between flow (i.e. traffic volume) and travel cost (i.e. travel time) for any given link in the network. The results are presented of the calibration of performance functions. Two types of functions are presented: (a) linear function and (b) nonlinear functions, based on the widely used Bureau of Public Roads form. These functions are intended for use in network equilibrium studies requiring the assignment of explicit car flows.

Keywords:
link performance function, travel simulation, regression

1. Introduction

Today it is an important challenge to minimize the travel cost of a particular urban transport system. The travel cost is usually considered to be travel time between the origin and the destination of travel. In order to calculate travel time between origin and destination, the network representation of the transport area is used [2].

The network includes two types of elements: a set of nodes (intersection of roads) and a set of links (street) connecting these nodes.

The other part of the urban transport system is the traffic flow (the mass of the moving vehicles).

The function, which is called Link Performance Function (LPF) [1], is presenting the relationship between link delays and link flows.

A performance function for a typical approach to a signalized intersection is shown in Figure 1. This function captures both the time spent in traveling along the approach under consideration and the delay at the downstream intersection. The travel time at zero flow is known as the free-flow travel time. At this point, a traveling car would not be delayed because of interaction with any other car moving along the link. The only source of delay at this point is the time associated with traversing the link and the expected delay associated with the probability of being stopped by a red signal indication. As the flow increases, the travel time monotonically increases since both the travel time along the approach increases (because of vehicle interactions at higher traffic densities) and the intersection delay increases (because of queueing phenomena) with the flow.

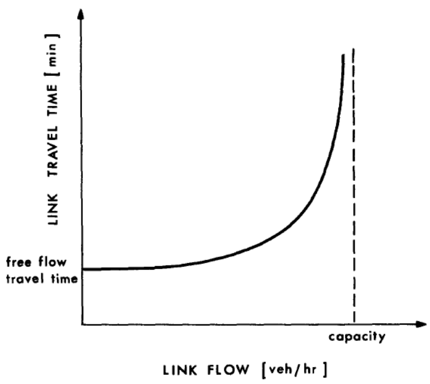

Figure 1. Typical link performance function for an approach to a signalized intersection.

Characteristically, the performance function is asymptotic to a certain level of flow known as the capacity of the transportation facility under consideration. The capacity is the maximum flow that can go through any transportation facility. When the flow approaches capacity, the queues at the intersection will start growing, clogging upstream intersections and finally causing traffic to come to a halt.

2. Common Link Performance Functions

The original intersection delay formula used by traffic engineers was calibrated by Webster [3] on the basis of Monte Carlo simulations:

$$t = \frac{r^2}{2c(1-\rho)} + \frac{R^2}{2q(1-R)} - 0.65\left(\frac{c}{q^2}\right)^{1/3} R^{(2+5g/c)}.$$

This is a complicated functional form, thus it imposes a significant computational burden on the calculations. During the equilibrium calculations the link performance functions have to be evaluated numerous times, so we use simplified formula.

A simplified function that is often used in practice is the equation developed by the U.S. Bureau of Public Roads (BPR). This equation is given by

$$t = t^0 \left[1 + \alpha \left(\frac{q}{C}\right)^{\beta}\right]. \tag{1}$$

In this formula t and q are the travel time of the flow, t^0 is the free-flow travel time, and C is the capacity of link. The quantities α and β are model parameters, for which the value $\alpha = 0.15$ and $\beta = 4.0$ are typically used to the highway.
In contrast with traffic flow theory the BPR curves are not asymptotic to any capacity value. A function that is asymptotic to a capacity flow was proposed by Davidson, based on queueing theory considerations. This function is

$$t = t^0 \left[1 + J\left(\frac{q}{C-q}\right)\right], \tag{2}$$

where *C* is the road's capacity and *J* is a parameter of the model. As with the BPR function, t^0 denotes the free-flow travel time (i.e., the travel time at zero flow).

3. The method of the estimation

First we will attempt to model the relationship between the flow and the travel time by fitting a linear equation (3) to observed data set.

$$t = a + bq. \tag{3}$$

The coefficients of the linear regression line (3) are estimated by the least square method

$$\hat{b} = \frac{\sum_{i=1}^{n}(q_i - \bar{q})(t_i - \bar{t})}{\sum_{i=1}^{n}(t_i - \bar{t})^2},$$

$$\hat{a} = \bar{t} - \hat{b}\bar{q},$$

where $\bar{q}$ and $\bar{t}$ are the sample means of the flow (q) and the travel time (t).
In the model of BPR the parameters can be estimated by using a linear regression if a logarithmic transformation is used on the data set. First we order the equation (1)

$$\frac{t - t^0}{t^0} = \alpha\left(\frac{q}{C}\right)^{\beta},$$

next we use logarithmic transformation

$$ln\left(\frac{t - t^0}{t^0}\right) = ln(\alpha) + \beta ln\left(\frac{q}{C}\right).$$

Now if we introduce the following variable

$$v = ln\left(\frac{t - t^0}{t^0}\right),$$

$$u = ln\left(\frac{q}{C}\right),$$

then the coefficients of the linear regression line

$$v = \ln(\alpha) + \beta u$$

can be estimated by the least square method again.
Similarly we can transform the Davidson's model to linear regression model without the intercept term. We introduce the following variable

$$w = \frac{t - t^0}{t^0},$$

$$z = \frac{q}{C - q}.$$

Then the coefficients of the linear regression line

$$w = Jz \tag{4}$$

can be estimated by the ordinary least squares

$$\hat{J} = \frac{\sum_{i=1}^{n} q_i t_i}{\sum_{i=1}^{n} {t_i}^2}.$$

4. Microscopic simulation of the traffic

The traffic model used here is based on a microscopic simulation of movements of individual vehicles through a network. The essential property of our model is that the vehicles move in real time and that their space-time trajectories are determined by IDM car-following model, network controls such as stop on red and speed limit. The parameter values of the IDM were calibrated in [4].

