EVALUATING THE IMPLEMENTATION OF TRANSIT SIGNAL PRIORITY (TSP) ON A BUS NETWORK, WITH A FOCUS ON EQUITY

Ms. Rachel Ivers
Transport Planner (MSc Transport Infrastructure and Logistics, BSc Spatial Planning)
Delft University of Technology

Abstract
This study evaluates the implementation of a Transit Signal Priority (TSP) system on a bus network and proposes a new transport appraisal method that focuses on equity to determine its feasibility. The main research question to be answered is ‘What are the equity and efficiency impacts of introducing transit signal priority on a city bus network?’

The method used to answer the research question is divided into a number of steps. First, commonly used transport appraisal methods are outlined as are their shortfalls in how they deal with the issue of equality. Next, the term equality is discussed which leads on to the components necessary for an equitable transport appraisal method, which is then defined. Third, the technical requirements for TSP are found. The next step tests this new method by identifying two contrasting zones (socially advantaged and socially disadvantaged) in the chosen study area, County Dublin, Ireland, by mapping socio-economic Census 2011 data using ArcGIS. The purpose of the contrasting zones is to test the equity based transport appraisal method. From that, TSP is modelled on the two identified routes using the National Transport Authorities ‘Greater Dublin Area Transport Model’. Next, the change in travel times and modal split is evaluated using the equitable transport appraisal method and a more common financial based transport appraisal method, again for comparison purposes.

The results of this study are in two parts. The first set of results are from implementing TSP on two contrasting socio-economic zones. The North Clondalkin corridor links a socially disadvantaged zone to employment and the Stillorgan corridor links a socially advantaged zone to the same employment location. The results show an approximate 10 minute reduction in travel time by bus on the North Clondalkin corridor and an approximate 7 minute reduction in travel time on the Stillorgan corridor. Both the car travel times and the cycle travel times see no significant change (less than 1 minute).

The second sets of results are the equitable and financial results of the two transport appraisal methods. The proposed equitable transport appraisal method shows that there is a 57% change in equality from the North Clondalkin zone and a 36% change in equality from the Stillorgan zone. Both see an increase in the level of equality within the zones and balances the level of equality between the zones when TSP is implemented. The CBA reveals a net present value benefit of €285,000.00, generating a cost benefit ratio of 1.8.

The use of the equitable appraisal method has the ability to see the effects a transport proposal has at a disaggregate level rather than the aggregate level of a CBA. Only focusing on the aggregated level has the potential to hide equity fluctuations between areas and therefore increase the level of inequality. However this issue is tackled in this paper with the use of the outlined equitable appraisal method which can be used in conjunction with a CBA.

Introduction
Today, the need for increased public transport provision, higher level of accessibility and an increased awareness of the role public transport plays in an inclusive society has grown. Reference [1] looks at accessibility not as reducing social exclusion but as enhancing the quality of life. Reference [2] suggests there is a strong correlation between a lack of access to adequate mobility and a lack of access to opportunities, social networks, goods and services. Finally [3] seeks to highlight the importance of understanding the social impacts and consequences, as well as the distributional effects of, transport decision-making. This
has resulted in a new focus towards increasing the provision of public transport in urbanised areas and making it more advantageous.

There are many ways in which public transport can provide increased accessibility for society, for example by increasing the number of available opportunities, reducing travel time, cost savings, providing to the needs and abilities of users and mitigating any time restrictions [4]. One possible way in which cities are making public transport more advantageous is by improving bus service reliability. Traffic, weather and driver behaviour can all reduce public transport's reliability [5]. However there are many ways in which the effects of these events on the service reliability can be reduced. Reference [5] outlines at three different levels how this can be achieved; at the strategic, tactical, and operational level, service reliability can be reduced through the prevention of bunching, overcrowding and uncertainty. These can be controlled through a number of measures like detours, slowing down, speeding up and the use of software and technology such as Traffic Signal Priority (TSP).

This study looks at evaluating the introduction of TSP to a bus network with a focus on the equity effects on a society. TSP is a traffic light control strategy that favours an approaching bus over the rest of the traffic on the road by introducing a little extra green time or a little less red time at traffic signals to reduce the time buses are slowed down by traffic signals [6].

**Current appraisal methods**

When implementing a new public transport innovation, the most common way of determining its feasibility is through an financially focused analysis most commonly a Cost Benefit Analysis (CBA) or a Multi Criteria Analysis (MCA). These two methods are the most common (ex-ante) evaluation methods that are used in many countries, however they have their pitfalls especially relating to how they deal with equality.

