Effects of Transit Real-Time Information Usage Strategies

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# ABSTRACT

Real-time information is becoming increasingly available to transit travellers. This paper discusses the effects of RTI available before the start of a journey in terms of line loads as well as passenger benefits. We consider that it can affect the choice of departure time and stop as well as the route choice. Two types of travellers with access to RTI are distinguished: Travellers who want to arrive at their destination as soon as possible and passengers who prefer to stay slightly longer at their current location if this can reduce their travel time. For illustration we use a network with irregular service arrivals and take the optimal strategy approach of Spiess and Florian as a benchmark for passengers without RTI access. We find that, as expected, travellers without RTI travel longer but also that particular combinations of traveller strategy and RTI provision lead to counterintuitive effects. We further illustrate that the two strategies of the RTI access travellers can lead to significant differences in loads. Implications for demand management are discussed.

Keywords: Public Transport Real Time Information, Route Choice Strategies, Simulation

# 1. INTRODUCTION

Nowadays transit users are supported more and more by real-time information (RTI) systems. These include countdowns at stops and web-based resources which can be accessed also through mobile phones and other hand-held personal devices. RTI affects the perception of the system and therefore the decision making process and the way the network is used. So far research has mainly focused on evaluation of user benefits and on impacts on ridership (see research.onebusway.org for an up-to-date list of contributions). The influence on route choice is less known and a comprehensive evaluation of the value of RTI from the point of view of network operators is lacking.

Passengers in transit networks often face complex departure time and route choice decisions. They have to judge whether timetables, if available, can be trusted and whether transfer times might be sufficient. This might influence the decision of the departure time from home, the choice of the origin and destination stop, as well as the choice strategy at each stop. There is much literature on the choice strategies of passengers at stops, but to our knowledge, far less on the other two above mentioned choice dimensions, departure time choice and stop choice, in connection with RTI.

Billi et al *(1)* discuss that the incorporation of information at stops, even just observation of elapsed time, can lead to more precise estimation of travel times and more complex strategies. Using simulation and a small scale example Hickman and Wilson *(2)* and Gentile et al. *(3)* discuss that the reduction of the average travel time (and of its variability) due to the availability of real time information on departure times is minor even for information with high accuracy level. However, they find the information may affect route choice significantly. Considering that the availability of information may make different stops/platforms attractive Nökel and Wekeck *(4)* confirm the impact of information on route choice and demonstrate that it can generate remarkable reduction of mean journey time. Also Cats et al *(5)* study the effect of RTI on traveller’s decision making through an agent based simulation. They also find that RTI can significantly reduce travel time of passengers and discuss that this can help operators to establish the economic value of implementing an RTI system network wide or at specific locations.

In the transit assignment literature in general frequency-based and schedule-based approaches are distinguished. The former is more useful for strategic planning and assumes that passengers split over “attractive lines” according to service frequency. Schedule-based approaches instead aim to take service details such as irregular headways into account when assigning passengers to routes (see e.g. *(6)*). A third assignment method is the “simulation based approach” in which single passengers are simulated and loaded to buses as in *(5)*. Aggregate results might though reflect the schedule-based approach.

We firstly note that without a precise timetable and RTI information and assuming (or fearing) that the service is very irregular also a single passenger can only make a decision according to the perceived service frequency *(4)*. Schmöcker et al *(7)* therefore describe the choice at bus stops with few information as a game where the risk averse passenger will include all lines in the choice set that potentially minimise the travel time. They show that this strategy is identical to the one proposed by *(8)* (referred to as S&F hereafter) which is still the basis for many assignment models. Taking the set of attractive lines at all stops the passenger might traverse together leads to the notion of hyperpaths *(9)*.

In contrast, with RTI the decision making process shifts towards a “schedule-based” approach. This means that the objective pursued by the decision maker may be different from “minimise the expected travel time”. Rather a range and/or combination of additional objectives may be considered such as “arrive as soon as you can”, “maximise the productive time – i.e. time which can be spent for activities different from travelling” and so on. In particular the concept of “maximising productive time” seems to be neglected in the transit route choice literature. Our hypothesis is that this leads to significantly different assignment results.

In general, we presume that the availability of RTI leads to higher loads on faster lines as passengers will have better information to time their arrival at bus stops according to the departure of such lines. In addition RTI will further “stretch” the hyperpaths considered by transit users. This means that passengers might consider additional stops in their choice if it happens that an infrequent service is departing from there. Similarly, at a particular stop, if the available lines are split between different platforms or adjacent bus stops passengers will become more flexible in their choice of which queue to join.

