Modelling the impact of unreliability on passengers' strategy choice in public transport networks - utilising the hyperpath concept

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Abstract:

Reliability can be defined as the notion of repetition or regularity (Bates et al., 2001). Reliability, in public transport is considered as one of the major attributes of a transit service (Yin et al., 2004, Balcombe et al., 2004). In transport system, 'total travel time' forms a crucial element while dealing with reliability, wherein the total travel time comprises of :- walk from origin, walk to destination, waiting for a service and in-vehicle travel time (Ceder, 2007, Bates et al., 2001). As the measure of reliability is closely related to statistical variance (Bates et al., 2001) 'total travel time' variance assumes significance. The necessity to model total travel time variance can be explained as *firstly* due to passengers being sensitive to the consequence of variance in total travel time which may result in late arrival at the destination, longer waiting time at the bus stops, missed connections at the transfer points(Bates et al., 2001). These consequences can be analysed by passengers choosing amongst the alternative lines arriving at a bus stop which are characterised by the generalised cost function which includes schedule delay, travel time cost etc(Bates et al., 2001). *Secondly* due to passengers having a value on the variability independently of the consequence at the origin/destination such as the increased stress associated with unreliability, which can be analysed by modelling passenger route choice from alternatives characterised by not just the components of generalised cost but also an additional term related to variability of 'total travel time' usually taken as standard deviation/variance of the total travel time distribution (Bates et al., 2001). These two approaches can be termed as the first being a 'scheduling approach' and the second being 'mean – variance approach'(Noland and Polak, 2002).

The inclusion of reliability as a route choice attribute in transit assignment is often characterised by the generalised cost having a parameter to quantify the 'impact on limitations of timings' (departure time constraint / arrival time constraint) e.g. 'scheduled delay'. The revised generalised cost including the time constraint components has been used in several transit assignment problems adopting schedule based network representation. In a network wherein the lines arrivals are not governed by schedules frequency based transit assignment is utilised. Route choice of passengers under the influence of reliability has been included in a 'non-scheduled' network and has been studied using the 'route-section' approach proposed by (De Cea and Fernández, 1993), in(Szeto et al., Szeto et al., 2011). The present paper aims to employ the 'mean-variance' approach to model reliability based

generalised cost and will utilise the 'hyperpath/strategy' concept in frequency based transit assignment models.

The 'hyperpath' approach in frequency based transit assignment is based on assigning the passenger flows to the 'shortest hyperpath'. For an exponentially distributed headway and random arrival of passengers the cost function is given as in equation (1)

$$C_i = \begin{cases} 0 \; if \; i = o \\ C_j + c_{ij} \; if \; i \notin B \\ \left(\left(\sum_{j \in T_i} \varphi_{ij} C_j\right) \Big/ \sum_{j \in T_i} \varphi_{ij} \right) + 1 \Big/ \sum_{j \in T_i} \varphi_{ij} \; if \; i \in B \end{cases} \qquad \text{eq(1)}$$

Where i- Nodes in the network
o – Origin node
c_{ij} – Cost of the arc connecting nodes i and j
C_j- Cost associated with node j
φ_{ij}- Frequency associated with arc connecting nodes i and j
T_i- Nodes belonging to the forward nodes set.
B- Bus stop node.

The present paper will modify the cost function to include reliability using the 'mean-variance' approach as shown in equation (2):

$$C_i = \begin{cases} 0 \; if \; i = o \\ C_j + c_{ij} \; if \; i \notin B \\ \left[\left(\left(\sum_{j \in T_i} \varphi_{ij} C_j\right) \Big/ \sum_{j \in T_i} \varphi_{ij} \right) + 1 \Big/ \sum_{j \in T_i} \varphi_{ij} \right] + \left[\tilde{\beta} \; std.dev \left(1 \Big/ \sum_{j \epsilon T_i} \varphi_{ij} \right) \right] if \; i \in B \end{cases}$$

eq (2)

Where $\tilde{\beta}$ - Reliability ratio – the measure of variability to the expected value.

Equation (2) will be utilised to derive an algorithm to compute the 'shortest hyperpath'. (Nguyen and Pallottino, 1988) indicate that the algorithm used to compute 'shortest hyperpath' essentially embeds the 'attractive line set' algorithm. Hence the paper will evolve an algorithm to identify the 'attractive line set' based on the costs given in equation (2) and will explore to see if there is any variation in the attractive line set due to the revised cost shown in equation (2).

The proposition essential to the efficient solution of the algorithm used to compute the shortest hyperpath indicates that the determination of current optimum subset of boarding arcs at stop node as given in equation (3) results in a 'greedy algorithm'(Nguyen and Pallottino, 1988).

$$\left(\left(\sum_{j \in T_{i*}} \varphi_{ij} C_j\right) \Big/ \sum_{j \in T_{i*}} \varphi_{ij} \right) + 1 \Big/ \sum_{j \in T_{i*}} \varphi_{ij} = \min_{T_i \subseteq N_i^+} \left\{ \left(\left(\sum_{j \in T_i} \varphi_{ij} C_j\right) \Big/ \sum_{j \in T_i} \varphi_{ij} \right) + 1 \Big/ \sum_{j \in T_i} \varphi_{ij} \right\} \quad \text{eq (3)}$$

The paper will hence seek to understand if under the revised cost function given in equation (2) the proposition given in equation (3) will hold. The limitation of assuming exponential distribution is that the waiting times of certain passengers are unrealistically high hence studies such as (Marguier and Ceder, 1984, Bouzaïene-Ayari et al., 2001, Gentile et al., 2005) proposed to utilise Erlang distribution of headways. The paper will also further modify the cost function given in equation (2) to model Erlang distribution of headways and formulate an algorithm for identifying the 'shortest hyperpath' using the same.

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