Theoretical Evaluation on the Effects of Changes from a Zonal to a Distance-based Fare Structure

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Abstract We illustrate with a hypothetical transport network that reflects common origin and destination relations in a regional transport network the effects of changing fares from a zonal to a distance-based structure. We take the zonal fare as a base case and model the effect of different fare/km, including non-additive fares, where the marginal price per km is decreasing. The results indicate some general trends that can be expected such as the range of fare in order to achieve similar fare revenue incomes. At this “fare parity point” the total travel time tends to reduce but the flows become less dispersed. Furthermore, in case of non-additive distance-based fare, we show that total utility could be improved at the fare parity point compared to additive fares.

Keywords Public transport, Pricing policy, Fare structures, Non-additive fares

1. Introduction

1.1. Background

Fare structure changes can have significant impacts on ridership and customer satisfaction and general insights are limited. Schmöcker et al. (2016) describe the need for such analysis since significant structural changes are an important current issue for a number of transport providers/authorities. Specifically experiences from the Netherlands show that changes from zonal to distance-based fare structures can lead to significant impacts for the operator as well as travelers with “some winners and some losers”.

There are numerous contributions aiming to establish “price sensitivity” for changes in fare levels (Lam and Zhou, 2000; Lo et al., 2003; Jørgensen and Preston, 2007; Farber et al., 2014), but the available (academic) literature on systematically assessing the effects of more significant fare structure changes such as the changes from a flat or zonal to a distance-based fare system is surprisingly scarce. There are some empirical studies that have shown that distance-based fare structures can improve social equity and transport ridership compared to flat fares (Daskin et al., 1988; Tsai et al., 2008). Farber et al. (2014)
discuss that distance-based fares can be useful for low-income, elderly, and non-white populations but impacts are diverse and may be negative for travelers living on the urban area. Furthermore, among distance based fare structures that can lead to similar overall revenues different fare structures are thinkable. Whereas in some system the fare per km remains constant, for example many bus lines in Japan have a base fare and then a marginally decreasing fare per km the longer the journey. Few studies have considered such non-additive fare structures in detail. An exception is Chin et al. (2016) who showed that non-additive distance-based fare structure has very different effects on downtown commuters compared to suburban-to-downtown commuters in Toronto.

1.2. Scope and objective of this study
In this paper we aim to further reduce this gap in the literature considering policy trends in some cities: We presume that in the (current) fare zonal system passengers pay a fixed fare for travelling in the zone independent of how much they travel in the zone within the time-validity period of the ticket. In the “future” distance-based fare structure, we presume that passengers’ routes are captured by for example mobile phone tracking through on-board detection of travelers. Application of this type of technology result in costs directly proportional to the distance the traveler covered by public transport. We explore a range of distance-based fares that charge in terms of price per km. We also presume that the fare to be paid does not differ between the various public transport modes such as bus, tram and train. We restrict our analysis to mode and route choice for single trips, i.e. leave out issues such as trip chaining and temporal changes, but include, to some degree, demand elasticity. We are furthermore only interested in the impacts of the zonal fare on the public transport demand. We therefore aggregate all non-public transport options that might exist especially for nearby destinations into one alternative mode, in the following referred to as “walking”. This mode should be understood though as reflecting a range of alternative travel options to the traveller. The attractiveness of our “proxy mode walking” can be controlled for by modifying its speed. We include walking for some specific nearby nodes in order to show demand elasticity effects with the changing fares. We further note that we do not consider crowding and capacity issues and focus only on fare and travel time trade-offs.

The remainder of this paper is organised as follows. The next section will introduce our modeling approach. Section 3 describes the case study network used. Section 4 discusses the results before Section 5 concludes the paper and discusses possible extensions.
2. Summary of Methodology

2.1. Frequency-based route choice and fare

We utilise a frequency-based assignment approach. This approach allows us to directly model the changed route choice strategy due to fare structure changes. Consider a passenger at node A who is travelling to destination C in below Figure 1. He has the choice between travelling with a direct slow bus (travel time 40 minutes) or between two trains that require a travel time of 15 min each. The bus only comes every 30 minutes; whereas the trains have both a frequency of 10 min each. In the absence of real-time information and assuming optimal strategies this would lead to a strategy taking the bus or train “whichever happens to arrive first” (Spiess and Florian, 1989).