The reminder of the paper is organised as follows. The following section describes our methodology. We utilise a simulation approach to simulate passengers using three different strategies. Two groups have access to RTI whereas the third group does not. Our focus in this paper is to provide a detailed discussion on the impact of these strategies on the three travel decisions (departure time, stop choice, route choice) with an illustrative example. In section 3 we describe the effects of this approach for the same network that S&F used to describe the optimal behaviour of passengers without access to information except for average service frequency. In Section 4 we extend the network to be able to describe the effect of “hyperpath stretching”. We repeat the same simulation as for the original network and discuss some differences. Section 5 summarises this study by drawing conclusions and discussing implications for transit operators.

# 2. SIMULATION APPROACH

## 2.1 Transit Networks

The effect of RTI availability has been studied using the example network used in the S&F paper (referred to as SFNet in the following). For illustration purposes in some of the following examples we only add a fifth line and refer to this as “Extended Network” (ENet). The additional line will help us to better illustrate the effect of hyperpath stretching.The topology of two networks and the characteristics of the lines are illustrated in FIGURE 1. The origin (Z1) is connected by walking links to stop A and in ENet additionally to stop E. The destination (Z2) can be reached from stop D and in the ENet from stop G as well. A unidirectional walking link connects stops C and F in ENet. In line with the results presented in S&F, it is assumed that the travel time of the walking links connecting the origin and the destination to the transit lines is nil.

**<Figure 1 about here>**

## 2.2 Headway Distributions

RTI (compared to published timetables) is of value if there is uncertainty in the network. For comparison with the well-known S&F case a situation is simulated in which on board travel times are deterministic and constant whereas the dispatching time of services from the depot is assumed stochastic. This leads to the same headway distribution for all stops along a line. The simulation might reflect conditions of BRT, metro services or of conventional bus services in which the link travel times are fairly constant over certain periods such as in non-peak times. The presence of random travel times would increase benefits accrued by the travellers using RTI. We assume headways independently distributed according to exponential distributions with mean equal to the average values reported in Figure 1. A Monte Carlo approach has been adopted to simulate the randomness of departure times *(10)*. Each run of the Monte Carlo simulation is defined by a particular realisation of timetables.

## 2.3 Time Expanded Networks

Earliest arrival journeys are identified through shortest path searches on time expanded networks (TENs) reproducing the particular realisation of travel times of a run. Each node in a TEN has two labels: the physical zone or stop where the “event” it represents takes place, and the time stamp of the event itself. For each run a set of nodes is generated representing the arrival and the departure of the service at each stop served by the line (FIGURE 2). The departure times from the initial stop of each line are randomly extracted in each run. The number of runs is such that each line is available in all of the 60 simulated minutes. The time of the following arrival and departure nodes are determined knowing the travel time of the line along the considered segment and the dwelling time at each stop. A departure node is connected to the following arrival node by a link, an arrival node to the following departure by a dwelling link. Departure nodes at the entry stops (A and E) are preceded by walking links. The time stamp of the tail nodes of such links are set equal to the random departure time of the run minus the walking time. At each stop the arrival and departure nodes of each line are connected to transfer nodes by alighting and boarding links respectively. Transfer nodes are connected to other transfer nodes with the closest higher time stamp at the same stop by a waiting link. Where two stops are connected by walking links, a walking link is created for each transfer node corresponding to arrivals/departures leading to a newly created transfer node at the head stop. The time stamp of this node is calculated using the cost of the walking link. Connectors are added to link the demand zones to the transport network. The origin is connected with the tail nodes of the walking links leading to the departure nodes. The destination is connected with the transfer points of the exit stops (D and G). For comparability with S&F results, alighting, boarding and dwelling durations are assumed equal to zero. The figure below shows the typical TEN configuration generated at stop C for one service of L3.

## <Figure 2 about here>

## 2.4 Decision Making Approaches

Three different decision making approaches have been considered. In two of them, referred to as “Busy (4)” and “ASAYC”, the decision maker is supposed to know the schedule of the lines in that run by consulting RTI. In the third, “Strategic”, s/he only knows average headways. Traditionally, it is assumed that travellers only consult journey planners for services with low frequency (generally less than 4-6 runs per hour). However, it seems reasonable to assume that passenger will take advantage of ubiquitous RTI also when frequency is high with increasingly easily access, especially through advanced smart phone technology. This reinforces our earlier statement that RTI causes a shift from frequency-based to real time schedule-based decision making.