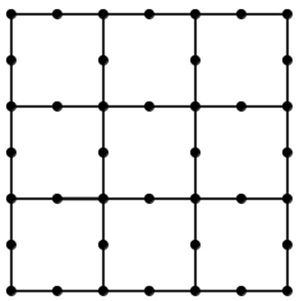

Figure 2. The Manhattan network.

In our Manhattan test bench start 12000 vehicles. We observe a 500 m long route with a signalized intersection on the end in the inside of the network. The cycle time of the traffic lights was 100 sec long, and the green time was 25 sec long. The departure of the intersection is 2.5 seconds per vehicle, so the capacity of the route was 360 vehicles per hour. The free-flow travel time can be computed by the following: the travel time is the sum of the average running time at zero flow level and the average time spent queueing at intersections, at that flow level. The average velocity of a car was 55 km/h, so it takes 32.73 seconds to drive the 500 m long route. If the arrival time at the intersection is a random time under the uniform distribution, then the average time spent queueing is

$$\frac{1}{4}\cdot 0+\int_0^{75}\frac{1}{100}t dt=28.125$$

seconds. That is the computed free-flow travel time is 60.855 seconds.
We measured the flow on the link in vehicle per hour and the average travel time in seconds. The result of the simulations is shown in Figure 3.

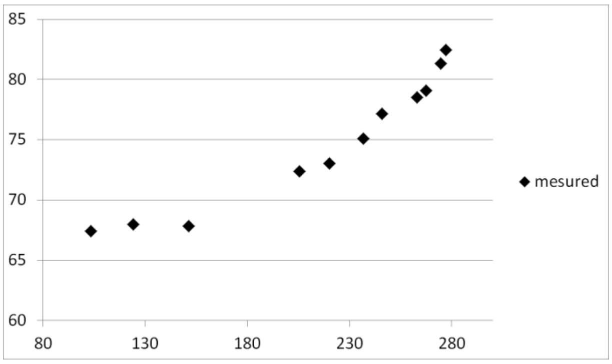

Figure 3. The measured data.

5. The estimation of link delay functions parameters

The estimated coefficients of the linear regression line are
$\hat{a}=56.7126,\ \hat{b}=0.0838,$
of BPR link performance function are
$\hat{\alpha}=0.4215,\ \ \hat{\beta}=1.2368,$
and Davidson's function is
$\hat{J}=0.1124.$
We fitted these link performance functions to our data set, as we see in Figure 4.

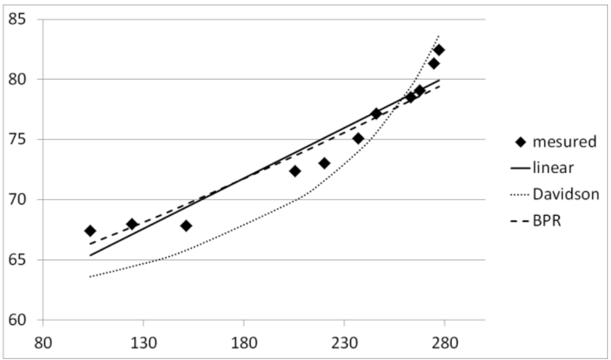

Figure 4. The fitted curves.

We computed all the three case the sample correlation coefficient (R) and the mean squared error (MSE) of the model. It was computed the correlation coefficient of the transformed sample in the BPR and Davidson's link performance functions.

Table 1. The value of R and MSE

	linear	BPR	Davidson
R	0.9565	0.9593	0.9944
MSE	2.3019	2.2266	4.5257

The correlation coefficient is very high in all three cases, moreover it is the best in the case Davidson's function, however the mean squared error is the greatest in this case. The correlation coefficient gives the quality of a least squares fitting to the data set, but the best line is not fitting on the pole (Figure 5), however in model (4) we required it.

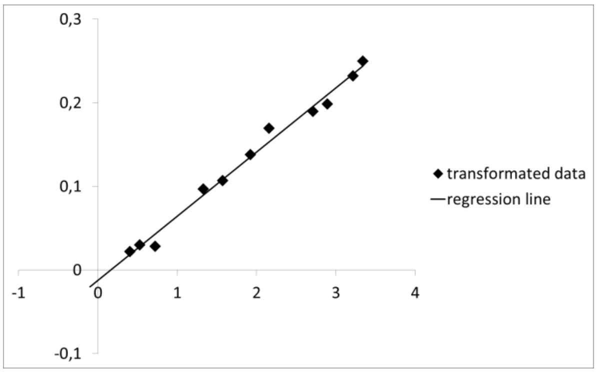

Figure 5. The best line to the transformed data.

We estimated the value of $\boldsymbol{t^0}$ by the least square method in model (2). That is we introduced the variable

$$z=\frac{q}{C-q}$$

and estimated the coefficients of the linear regression line

$$\boldsymbol{t}=\boldsymbol{t^0}+(\boldsymbol{t^0}\boldsymbol{J})\boldsymbol{z}.$$

The value of the estimated free-flow travel time and parameter *J* are
$\widehat{t^0}=65.184,\ \ \hat{J}=0.0777.$

The mean squared error of the new model is 0.2994. We can touch up the model of BPR by change the value of the free-flow travel time, but it requires other method to find the best.
Summarizing up we can use linear model in low flow and the Davidson's model close to the capacity.

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