The main point for our discussion is that in a distance-based fare structure the route via B would become comparatively more unattractive then the direct bus route from A to C. This could hence lead to passengers wanting to commit themselves to the direct A to C route only, leading to changes in line loads in the network. If A to C is further a non-public transport option it would mean the introduction of the distance-based fare would lead to a likely loss of passengers.

We note that the vice versa situation might also occur. If node B is in a different zone and traversing additional zones is charged by a significant amount, the passenger in the zonal fare system might not consider the indirect route, but if a low distance-based fare is introduced the indirect route might become attractive.

![Fig. 1. Illustration of the hyperpath concept](image)

We further note that, from a methodological point of view, finding the optimal hyperpath with distance-based fares is simple if the fares are additive but not so if the distance-based fare structure is non-additive as common in public transport networks. To overcome this problem the paper by Florian and Constantin (2015) discusses the idea of a “state-augmented” network originally proposed in Lo et al (2003). Further, Maadi and Schmöcker (2017) proposed 2-stage solution approach for finding hyperpath with non-
additive link costs in transit network which we will also utilise here. This solution approach utilizes the idea that for link-based non-additive fare structures three types of OD pairs can be distinguished. Type 1 are OD pairs for which we obtain the same optimal hyperpath in the network with considering minimum fares and hyperpath specific fares. Type 2 are OD pairs where the optimal hyperpath changes after assigning fares but the Bellman principle still holds. In other words, the strategy of taking detours for the sake of saving fares further downstream never pays off and hence the optimal (hyper-)path from an origin to one node is the optimal hyperpath independent as to whether the node itself is the destination or which the optimal hyperpath includes traversing it. This property might though not always hold so that there are potentially different optimal hyperpaths to an intermediate node depending on what the final destination is, we refer to these as Type 3 OD pairs.

In Maadi and Schmöcker the approach is tested on general networks. Here, we implement the same ideas into a frequency-based assignment with a transport network as in Figure 2. For each station we introduce boarding links at which waiting times according to the line frequencies that serve the station occur. By including more lines in the choice a passenger can hence reduce the expected waiting times. If stations are close-by, we further introduce walking links so that passengers can avoid public transport if it is not attractive enough. Walking links are generally slower than public transport but free. Therefore “a walking link” could also reflect modes such as taxi if we consider a trade of between travel time (which obviously is fast for taxi) and charges to be paid (which obviously is also higher for taxi). The faster the walking links and the more walking links there are in the network the more competition the public transport operator faces from alternative modes.

Fig. 2. Schematic representation of a public transport lines serving three stations
2.2. Notation

A Set of all links
P Set of all on-board public transport links
B Set of all boarding links
W Set of all walking links
X Set of all trips made in network
\( v_a \) Flow on link \( a \) in distance-based fare
\( v_z \) Flow on link \( a \) in zonal fare
\( t_a \) Travel time on link \( a \)
\( d_a \) Length of link \( a \)
\( c^D \) Cost per 1km in distance-based fare system
\( c^P \) Zonal fare to be paid for using public transport in periphery zones
\( c^C \) Zonal fare to be paid for using public transport in city zones
\( x_{ijr} \) Number of trips from \( i \) to \( j \) expected to use route \( r \)
\( n^C_r \) Number of city zones travelled using public transport system when travelling from \( i \) to \( j \) on route \( r \)
\( n^P_r \) Number of periphery zones travelled using public transport system when travelling from \( i \) to \( j \) on route \( r \)