In Busy (4) the decision maker knows the following four earliest arrival journeys, where “journey” is used to designate a path in the time expanded network. This strategy is chosen to reflect the typical information provided by journey planners, which often give a list of the next possible connections to the destination. The number four is chosen as this is the typical minimum number of options presented by for example the *Transport for London* journey planner ([www.tfl.gv.uk](http://www.tfl.gv.uk)). The decision maker then selects among these four the option with the shortest travel time. Travel time is defined as the time elapsed from the departure of the first used line to the time he arrives to destination. He is assumed to leave from the origin of his journey at the latest moment which allows him to board the service he has chosen. The difference between the time at which the traveller consults the information and that at which he leaves the origin is called “saved time” in the following. The approach can be considered typical of a person who is busy both at the origin and at the destination, and hence he aims to reduce as much as he can the travelling time without delaying excessively the arrival at the destination.

In ASAYC (As Soon As You Can) the only goal of the decision maker is to get to the destination at the earliest time regardless of travel times. Therefore he (knows and) chooses the next earliest arrival journey. Also in this case he leaves the origin at the very last moment ensuring that he can take his intended service and therefore might still have some saved time compared to the traveller without information.

In Strategic the traveller does not have access to RTI i.e. the actual schedule of the service in the specific run. Therefore the choice can only be based on expected travel time and it is not possible to distinguish between earliest arrival connections and shortest connections. It is assumed the decision maker leaves immediately from the origin and adopts the “take whatever attractive lines” approach considered by S&F. Note that, applying the route choice algorithm of S&F, L5 is not attractive for the traveller without RTI. Therefore, he only uses the SFNet portion of ENet.

Clearly different, more complex, strategies are conceivable and could be generated by different cost functions. For example, it is likely that passengers consider fares, transfer penalties, seat availability and/or different decision processes such as consideration of RTI in connection with previous experience. Furthermore, decisions may be subject to particular constraints such as that some passengers might be captive to a subset of lines or specific departures times because of ticket validity. Considering such additional factors would reduce the impact of RTI: e.g. if the traveller aims to minimize the arrival time but he can only use certain lines because of his tickets, he will have smaller chances to select a trip using RTI different from that he would choose without RTI (e.g. he might be able only to choose a different departure time).

## 2.5 Simulation Parameters

1,000 simulation runs have been carried out for both networks. In every run the distribution of the demand among the different lines has been calculated under each decision making approach. A unitary demand from Z1 to Z2, uniformly distributed over 60 min has been assigned using time steps of 1 min.

As strategic travellers have no additional information they arrive uniformly distributed at the departure stops. This is though not the case for the two groups of travellers with RTI. For these travellers it is the decision to travel and accessing the RTI that is uniformly distributed whereas the arrival at the departure stop coincides with the departure time of the chosen services. The 60 minutes for which the results are collected are preceded by 20 simulated minutes for the warm-up of the simulation to ensure that all lines are available also to the earliest fractions of demand.

# 3. S&F NEWORK (SFNET) RESULTS

## 3.1 Monte Carlo Simulation

The simulations were run using MATLAB 2013a. Altogether, the 1,000 runs for each of the three decision making approaches the simulation of SFNet requires around 12 min on a Intel® Core™2 Duo CPU E8400 at 3.00 GHz with 2 GB RAM. Precision (spread of results around the mean) and accuracy (in terms of difference between S&F and our results) of the simulations are good: e.g. under the Strategic decision making approach the 95% CI of the mean travel time is [26.91, 27.06] and that of the share of L1 is [0.488, 0.507]. The convergence of the simulations as to loads is slower than for average travel times because the sensitivity of loads to actual schedules is higher than that of travel times (Table 1).

**<Table 1 about here>**

In other words, changes in the timetables may have small effects on the user costs but can lead to very different situations in terms of network usage. Clearly the effect of the variation of timetables is amplified if the travel behaviour is based on actual departure times. Therefore, we discuss results from a network usage as well as from a traveller utility perspective.

