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van der Gun, Jeroen; Pel, Adam; van Arem, Bart

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Travel Times in Quasi-Dynamic Traffic Assignment

Jeroen P.T. van der Gun, Adam J. Pel, and Bart van Arem

Abstract

By extending static traffic assignment with explicit capacity constraints, quasi-dynamic traffic assignment yields more realistic results while avoiding many disadvantages of dynamic assignment. We analyse the computation of travel times in quasi-dynamic assignment models.

We formulate and check requirements for the correctness of resulting travel times, addressing both the calculation of travel times for individual routes and links itself, as well as the differences between travel times of different travel choices. We demonstrate that existing approaches for travel time computation in literature fail to satisfy all requirements and derive a new link travel time formula from vertical queuing theory that does meet all requirements.

We discuss expected changes to assignment results and methodological advantages for pathfinding and model extensions, including horizontal queuing. The new link travel time formulation is finally applied to three example scenarios from literature.

		Absolute Correctness			Relative Correctness		
		I. Corridor Compatibi-lity	II. Route is Sum of Links	III. Steady State Consist-ency	IV. Correct Derivati-ves	V. First-In-First-Out	VI. Stops have No Effect
STA	BPR (1964)	✗	✓	✓	✗	✓	✓
QDTA	Bakker et al. (1994)	✗	✓	✓	✗	✓	✓
QDTA	Lam and Zhang (2000)	✗	✓	✓	✗	✓	✓
QDTA	Bundschuh et al. (2006)	✓	✓	✗	✗	✓	✓
QDTA	Gentile et al. (2014)	✗	✓	✓	✗	✓	✓
QDTA	Bliemer et al. (2014)	✓	✗	✗	✗	✗	✗
QDTA	Nakayama and Connors (2014)	✗	✗	✗	✗	✗	✗
QDTA	Brederode et al. (2018)	✓	✓	✗	✗	✓	✓
QDTA	Our formulation	✓	✓	✓	✓	✓	✓
DTA		✓	✓	✓	✓	✓	✓

Formula requirements

Requirements for Absolute Correctness ensure a valid composition of the travel time calculation for individual routes and links.

I. Corridor Compatibility: travel times on a corridor network are compatible with queuing theory calculations.

II. Route is Sum of Links: the travel time of a route equals the sum of travel times of the links along the route.

III. Steady State Consistency: link travel times are based on both instantaneous traffic propagation and homogeneous traffic composition, or on neither.

Requirements for Relative Correctness ensure a valid comparison between travel times of alternative routes or alternative demand patterns.

IV. Correct Derivatives: in case of a link with a fixed exit capacity, the partial derivatives of the link's travel time with respect to both the link's demand and the link's flow have the correct sign.

V. First-In-First-Out: route travel times respect the first-in-first-out property of links: it is not possible to leave a link earlier by entering it later.

VI. Stops have No Effect: insertion of intermediate stops in a route cannot change the route's travel time (other than the time spent stopped).

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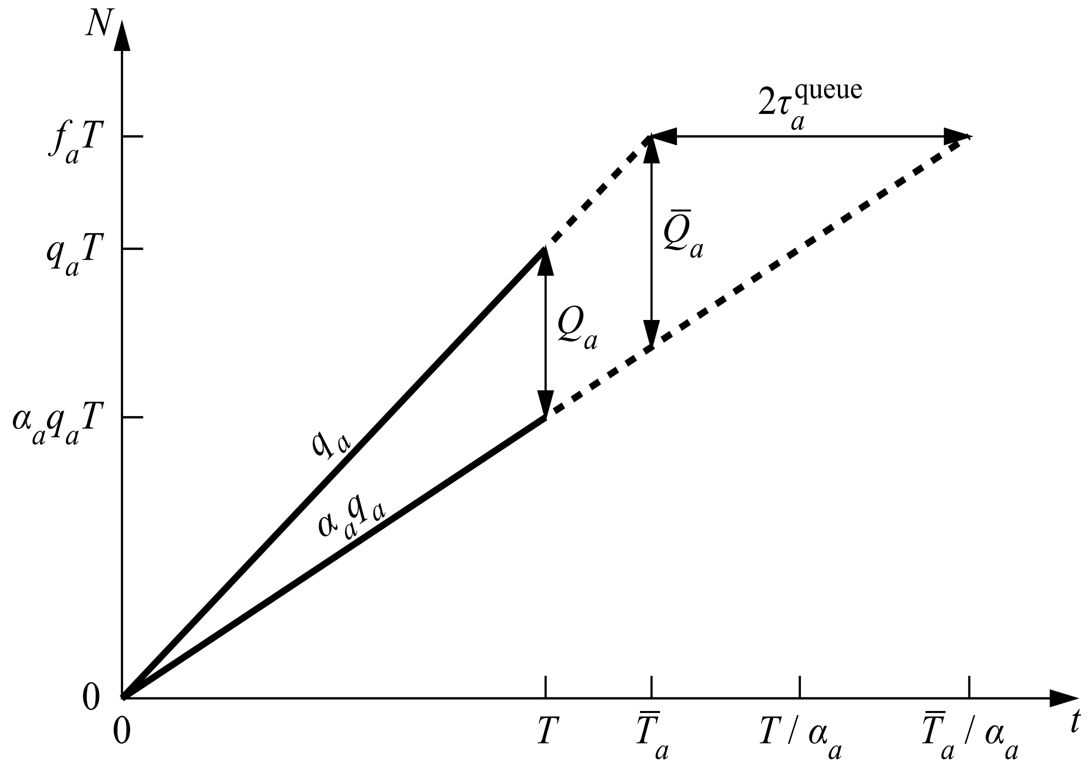
Jeroen P.T. van der Gun
Dept. Transport & Planning
Delft University of Technology
The Netherlands
J.P.T.vanderGun@tudelft.nl

