Multiclass Traffic Assignment Problem with Flow-Dependent Passenger Car Equivalent (PCE) of Trucks

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Background and Objectives

INTRODUCTION

Although most multiclass traffic assignment models can capture the interaction between trucks and passenger cars, they assume that the Passenger Car Equivalent (PCE) value of truck is only flow-independent. However a large body of studies and the Highway Capacity Manual show that PCE values for trucks are a function of geometric parameters and truck flow

OBJECTIVES

- Develop fitting functions for flow-dependent PCEs of trucks based on the latest Highway Capacity Manual (HCM) 6th edition
- Formulate a multiclass traffic assignment model to describe the flow distribution of trucks and passenger cars across a general network
- Explore the properties of the proposed traffic assignment model

Fitting Functions for Truck PCEs

RELATIONSHIP BETWEEN PCEs AND PERCENT OF TRUCKS

It was found that the Power Function is able to describe the relationship between the percent of trucks and the PCE well, as reflected by the R^2 coefficients of determination pretty close to 1

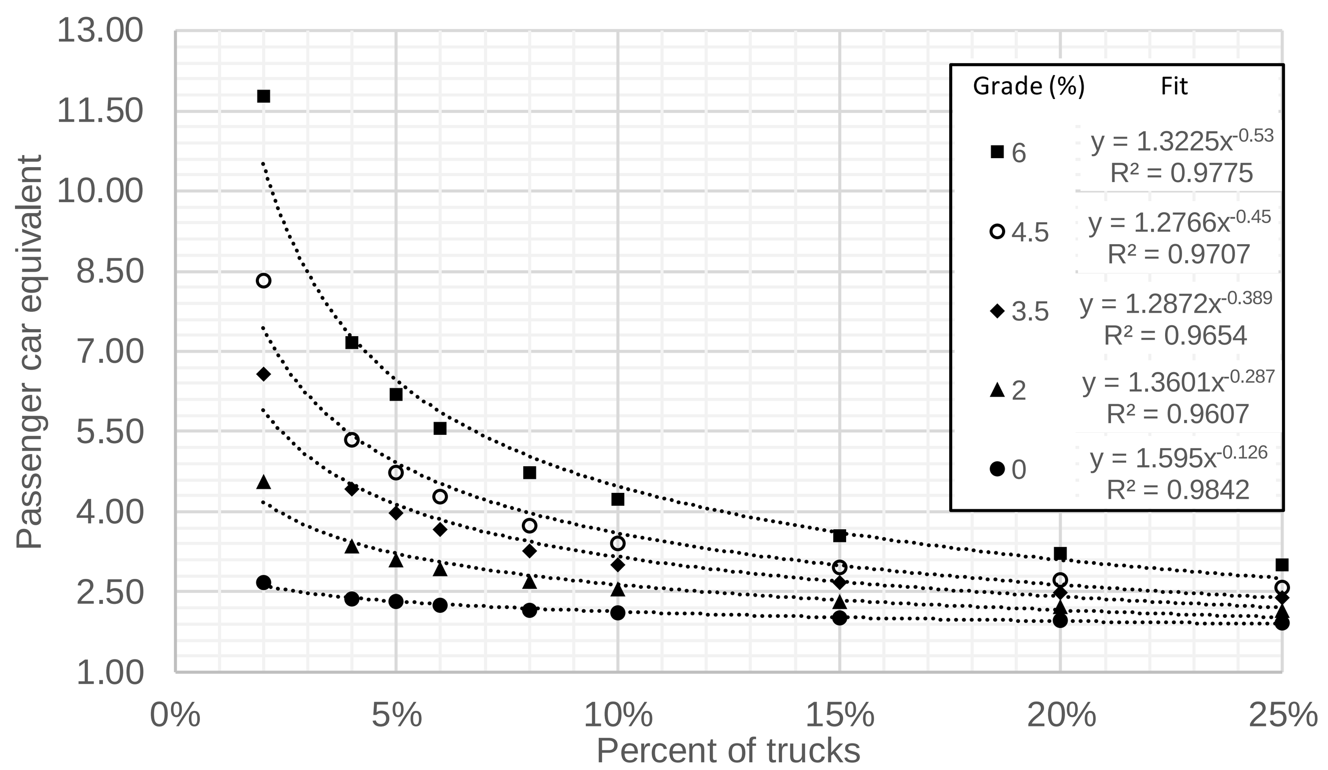


Figure 1. PCE of trucks for 0.875 mi grades in multilane segments

EXAMPLE DELAY FUNCTION, LEVEL TERRAIN

$$P_a^T = 1.595\left(\frac{v_a^2}{v_a^1+v_a^2}\right)^{-0.126}$$

$$t_a(x) = t_a^0\left[1+0.15\frac{(v_a^1+P_a^T v_a^2)^4}{c_a^4}\right]$$