## 3.2 Network Usage

We illustrate the effect of RTI on line usage with FIGURE 3. In the upper part of the figure the bars represent the load of each segment (segments of the same lines are clustered) for different decision making approaches. From the loads the homogeneity of line usage with several segments can be derived, which we define as the ratio between minimum and maximum load of the line: e.g. under Busy (4) segment two carries 84% of the passengers, segment three 44%, therefore the homogeneity is 0.44/0.84=0.52. Low values of homogeneity point to unbalanced usage of lines and may suggest the need for redesigning the route. In the bottom part of the figure we show the average waiting time of passengers at the stops. The larger the size of the circles, the more passengers board at the stop. This stop-related information can be useful for operators, retailers, and publicity vendors, which may use it to decide where to locate their services.

**<Figure 3 about here>**

Busy (4) aims to minimising the travel time without delaying arrival time excessively. In comparison to the network usage generated by the Strategic (non RTI) traveller, passengers migrate from the slow L1 and L4 to L2 and L3. In particular Busy (4) induces a reduction in the load to 1/3 compared to the non RTI solution. L2 increases its maximum share (segment 2) by 2/3 and its usage becomes less homogeneous because at B half of the passengers travelling on segment 2 transfer to segment 4 (L3) which is faster than segment 3 (L2). L3 is used by very few persons without RTI access, but it becomes the second most used line here. In addition, in the Strategic solution segment 4 is not used at all whereas under Busy (4) the patronages of the two segments of the line are comparable. At stop C, although L3 is faster, there are twice as much passengers changing from L2 to L4 because L4 is much more frequent. However, the ratio of the shares of L4 and L2 is smaller than in the Strategic case because of the tendency to prefer fast lines induced by the availability of information. Note that there is no transfer of passengers from L3 to L4 because L3 is faster and the dwelling times have been set to 0 to reproduce the conditions of the S&F network. Clearly stop A is used by all passengers in all the decision making models but there is no waiting time for Busy (4) and ASAYC because in these strategies passengers arrive at the departure stop at the very last moment (boarding times are neglected to make the results comparable to those of the original S&F model). The different usage of lines is mirrored in a different usage of stop B, which is not used in the S&F solution but under ASAYC serves 40% of passengers and has the highest average waiting time under Busy (4).

In general, under ASAYC the usage of lines is in between those observed with Strategic and Busy (4). Compared to Strategic travellers, passengers tend to shift to faster lines as consequence of the availability of information but their tendency to reduce the travel time is limited by the goal of getting to the destination as soon as they can so that options with smaller waits can be attractive despite longer travel times. Compared to Busy (4), this means more passengers for L1 and less for L2 and L3. The load of L4 does not change much because there are fewer passengers arriving at stop C but the line captures more passengers from L3 in comparison to Busy (4) because the line frequency is more important in ASAYC. Similarly, the homogeneity of L2 usage slightly increases because segment 3 is relatively more attractive than under Busy (4). The homogeneity of L3 is constant because the line loses passengers to L2 between B and C, and to L4 between C and D. In ASAYC there are fewer boarders at stops B and C than in Busy (4). The average waiting time increases at stops B and C since travellers do not aim to minimize travel time.

## 3.3 User **Utility**

FIGURE 4 illustrates the results for the three passenger groups in terms of waiting, on-board and travel time for the three passenger groups. Costs (waiting and travel time) are illustrated with positive values, whereas benefits (saved time) are shown with negative values. We observe a travel time for Strategic passengers of 26.98 min, which is lower than the analytically derived value of 27.75 min by S&F. This is due to the time discretization in the simulation in which we round non-integer arrival times down to the nearest integer. The fact that services can only arrive at full minutes means that the probability that the more frequent lines arrive earlier is underestimated. Therefore in our example the line share of the more frequent but slower L4 is slightly underestimated leading to the reduction in the overall travel time.

The average journey time duration, i.e. from departure at Z1 to arrival at Z2 (and not from the time in which information is accessed for Busy (4) and ASAYC) is, as expected, maximum for Strategic, intermediate for ASAYC (22.37 min, -17% compared to Strategic) and minimum for Busy (4) (20.70 min, -23%). Busy (4) has the minimum overall travel time though it entails more waiting time (1.49 min) and transfers (0.84) than ASAYC (1.24 min and on average 0.61 transfers) which can be easily explained and summarised as follows: A more dynamic behaviour is needed to shorten the overall journey time. We further demonstrate that both the strategies using information are more “dynamic” than the Strategic one. The latter one only requires 0.50 transfers but with a higher waiting time of 3.51 min. The implication of this finding is that the effectiveness of information provision reduces if transfer penalties are introduced in the cost function and if there are factors increasing the reluctance of transit users to change, such as inconvenient stop layouts or disabilities.