2.3. Utilities determining passenger choices

We presume all passengers choose the shortest hyperpath from their origin to the destination where time costs can be transferred into monetary costs via a value of time (VOT) factor. In the case of constant distant-based fares the attractiveness or disutility of an origin-destination specific hyperpath can hence be expressed as follows:

\[
g^d_h = VOT \left( \sum_{i \in B_h} \alpha_{ih} w_{ih} + \sum_{a \in W_h \cup P_h} \beta_{ah} t_a \right) + \sum_{a \in P_h} \beta_{ah} d_a c^D
\]

where the main challenge is to obtain the optimal set of (single or multiple) routes and the split between these paths to minimise \( g^d_h \). This is equivalent to obtaining the probabilities \( \alpha_{ih} \) of traversing a specific node \( i \) and probabilities \( \beta_{ah} \) of traversing a specific link when choosing hyperpath \( h \).
In case of zonal fare a different problem formulation is required. The main issue is that passengers might want to avoid travelling public transport for a short distance in a specific zone in order to save costs. We can formulate this as above with to be determined parameters $\gamma_{rh}$ that denote the route split within a given hyperpath. In our model implementation we solve the problem by defining zone-specific “entry fares” to the system when a passenger uses a public transport link for the first time and by adding additional costs on “zone-crossing links” when a passenger enters a new zone.

To note is that in the zonal system we do presume the same ticket can be used even if the passenger interrupts his/her journey by taking a walking link, where zonal tickets have a validity for a certain time period. As we only consider single trips, we do not consider that zonal tickets of previous journeys might be still valid for subsequent journeys. (Perceived) travel times of on-board links are fixed and flow independent meaning that as discussed, congestion issues are ignored.

3. Case Study Network specification

In the following a network is specified that allows representing most major types of Origin-Destination (OD) pairs that characterize traffic within a zonal public transport area. Figure 3 illustrates the proposed network. Five fare zones are modeled which travelers might traverse to reach their destination. The zones are referred to as City 1 (C1), City 2 (C2) as well as Periphery 1, 2 and 3 (P1, P2 and P3).

Different public transport modes are included in the network to reflect the effect of interchanges and changing mode usage in case of fare structure changes: One fast, but infrequent intercity train line. A number of local train lines that are presumed to be frequent in particular in the city center and fairly fast (but slower than the intercity train line). Some bus lines that reflect infrequent and slow public transport connections. Such connections are though often important to guarantee access in the peripheral areas.

Walking links, where, as discussed in previous section, “walking” can general be considered as a “proxy” for usage of an alternative mode, e.g. could also represent using taxi, cycling or a private car.
Fig. 3 Network structure to illustrate changes from zonal to distance-based fare; blue indicates demand nodes, yellow transfer nodes. The network has a scale of 12.5x30 km.

We vary the speed of these walking links to illustrate the effect of fare changes depending on the quality of the alternative modes. To keep the network simple, walking links are further only included between a selection of “critical” node pairs where depending on the fare and the competiveness of the modes walking might be attractive. As an example, we include walking links from P1b to C1a to illustrate that depending on the fare people will choose non public transport option. In the zonal price structure demand from P1d with a destination in C1 will trade-off a short walk to a station in P3 with a longer walk to a near station in C1 from which the fare will be cheaper as no fare for P3 will have to be paid. Intersection between lines in the graphs are assumed to be interchange points. Each interchange station is represented by a frequency-based transit representation as in Figure 2. The assumed link speeds and service frequencies are listed in Table 1.

Table 1 Link Attributes

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<tr>
<th>Links</th>
<th>Travel Speed</th>
<th>Service frequency</th>
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<tr>
<td>Walking links/ alternative access mode (no fare)</td>
<td>5 or 10 km/h</td>
<td>No waiting (infinite frequency)</td>
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<tr>
<td>Bus line in periphery</td>
<td>20 km/h</td>
<td>1 per hour</td>
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<tr>
<td>Local train/tram lines within city</td>
<td>40 km/h</td>
<td>6 per hour within city zones</td>
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<td>4 per hour from city across zones</td>
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<td></td>
<td></td>
<td>2 per hour from P1 to P2</td>
</tr>
<tr>
<td>Express/intercity train</td>
<td>100 km/h</td>
<td>4 per hour</td>
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For evaluating the effect of fares, it is further important to consider the trade-off of the traveler’s between time and fare. We assume the three values $VOT^{High} = 45 \frac{\$/h}{h}$, $VOT^{Mid} = 30 \frac{\$/h}{h}$ and $VOT^{Low} = 15 \frac{\$/h}{h}$. These are to reflect different population groups with different income and sensitives to fare changes. Clearly this is a rough classification, Mackie et al (2001) for example show that values of time ideally should be further differentiated according to trip purpose, time of day and length of journeys.