Reference [7] say that studies have indicated that it is very difficult to monetise all the impacts of transport projects (i.e. CBA and MCA), in particular benefits or costs that do not have constant economic values. Take travel time as an example, which factors should be taken into account when putting a monetary value on time saved i.e. geographic zone, profession, social status, or travel purposes?

Reference [8] states that a CBA generally ignores the distributional and equity effects and other ethically important implications of choice options for example, in the area of social exclusion. Reference [8] goes on to state that this is an important oversight for contemporary policy analysis, as it is now widely recognised that 'sound' policies should meet three criteria: i) effectiveness, ii) efficiency and iii) equity and so a CBA is incomplete if equity or fairness is not considered [9].

A disadvantage [8] with a MCA is the risk of double counting. Reference [8] gives the example that, a new bus service may reduce travel times as well as the level of social exclusion, but social exclusion is reduced as a result of the reduction in travel times, so there is overlap between the impacts of the two indicators. MCA also does not inherently identify the spatial or social distribution of impacts across different population groups, however this needs to be specifically identified as a separate necessary step if there is concern to protect or enhance the accessibility of particular ‘at risk’ groups.

**Equality**

Determining equity is difficult because there is no standard definition of distributional equity for transport benefits [10]. The most relevant definition of equity refers to it as ‘the fairness and justice of the distribution of the impacts (benefits and costs) of an action on two or more units’ [11]. Depending on the available data and the chosen equity (or inequality) measure, units can stand for individuals or groups. For the definition of groups, one can use collective units, such as households, disabled people, non-drivers, land-use type, or regions, and characteristics, such as income, travel cost, population, or age. This definition aids to the establishment of groups in the case study later in the paper.
There are many dimensions (or components) to equality. Social exclusion, poverty and accessibility have all been discussed in literature which aims to give thresholds to individual areas but the overall term 'equality' aims to go further and looks at the difference between these levels and tries to reduce this by achieving a higher and fairer level of transport provision.

Components for an equitable appraisal method
Determining equity is difficult because there is no standard definition of distributional equity for transport benefits [10]. There are a number of equity types and principles categorised by [12], [13], [8] including horizontal, vertical equity and territorial equity, territorial cohesion, transport users should pay their way, individuals that are negatively affected by policies need to be compensated, egalitarianism, solidarity and finally spatial and social equity.

In general, most transport infrastructure projects address spatial, horizontal, vertical, environmental, social, intergenerational and regional equity [13]. References [12, 14, 8] identify two general categories of transport equity; horizontal and vertical equity. Horizontal and vertical equity usually conflict; if vulnerable groups are being prioritized then everyone is not being treated equally. As a result vertical equity is considered more suitable to this study. Vertical equity (social justice, social inclusion) is concerned with distributing resources between individuals of different abilities and needs [12]. A planner following a vertical equity philosophy would believe that disadvantaged populations, such as lower income families or ethnic minorities should receive priority consideration in public transportation projects [15].

Reference [8] proposes adopting an approach that brings together accessibility based equity analysis underpinned by two ethical principles of egalitarianism and sufficientarianism. The reasons being, that they are seen to be more suited to redistributing transport resources toward currently disadvantaged population groups and areas. In order to do this reference [8] identifies 'socially relevant accessibility impacts' (SRAI), which take the form of accessibility measures and indicators for egalitarian or sufficientarian theories. Consequently these two theories are looked at in more detail and the egalitarian theory was considered the most suitable to this study as: this theory is useful to legitimate the evaluation of the (in) equality of accessibility, so directly accessing unemployed to employment areas rather than over all journey time reduction on whole population and therefore (improved) accessibility to basic destinations [16], [8]. Secondly it encourages a focus on the relative level of accessibility between different social groups [8].

The points below determine the method and poses questions that need to be answered to ensure that an area is appraised in an equitable manner.

1) Accessibility measures:
   - Individual component (What do people need?)
   - Land use component (Where are locations of activities needed?)
   - Transport component (How to get there?)
   - Temporal component (When to do there?)

2) Combining the egalitarian theory and accessibility measures:
   - Accessibility should be measured for the activities with the most relevance to the policy agenda, including access to employment, education, health and welfare services, etc.

3) Indicator:
   - (Journey Time) A way to measure journey time is for all people living in a certain area to a (selection of) destination(s) that are assumed to be most relevant from a SRAI perspective [8].