Travellers have the chance to spend on average 7.65 min at home under Busy (4) and 3.28 min under ASAYC. Under Busy (4) and Strategic there are similar patterns of arrival times, with Busy (4) passengers arriving, on average, later. ASAYC passengers indeed arrive earlier as is expected given the objective of this strategy: 90% of passengers have arrived at the destination after 79.16 min, whereas the same threshold is only reached after 80.35 min and 82.49 min under Strategic and Busy (4) respectively. This illustrates that an accurate analysis of the RTI effect in terms of user benefits requires knowledge about user's strategic behaviour and trade-off between "saved" times and early arrivals.

**<Figure 4 about here>**

# 4. Expanded Network (ENet) Results

## 4.1 Motivation for ENet: Hyperpath Stretching

When RTI is not available, alternatives that do not serve the same platform or stop cannot be part of the same hyperpath for the Strategic traveller. This is because the strategy "Take whatever comes first" requires that the traveller can actually observe (and access) which line comes first. In our simulation it is assumed that stops A and E as well as C and F are not visible from one another and therefore lines departing from A and E, or C and F respectively, cannot be part of the same hyperpath (We note that the assumption regarding A and E is not consistent with the nil walking times from the origin to both of them. As mentioned, we had to retain it to allow an easy comparison with the S&F assignment in the absence of RTI). L5 is made up of two segments, with on-board travel times of 20 and 7 min and an average frequency of 2.5 min. Hypothesising exponential headways and uniform arrival of passengers as in S&F, the expected travel time of the line is 29.5 min. It follows that the line is not considered by the traveller at Z1 if RTI is not available because the expected travel time of SFNet is 27.75 min for the Strategic traveller without RTI. Analogously, L5 is not attractive at stop C because the expected travel time to the destination using it is 12.5 min whereas the set of the two original S&F lines has an expected travel time of 11.5 min.

## 4.2 Monte Carlo Simulation

The overall simulation time is about 33 minutes. The standard errors of the different output variable means are generally smaller than in the previous case: i.e. that of the mean travel time under Busy (4) is 0.040 against 0.055 for SFNet. Five runs are needed to reach a relative accuracy of 5% for this output, 339 for an accuracy of 1%.

## 4.3 Network Usage

Under Busy (4) L5 does not serve many passengers: Its busiest segment, 8, is used by 13% of the passengers, whereas segment 7 is used by only 4% (FIGURE 5). This is mainly because L5 is a slow line and Busy (4) is a bounded search of the shortest connection. The most used line is L2, which serves 65% passengers on segment 2 and 39% on segment 3. L2 and L3 show approximately the same homogeneity of usage, whereas the homogeneity of L5 is low.

**<Figure 5 about here>**

Two interesting observations regarding the split of passengers can be made that result from the addition of L5:

* In comparison with SFNet, the patronage of L1 increases (from 0.16 to 0.31) by attracting passengers from L2 (from 0.84 to 0.65). This can be explained by considering the decision making approach and the average headways of the lines: The frequency of L5 is more than twice than that of lines L1 and L2 (0.4 versus 0.0167 veh/min). This means that generally among the four next departures considered by Busy (4) on average (more than) two suggest L5. Since L5 is slower the travellers tend to prefer one of the remaining two options. However, the travellers are presented with fewer faster alternatives, therefore their capacity of selecting faster lines to minimise the travel time is reduced, which means that they choose L1 more frequently than in the case of the original S&F network.
* Secondly, the behaviour at stop C changes. Analogously to what happens in SFNet there is no transfer from L3. Stop C is the end of L2 so passengers traversing this stop must transfer. In the simulation 24% of them choose L3, 54% L4 and 22% L5. The latter two percentages might be surprising if one looks at the features of the lines: L4 and L5 have the same sum of travelling time: 10 minutes on board for L4, or 3 minutes walking plus 7 minutes on board for L5. However, L5 is more frequent so one would expect it to be chosen more often than L4. Instead L5 attracts not even as many passengers as L3 which is faster but much less frequent. This is a consequence of the search for the earliest arrival connection used in our simulation: We determine it by a simple forward-search Dijkstra algorithm on the time expanded network which stops as soon as the destination is reached. The path C-walking-F-L5-G-Z2 entails more nodes and links than C-L4-D-Z2 in the time-expanded network so it is explored always later than the other by the algorithm. The Dijkstra algorithm was coded so that when it compares two alternative subpaths to a node, if the path under analysis has the same cost as the current shortest path, the current shortest path is not updated. Therefore, the paths departing from C and including the walking link from C to F are never suggested by this “journey planner” when they have the same arrival time as those using L3 or L4. Note that this is not an error of the journey planner because the issue arises only when the two paths have the same arrival time and hence are both optimal. This example demonstrates that even the way in which information is coded and analysed may affect the usage of networks. A transit operator who is concerned that some lines will get overly used might be able to even out loads by changing the way some information is provided without increasing the costs for users.