New travel time formula derivation

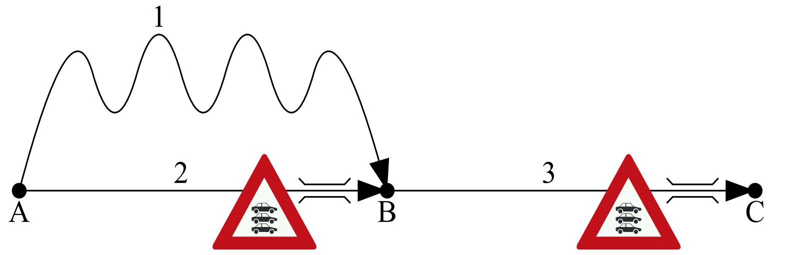


τ_a	Travel time of link a
τ_a^{ff}	Free-flow travel time
$\tau_a^{\text{queue}} \geq 0$	Queuing delay
$f_a > 0$	Traffic demand
$q_a \in (0, f_a]$	Link inflow
$\alpha_a \in (0,1]$	Outflow-to-inflow ratio
$T > 0$	Study time period duration
$Q_a = (1-\alpha_a) q_a T$	Queued vehicles at time T
$\bar{T}_a = \frac{f_a}{q_a} T$	Time last vehicle enters
$\bar{Q}_a = (1-\alpha_a) f_a T$	Maximum queued vehicles

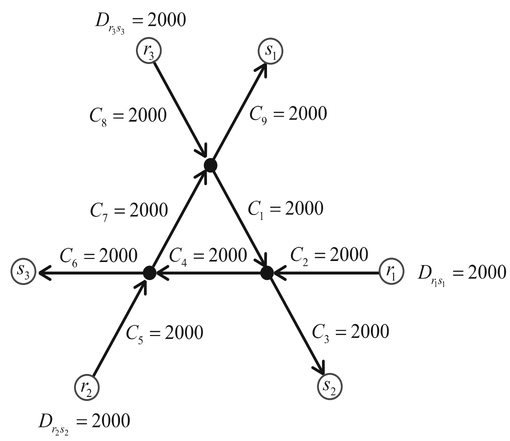
$$\tau_a = \tau_a^{\text{ff}} + \tau_a^{\text{queue}}$$

$$\tau_a^{\text{queue}} = \frac{f_a}{q_a}\left(\frac{1}{\alpha_a} - 1\right)\frac{T}{2}$$

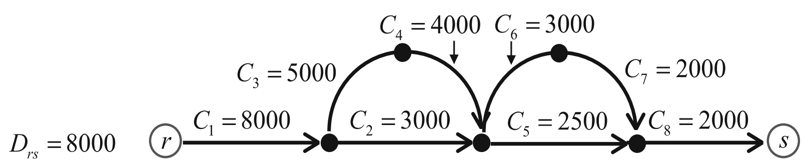
Test network for requirements V-VI



Example scenarios from literature



Bliemer et al. (2014)
network loading example



Bliemer et al. (2014)
stochastic user-equilibrium example

Brederode et al. (2018)
network loading example with spillback

Conclusions

- We derived a new formula for link travel times in quasi-dynamic assignment, theoretically underpinned with vertical queuing and instantaneous propagation of traffic flows.
- We showed that existing travel time computation procedures violate requirements for both the absolute correctness and relative correctness of the resulting travel times.
- We demonstrated that our own proposed definition of link travel times does satisfy all requirements and can be used to substitute the Bliemer et al. (2014) formulation. In networks with only diverges, both formulations yield identical results.

Further advantages

- Consistent travel times for public and demand-responsive transport.
- Congested link travel times usable for pathfinding and fleet dispatching algorithms.
- Horizontal queuing extension possible based on fundamental diagram, that can be applied with quasi-dynamic flow propagation methods with spillback like Raadsen and Bliemer (2018).
- Further extensions to the quasi-dynamic model easier than in dynamic and static models:
  - Stationary queues for traffic lights as additional delay.
  - Traffic control responsive to average traffic flows in studied time period, such as signalised intersections, lane management, or variable speed limits.
  - Different travel times for different vehicle classes, such as trucks, public transport, or automated vehicles.
- Faster convergence of equilibrium assignments.

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