Figure 3 shows in total 16 demand points that can be origins and destinations. Four OD pairs each are located in zones C1, C2 as well as P1, P2. They are defined in order to create following types of demand points:

- **P1a, P2a:** Periphery locations with good access to local bus lines; within walking distance to local train line; interchange to city always needed.
- **P1b, P2b:** Periphery locations within walking distance to both bus and direct train to city. Also, possible to use alternative mode (e.g. walk, cycle) to city.
- **P1c, P2c:** Periphery location, most remote, medium good bus access, long access to local train.
- **P1d, P2d:** Located outside city zone but with close and good access to both cities.

- **C1a, C2a:** Non-central city location, access to local train lines; walking to other city centre destinations not attractive by alternative modes.
- **C1b, C2b:** Very central location, good access to all transport modes.
- **C1c, C2c:** Non-central city location, access to single local train line and buses. Walking to C1b or C2b respectively and other major train stations possible.
- **C1d, C2d:** Central city location, access to several buses. Walking to Cib and other major train station possible, e.g. historic city centre.

We define the demand by following matrix where parameters $\alpha, \beta, \gamma$ and $\delta$ define the relative size of the demand: $\alpha$ denotes the demand between the two city centre OD pairs of C1 and C2; and $\beta$ the demand among the four periphery OD pairs in zones P1 and P2 respectively. $\gamma$ denotes traffic from the periphery into the nearby city centre and the remaining demand $\delta$ denotes, presumably less common, demand between origins and destinations that tend to be further apart.
In the following we show the effect of fare changes for all three VOT values and for four demand scenarios as in Table 3. The demand will be generated between all respective OD pairs. In Figure 3 there are four nodes in all zones and in the base case, for example, between all 12 node pairs within C1 a demand of 1000 passengers is generated.

### 3.1. Evaluation Measures

We specify three evaluation measures. These are changes in total travel time $TR$, total fares paid $FR$ and changes in the amount of walking $WR$. We report all these measures as ratios between a specific distance-based fare compared to the zonal fare.

\[
TR = \frac{\sum_{a \in A} v_a t_a}{\sum_{a \in A} v_a t_a}
\]

\[
FR = \frac{\sum_{a \in A} v_a d_a c^D}{\sum_{i,j,r} x_{ijr} (n_{ijr} c^C + n_{ijr} c^P)}
\]

\[
WR = \frac{\sum_{a \in A} v_a d_a}{\sum_{a \in A} v_a d_a}
\]

$TR$ is primarily showing the impact of the fare on the passengers. The larger $TR$ the more passengers will forgo travelling on the shortest path in order to save overall travel time. Similarly, $WR$ shows how much more or less passengers are taking non-public transport options in case of a fare change. Note that, since we presume all walking links have the same speed, $WR$ also presents the amount of distance travelled walking. Finally, $FR$ is important to both operators and passengers. If the ratio is larger 1 then the operator will obtain more fare revenue (and accordingly passengers have to pay more).
In addition to these network wide measures we report in the following changes in line loads as well as which nodes in the network generally are better or worse off after the fare structure change.

4. Results

4.1. Network-wide fare, travel time and walking ratios

As the reference zonal case we presume that the three P zones are each charged with $4 and the two C zones are charged with $8 each as shown in Figure 3. We now compare this to a distance-based charge in the range of 0.2 to 5 $ per km. Figure 4 shows the 12 diagrams (4 demand scenarios times 3 VOTs) for our three network wide evaluation measures TR, FR and WR. As the ratio of 1 is an important value we highlight this with a dotted. The distance-based fare for which an equal amount of fare compared to the zonal fare is achieved, we call in the following “fare-parity point”.