For ASAYC passengers L5 attracts one fourth of passengers at the beginning of the journey, subtracting passengers from both L1 and L2 in comparison to SFNet. In this case minimising travel time is not an objective for the decision maker and L5 is chosen more often because it is slower but its average frequency is twice those of the concurring lines at A. L2 remains the busiest but its patronage reduces to 0.44 in the segment A-B from 0.61 in SFNet. The homogeneity of L2 usage slightly increases in comparison to Busy (4) but still segment 3 carries one third less than segment 2. Similarly, the homogeneity of use of L5 increases because of the higher patronage for segment E-G. Stop B is still the one with the highest average waiting time.

## 4.4 User Utility

As in SFNet, Busy (4) is the decision making approach with the smallest journey time (22.45 min) and Strategic that with the highest (FIGURE 6). Note that Strategic users keep using only SFNet so the results remain the same for this passenger group.

The above discussed “shadowing effect”, that fewer fast connections are “visible” to travellers due to the addition of L5, has also some negative consequences on user utility. Because of the reduced usage of the fast line at A, the average journey time in the network with five lines is higher than in SFNet, for both Busy (4) and ASAYC although under the latter the effect is smaller. The shadowing effect is reduced if the number of options presented to the traveller increases: the journey time for two options, i.e. Busy (2) is 23.94 min, for Busy (6) it is 21.42 min. Also the possibility of spending more time at the origin is reduced when the 5th line is added: the saved time is 3.48 min under Busy (4) and 1.43 min under ASAYC. More frequent choices of lines L1 and L5 decrease the number of transfers and the waiting time for both the strategies using information in comparison to SFNet. Passengers adopting Busy (4) travel longer with the addition of the fifth line but still they arrive at the destination earlier than in SFNet, due to the reduction in saved time: the 10th, 50th and 90th percentiles of the arrival times at the destination are 30.55min, 54.85min and 79.25min respectively in the former case; 31.99, 57.31 and 82.49 in the latter. The same holds for ASAYC: the percentiles are 30.19, 54.26, 78.44 respectively in ENet, versus 30.22, 54.66, 79.16.

**<Figure 6 about here>**

# 5. CONCLUSIONS

This study described the effect of real-time transit information on network usage as well as travel times of passengers. RTI can be used in different ways by travellers, we study two possible strategies namely to arrive as fast as possible and to minimise the time between origin and destination. We only consider time dimensions in the decision making processes to assess the maximum impacts that RTI availability can generate. Further, as a benchmark for optimal behaviour without RTI, we compare the two solutions to the optimal strategies approach proposed by S&F.

Our results show that even in relatively simple networks different combinations of RTI provision and traveller strategies lead to significantly different solutions. We find that RTI can reduce travel times for the S&F network by around 20% and on top of that allow the traveller to spend more productive time. From network management perspective we conclude that loads can significantly differ depending on available information and passenger strategy. Further, we observe that the way in which the RTI is elaborated and communicated can make differences and in some cases cause unexpected consequences: For instance we observe that adding a line to an existing network can increase the average travel time. We therefore deduce that travel demand can be influenced by small changes in the journey planner information display.

Our study can be extended in a number of ways. Limitations such as missing consideration of dwell times or ignoring the variation in bus run times have already been mentioned. Further, we assumed a very irregular service with exponential headway distribution. Current work investigates the effect of changes in reliability on the benefits of RTI. More studies are also needed to derive some general conclusions on the expected travel time savings. In particular larger networks should be analysed. For these also the convergence rate should be studied to check the implementation of the presented approach to real world cases. Different user cost functions and journey planning strategies should be explored. By obtaining data when users access RTI information in connection with GPS data or smartcard data tracking their behaviour, one might get more information on actual strategies used by passengers.