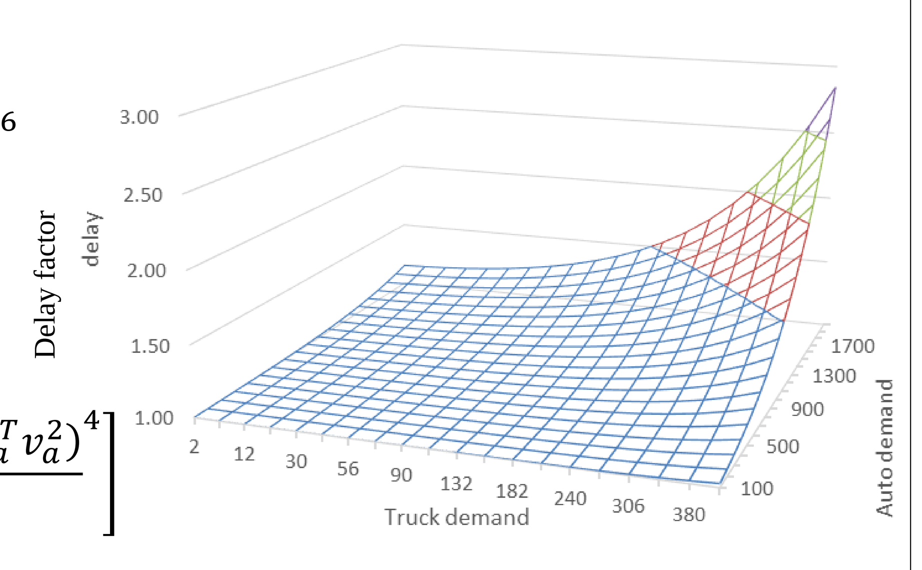


Figure 2. Modified BPR Function

$$t_a(x) = t_a^0\left\{1+0.15\left[\frac{v_a^1+1.595\dfrac{v_a^{2\;0.874}}{(v_a^1+v_a^2)^{-0.125}}}{c_a^4}\right]^4\right\}$$

Coefficients for each combination of grade and length

Multiclass Traffic Assignment

NETWORK EQUILIBRIUM CONDITION

$$\Delta x^{w,m} = E^{w,m} d^{w,m} \qquad \forall w \in W, m \in M \qquad (1)$$

$$x_a^{w,m} \geq 0 \qquad \forall a \in A, w \in W, m \in M \qquad (2)$$

$$x_a^m = \sum_{w \in W} x_a^{w,m} \qquad \forall a \in A, m \in M \qquad (3)$$

$$v_a = x_a^1 + \alpha_a (x_a^2)^{\beta_a}(x_a^1 + x_a^2)^{1-\beta_a} \qquad \forall a \in A \qquad (4)$$

$$t_a(v_a) \geq \rho_j^{w,m} - \rho_i^{w,m} \qquad \forall a \in A, w \in W, m \in M \qquad (5)$$

$$\left[t_a(v_a) + \rho_i^{w,m} - \rho_j^{w,m}\right] x_a^{w,m} = 0 \qquad \forall a \in A, w \in W, m \in M \qquad (6)$$

VARIATIONAL INEQUALITY MODEL

The network equilibrium conditions (1)-(6) are equivalent to finding $x^* \in \Lambda$ that solves the following VI:

$$\sum_m \sum_w \sum_a t_a\left[\sum_{\hat{w}} x_a^{\hat{w},1^*} + \alpha_a\left(\sum_{\hat{w}} x_a^{\hat{w},2^*}\right)^{\beta_a}\left(\sum_{\hat{w}} x_a^{\hat{w},1^*} + \sum_{\hat{w}} x_a^{\hat{w},2^*}\right)^{1-\beta_a}\right]\left(x_a^{w,m} - x_a^{w,m^*}\right) \geq 0, \forall x \in \Lambda$$

where $\Lambda = \{x\}$, satisfying constraints (1) and (2).