We suggest following range of observations are important: For very low distance-based fares, the current zonal fare system is more expensive and people with low income would walk less and accordingly also safe travel time. People with high VOT do not change their behaviour. Therefore, the lower the VOT, the lower a distance-based fare is needed to achieve revenue parity (as with low VOT demand becomes more elastic and more people with low income will start using public transport).

On the contrary with very high distance-based fares people walk more and accordingly also require more time. At some fare level point people replace traveling by PT with the alternative mode. The point at which this occurs depends again on the VOT. The lower the VOT the earlier the change is occurring. In case of VOT = 15 we can observe a fairly gradual increase in walking, whereas for VOT values of 30 and 45 we observe some jumps at which people suddenly start to walk more. The higher the VOT, the higher the fare when the jump occurs.

In line with this, an important difference is that the medium and high income groups in general are willing to keep their travel time and walking amount constant by paying the additional fares. In contrast we observe a continuous increase in travel time and walking amount for low income groups. At the jump points we can observe total fare (and revenue) drops and travel times increase. We can probably consider the jump points as reasonable upper bounds for the fare.

The fare revenue parity level is achieved always between 0.5 to 1 $ per km. In general the fare parity point appears to be a user friendly fare as total travel time and walking is less than in the current zonal fare system. This illustrates the general weakness for zonal
based fares in that some short trips are overpriced. We note though that in our assumption all tickets are used only for a single journey. Further, when one would consider a population mix, one needs to be careful in considering differences for low and high income groups. Consider the base demand scenario. For the high income group we obtain fare-revenue parity value at nearly 1 $/km. At this point though the low income group with VOT=15 needs to pay 130% of the fare they pay currently. Comparing the four different demand scenarios we observe in general fairly few differences regarding the location of the revenue parity point. We observe though that the size of the jump changes in the scenarios. In the short-distance and the morning commute scenarios people replace more trips with walking than in the scenario with more cross-zonal trips.

4.2. Flow differences

Figures 5 and 6 show the network with the resulting flows in the zonal fare scenario as well as the distance-based fare scenario with 0.5 $/km, VOT = 30. We choose this scenario as it is close (though slightly below) the fare-revenue parity point. The thickness of the lines reflects the 2-directional line flows; as reference values we add the flow on one link. The modes are indicated with different colours, i.e. black for train, blue for bus and green for walking.

We find that in the zonal fare scenario flows are more distributed. This is to be expected as passengers can be more flexible with their route choices inside a zone where the charge is fixed. As a result of this, for example, the northern train line in our network is not used anymore in the distance-based scenario. Further, we find that in the distance-based scenarios people prefer to take the slower bus more than in the zonal based scenario since in our networks all bus lines are direct, compared to the faster tram which travels only in north-south and east-west direction, so that the distance-based charge would be larger. Links that are instead not used in the distance-based fare are the walking links from node 4 (P1d) to the interchange point in C1: Whereas in the zonal fare passengers could save the charge for a full zone by walking slightly more, this is not the case in the distance-based case and passengers with a medium or high VOT will prefer this option.
**Fig. 4** Changes in fares, travel time and walking depending on distance-based fare

To further show the positive and negative effects of the fare structure change, Figures 7 and 8 show the optimal hyperpaths between three OD pairs. It illustrates the mentioned
change in path choice for passengers from P1d to C1d. Take further passengers travelling from C1d to C2d. Here the hyperpath effect discussed in the introduction becomes apparent. In the zonal system passengers can reduce waiting time by choosing “whichever bus comes” first at C1d. The additional wait to limit one’s choice to only consider the more direct line does not pay-off. In the distance-based fare system though passengers are not willing anymore to take the detour as it incurs higher fares. This example illustrates why a distance-based fare is likely to lead to flows more focused on fewer links. Our third example of changing path choice between nodes P1b to P2b illustrates a further point. In the zonal-based fare passengers will avoid the higher priced city zones, whereas with distance-based fares, travellers can choose the more frequent route via the city as now the fares on both routes are similar. This shows that in the distance-based fare structure we might expect some traffic to re-route via city centre routes, especially if congestion is not an issue.