# References

1. Billi, C., G. Gentile, S. Nguyen, S. Pallottino, U. Pisa, and D. Informatica. Rethinking the wait model at transit stops. 1984, pp. 1–8.

2. Hickman, M. D., and N. H. M. Wilson. Passenger travel time and path choice implications of real-time transit information. *Transportation Research Part C: Emerging Technologies*, Vol. 3, No. 4, Aug. 1995, pp. 211–226.

3. Gentile, G., S. Nguyen, and S. Pallottino. Route Choice on Transit Networks with Online Information at Stops. *Transportation Science*, Vol. 39, No. 3, Aug. 2005, pp. 289–297.

4. Nökel, K., and S. Wekeck. Boarding and alighting in frequency-based transit assignment. *Transportation Research Record: Journal of TRB*, Vol. 2111, 2009, pp. 1–17.

5. Cats, O., W. Burghout, T. Toledo, and H. N. Koutsopoulos. Modeling Real-Time Transit Information and Its Impacts on Travelers’ Decisions. 2012.

6. Nuzzolo, A., and U. Crisalli. The Schedule-Based approach in dynamic transit modelling: A general overview. In *Schedule-Based Dynamic Transit Modeling: theory and applications* (N. H. M. Wilson and A. Nuzzolo, eds.), 2004.

7. Schmöcker, J., and M. Bell. A game theoretic approach to the determination of hyperpaths in transportation networks. In *Selected proceedings of the 18th International Symposium on Transportation and Traffic Theory (ISTTT)*, 2009, pp. 1–21.

8. Spiess, H., and M. Florian. Optimal strategies: A new assignment model for transit networks. *Transportation Research Part B: Methodological*, Vol. 23, No. 2, Apr. 1989, pp. 83–102.

9. Nguyen, S., and S. Pallottino. Hyperpaths and shortest hyperpaths. In *Combinatorial Optimization*, 1989, pp. 258–271.

10. Asmussen, S., and P. Glynn. *Stochastic simulation: Algorithms and analysis*. 2007.

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| **Segment** | **Line** | **Out node –** **In node** | **Average headways (min)** | **Travel time (min)** | **Passenger load in S&F assignment** |
| 1 | L1 (blue) | A-D | 6 | 25 | 0.50 |
| 2 | L2 (red) | A-B | 6 | 7 | 0.50 |
| 3 | B-C | 6 | 0.50 |
| 4 | L3 (green) | B-C | 15 | 4 | 0 |
| 5 | C-D | 4 | 0.08 |
| 6 | L4 (yellow) | C-D | 3 | 10 | 0.42 |
| 7 | L5 (purple) | E-F | 5 | 20 | - |
| 8 | F-G | 7 | - |

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FIGURE 1 SFNet and ENet.

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| **Nodes**[a]: Departure node[b]: Arrival node[c]: Transfer node | **Links**[1]: Line link[2]: Dwelling link[3]: Alighting link[4]: Boarding link[5]: Waiting link[6]: Walking link |

FIGURE 2 TEN for one run of L3 at stop C.



FIGURE 3 SFNet usage under different strategies.



FIGURE 4 Wait, On-board and Saved time results for SFNet.



FIGURE 5 ENet usage depending on RTI user strategy.



FIGURE 6 Wait, On-board and Saved time results for ENet.

TABLE 1 Number of simulation runs1 needed to achieve given precision levels

|  |  |  |
| --- | --- | --- |
| **Target relative precision2** | **Busy (4)** | **Strategic** |
| *Average travel time* | *Load of L1* | *Average travel time* | *Load of L1* |
| 1% | 425 | 49,410 | 223 | 5,235 |
| 5% | 10 | 1,141 | 6 | 121 |
| 1 Estimates based on the first 50 runs of the simulation2 Here defined as ratio between the semi-width of the 95% confidence interval of the mean of the studied quantity and the estimated mean, i.e. $1.96∙\frac{SE\left(\hat{u}\right)}{\hat{u}}$ where $\hat{u}$ is the estimated mean and $SE\left(\hat{u}\right)$ the standard error of the mean. |