NON-UNIQUENESS PROPERTY

The cost increases when truck flow disperses

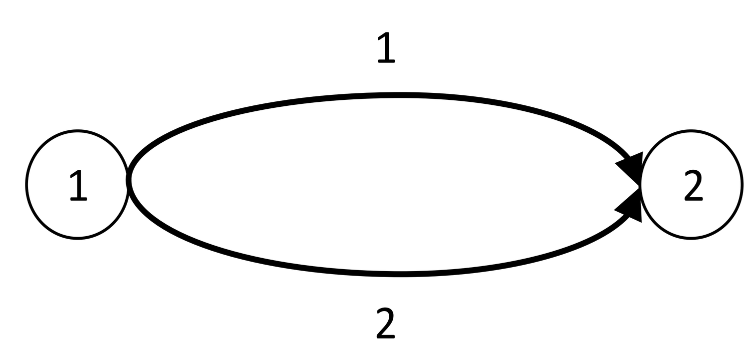


Figure 3. A Toy Network

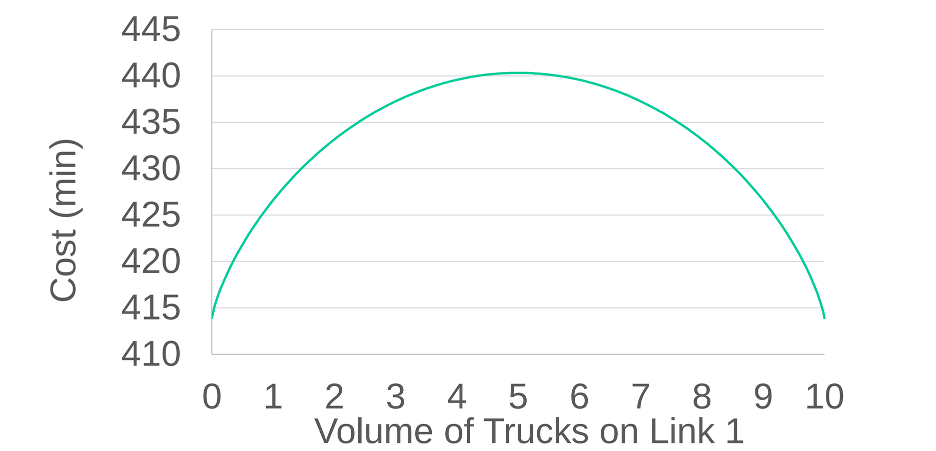
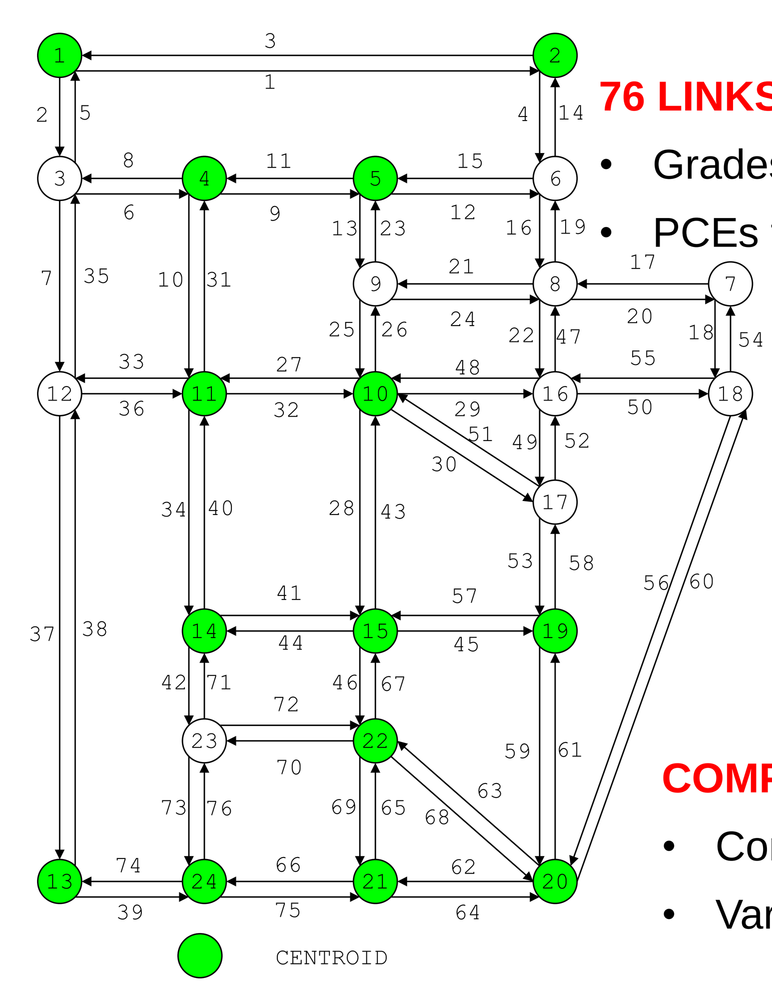