We note that in this analysis we did not consider congestion effects which are likely making the above shown effects even worse for the distance-based case: Take the case that a crowded bus arrives in the C1d to C2d example. In the zonal-based fare passengers can be more easily persuaded to take less crowded routes giving a transport operator better potential means for demand management. Also in the third example (P1b to P2b) the zonal fare structure can be used as a tool to divert passengers away from the city centre if there are alternative, less congested routes.

![Diagram](image.png)

**Fig. 5** Flows assuming VOT = 30; base demand and zonal fare
4.3. Impacts on OD pair level

Our focus in this section are the impacts on single OD pairs. In Tables 4 and 5 we continue using a distance-based fare of 0.5 $/km. We illustrate which OD pairs are relative “winners” or “losers” after a shift to a zonal based fare. For this we ignore the demand but only look at the generalised cost for the shortest (hyper-)path between OD pairs as
defined in Section 2.4. Since our distance-based fare is low, most utilities decrease as discussed in 3.1. Our prime interest is though the difference in how the fare change impacts different OD relations.

The main winners from a change to a distance-based fare in our network would be the city-to-city connections. The reason is that in the zonal structures the city charges are double the price for the other zones. In particular the connection between C1d to C2d will benefit from the lower charge. Another winner from the fare change is the OD pair P1c to C1d. These are OD pairs for which connections in the zonal structure exist only via different zones. Though such connections might be indirect and hence also incur a fairly large amount of distance-based fares, these are often still lower than in the zonal case. “Loosing” connections are on the contrary long-distance connections for the P zones, such as passengers travelling from P1 to P2.

Table 5 illustrates the utility differences for VOT = 30. In this case all values are smaller as the relative impact of fares increases or decreases are less important than for passengers with low VOT. The observed patterns are all relatively similar to the case with VOT = 15 though.

Table 6 uses a distance-based fare of 1 $/km and VOT = 15. In this case, on average the disutility increases by 12 units, that is weighting all OD pairs equally on average people incur more generalised costs at this fare level. Further, with higher fares/km it becomes clearer that long distance OD pairs in general will be relative “losers” as the upper right and lower left part of the table turn red. In other words, travelling to close by destinations such as P1 to C1 or within a zone is relatively cheaper than travelling to “other” zones such as from P1 to P2 or from P1 to C2. Finally, the table shows that now also some far away C1 to C2 connections suffer from the change in the fare structure (see C1a to all four C2 destinations). Furthermore, it is interesting to observe that the changes in the disutility gains or losses are far from linear. Take P1a to P2a, here now the distance-based fare utility loss increases by 52 units (from 16 to 68) whereas, for example, the utility loss for C1d to C2d is only 20 (from -57 to – 37).
Table 4 Changes in generalized costs between OD pairs, base demand, VOT = 15, (zonal fare) – (distance-based fare) at 0.5 $/km; the more green/red, the more the costs reduce/increase in the distance-based fare; white = mean utility reduction of -16

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Table 5 Changes in generalized costs between OD pairs, base demand, VOT = 30, (zonal fare) – (distance-based fare) at 0.5 $/km; white = mean utility reduction of -8.6

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Table 6 Changes in generalized costs between OD pairs, base demand, VOT = 15, (zonal fare) – (distance-based fare) at 1 $/km; white = mean utility increase of 12

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4.4. Non-linear distance-based fare structure

In this section, we add cases of non-additive fares where the marginal cost per km-travelled is decreasing for longer journeys as is commonly the case and compare them to a few of the linear fares shown in previous section. We provide the details of the seven fare scenarios in Table 7. Scenario LFS-4 is the fare parity point found in previous section. In the non-additive cases passengers pay decreasing amount of fares per km travelled. In non-additive Scenarios 1 and 2 we define a “fare capping scheme” similar to what is in practice in some cities such as London. Passengers do not have to pay any more, if their total travel expense has reached a certain limit. In case of NFS-1 this is $9.5 and in NFS-2 it is $10.