Figure 4. Social costs for different equilibrium patterns

Numerical Example and Discussion



76 LINKS, 24 NODES

- Grades set to 3.5%
- PCEs from 2.2-3.4

COMPARISON

- Constant PCEs
- Variable PCEs

Figure 5. Sioux Falls network

Discrepancies as large as 12.8%

VARIANCE OF LINK FLOW DISTRIBUTION

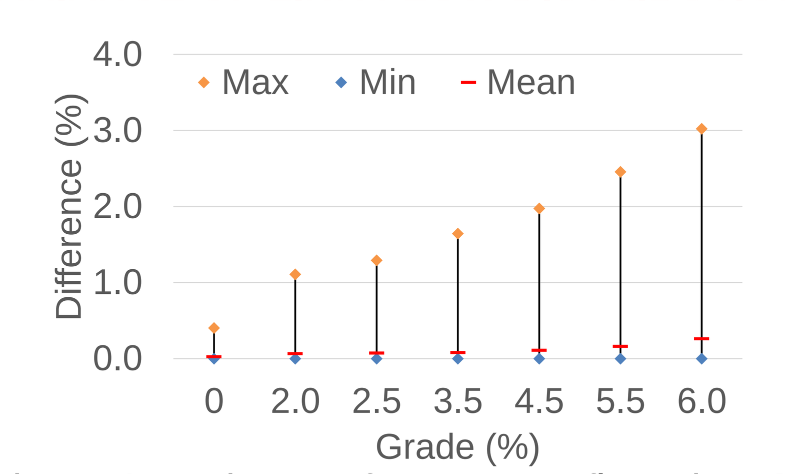


Figure 6. Variance of aggregate flows in PCE

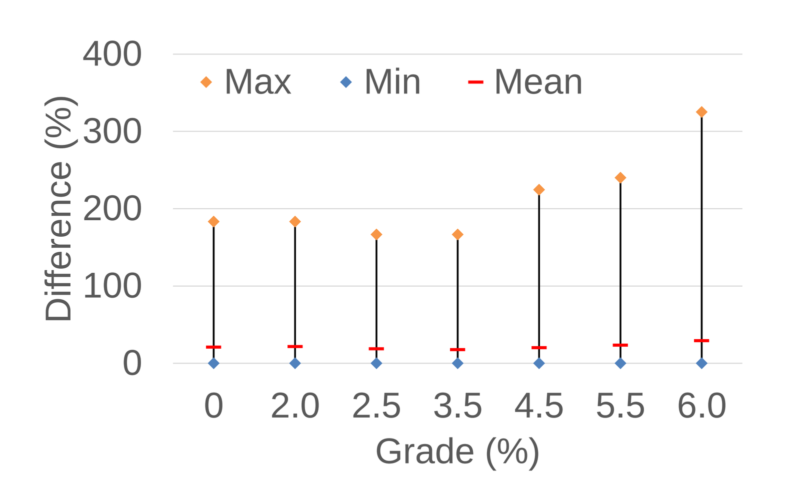


Figure 7. Variance of truck flows

Finding pricing schemes to optimize a point measure

Let $\boldsymbol{\tau}$ be a given vector of tolls. Solving the following problem provides an estimate of the largest system delay, $\Psi_{max}(\boldsymbol{\tau})$, induced by $\boldsymbol{\tau}$:

$$\Psi_{max}(\boldsymbol{\tau}) = \max_{x,v,\rho} \sum_{a \in A} t_a(v_a) \sum_m x_a^m$$

s.t. (1)-(4)

$$t_a(v_a) + \tau_a^m \geq \rho_j^{w,m} - \rho_i^{w,m} \qquad \forall a \in A, w \in W, m \in M \qquad (7)$$

$$\left[t_a(v_a) + \tau_a^m + \rho_i^{w,m} - \rho_j^{w,m}\right] x_a^{w,m} = 0 \qquad \forall a \in A, w \in W, m \in M \qquad (8)$$

1. Minimize the largest social cost: $\boldsymbol{\tau}^* = argmin\{\Psi_{max}(\boldsymbol{\tau}): \boldsymbol{\tau} \in \Gamma\}$
2. Minimize the smallest social cost: $\boldsymbol{\tau}^* = argmin\{\Psi_{min}(\boldsymbol{\tau}): \boldsymbol{\tau} \in \Gamma\}$
3. Minimize the "most-likely" social cost:

- $\boldsymbol{\tau}^* = argmin\left\{\sum_{a \in A} t_a(v_a^*) \sum_m x_a^{m*} : \boldsymbol{\tau} \in \Gamma; (\boldsymbol{v}^*, \boldsymbol{x}^*) = \right.$

Conclusions and Recommendations

- We proposed the use of power functions fitted to the discrete PCE values presented in the latest HCM (6th edition)
- The equilibrium link flow distribution for the VI formulation was proved to exist but may not be unique, impacting the social cost
- Taking the congestion pricing design problem as an example, several approaches were provided to deal with such impact
- We recommend that the additional impact of truck flow on link and signalized intersection capacity proposed by the HCM 6th edition

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