Table 7 Fare structures in $/km shown in Figure 9

<table>
<thead>
<tr>
<th>Distance</th>
<th>Linear, Additive Fare Structure</th>
<th>Non-additive fare structures</th>
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<tr>
<td></td>
<td>LFS-1</td>
<td>LFS-2</td>
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<tr>
<td>Up to 2 km</td>
<td>0.8</td>
<td>0.9</td>
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<td>2.1 km - 3 km</td>
<td>3</td>
<td>3.5</td>
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<td>3.1 km - 4 km</td>
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<tr>
<td>Over 5.1 km</td>
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In Figure 9 we compare disutility and total fare revenue for these fare structures in case VOT=$15. Trend lines show that the total travel time for all travelers is reduced at the fare parity point, so that one can argue that such a fare structure can improve the Pareto optimal front that provides the least travel time for a given or more revenue income. For example, an operator aiming to maximize revenue will be indifferent to LFS-4 and NFS-3, but travelers would prefer NFS-3. Further NFS-3 is clearly better than LFS-2 for both operator and travelers.
5. Conclusions and further work

We believe the above case study illustrates some general trends that can be expected if a fare structure change from a zonal one to a distance-based one is implemented. From our results we believe following points discussed in previous section are most important:

We provide a general range of between 0.5 – 1 $ for which fare revenue parity might be achieved in our case study. We showed though that the VOT as well as the attractiveness of the other modes in connection with demand elasticity are important factors to determine the value for the distance-based fare that ensures no revenue will be lost.

At the point at which fare parity is achieved customers require in total less travel time to complete their journeys. This appears to be an important advantage of a distance-based fare.

However, we believe our findings might be considered favourable or “an upper limit” to the advantages of the distance-based fare. Most importantly, in our case study we presume that each trip is charged anew, in some zonal fares, zonal ticket can be used for multiple trips within the validity time period of the ticket. Considering these aspects will hence further reduce the benefits of the distance-based fare.

We show that flows become less dispersed in the distance-based case as customers will stick to shortest-distance routes. Also here, we suggest, that furthermore the distance-based fare structures are employed in which customers pay according to the shortest distance between origin and the destinations, but customers are free to take any or at least a range of alternative routes as well but would not be charged for making a detour (in terms of distance).
based case is dealt favourably with in our simplified case study. As discussed, in case congestion and capacities would be considered, this would impact the distance-based case more as passengers would less likely divert making these issues potentially even more important. Furthermore, the different pricing of zones can be a demand management tool to protect the city centre against public transport crowding, whereas in the distance-based case, we would expect some more passengers to travel via the city centre. Again, also here considering congestion issues would further weaken the case for distance-based fares. Though our four demand scenarios show similar trends, we show that care must be given to the impacts for different OD pairs. Whereas some customers can be significantly better off in the distance-based case at fares close to the fare parity level, others travelling for long distance might incur significantly more financial burden. Therefore, to obtain customer acceptance, it appears imperative to discuss with these the potential impacts. What might make the implications of a distance-base fare worse is that heavy commuters who are willing to travel longer in order to be able to afford reasonable accommodation are likely to be among those most disadvantaged by the fare structure change. In further work on the example network trip chain aspects and regressive fares could be explored. In order to bring this work forward to a level where more confident and precise estimates about the fare structure impact specifically for real network can be made, one would need to obtain data on the parameters used in this study including demand distribution on a more detailed network. Finally, we show that in networks where links have different speeds, non-additive fares can lead to a fare parity point with lower total travel time, meaning that using non-additive fares with fare stages of decreasing cost, can help passengers to save travel time by using faster links. However, the case study illustrated in this paper is not sufficient to draw general conclusions for what type of networks and demand scenarios non-additive fares are particular useful. We suggest this is an important area of further work given technological trends that favour the introduction of such fare structures.

References
EMTA (2016). Determining Fare Structures: Evidence and Recommendations from a Qualitative Survey among Transport Authorities, pp. 5