In order to test this method a socially advantaged and socially disadvantaged area in the study area will be found to evaluate the equity impact of introducing TSP.
The Lorenz curve and Gini index are used to analyze income inequality in a population. The Gini index, denoted by $G$, is calculated using the following equation:

$$G = 1 - \sum_{k=1}^{n} (X_k - 1)(Y_k - 1)$$

Where $X_k$ is the cumulated proportion of the population variable, for $k = 0, \ldots, n$, with $X_0 = 0, X_n = 1$, and $Y_k$ is the cumulated proportion of the public transport service variable, for $k = 0, \ldots, n$, with $Y_0 = 0, Y_n = 1$.

The Gini index can also be calculated from the Lorenz curve and line of equality using the following equation:

$$Gini = A_{equal} - A_{Lorenz}A_{equal}$$

Where $A_{Lorenz}$ is the area underneath the Lorenz curve and $A_{equal}$ is the area underneath the line of equality. Because the axes are scaled from 0 to 1, $A_{equal}$ will always equal 0.5. A perfectly even distribution of supply would result in a Gini index of 0 while a perfectly unequal distribution of supply would result in a coefficient of 1.

The above equations describe the process of visualizing egalitarianism through the Lorenz curve. The Gini index is then an indication for the level of (in)equality of the accessibility indicator (journey time).

Common fields of application include health, education and port activities. Any equity analysis that has been conducted in past literature has been done so after the proposal or policy has been implemented. No research could be found that deals specifically with the equality of (public) transport proposals (at appraisal stage) on socially advantaged and disadvantaged areas and different mobility users, which is what this paper focuses on.

### Technical requirements for TSP

Three main components are required to implement TSP: vehicle detection systems, communication systems and traffic control systems. For the purpose of this paper the details of TSP will not be discussed further except to state that it is possible to implement in the chosen study area.

### Case study – County Dublin, Ireland

Vertical equity and the four accessibility measures were applied to the study area to identify two contrasting areas from which to introduce TSP and determine any changes in equity.

Using the three stages in the equitable transport appraisal method two areas with different land uses (to the West and South East of County Dublin) have been identified that have different socio economic profiles, found using Census 2011 data and ArcGIS. These areas have differing (Individual component) social classes, economic status, number of households with no cars, and means of travel to work, with the South West having a higher socio-economic demographic then the West.

With regard to the Land Use component the highest area of employment and retail locations is Dublin city centre. This coincides with stage two of the equitable transport appraisal method where the greatest access to policy measures such as employment, education etc, exist in the city centre.
Next it was determined if these areas have the required Transport and Temporal components to link the origin and destination zones. They both have Quality Bus Corridors (QBCs) to Dublin city centre.

To conclude the North Clondalkin zone to the West is the socially disadvantaged area and the Stillorgan zone to the South East is the socially advantaged area. These two areas will be used as a comparison between travel time and modal split which regard to their access to the city centre and therefore determine the level of transport equity within and between these zones.

Figure 14 Origin & Destination in study area
1: North Clondalkin zone (origin)
2: Stillorgan zone (origin)
3: Dublin City Centre zone (destination)

Modelling
Stage three of the equitable transport appraisal method requires the journey time for the two areas and modal split to be found. The NTA’s Greater Dublin Area (GDA) transport model (2006) is a strategic multi-modal, network based transport model covering the GDA (i.e. the counties of Dublin, Meath, Kildare, Wicklow and Louth). The GDA transport model is owned by the NTA, who are the authority responsible for its maintenance and use.

To find current travel times and modal split the model was run with no interference. To determine the changes in travel time and modal split when TSP is introduced a two-step approach was necessary to model TSP. From the highway side, modifying the traffic light sequences, and from the public transport side modifying the delay file to ensure that the bus sees an advantage over the car when TSP is introduced.

Highway side - The GDA model contains coded networks for all mechanised modes of travel. In County Dublin area full junction details are included for all major junctions (the simulation network). The simulation network is encoded in a large text file containing details for all 2,000 + junctions which are simulated. It is possible to change the signal green time to mimic TSP, give a little extra green time in the direction the bus is travelling. It is important to note that the cycle time per node was not changed just the stage duration and inter-green time.

Public Transport side - On the public transport side the highway link travel times are passed from the highway assignment and used in the calculation of bus travel times; therefore the change in junction times is passed on to the buses. This means that implementing TSP will affect bus and car travel times equally. However this study aims to give the advantage of TSP to the bus over the car. This requires one more step to be completed on the public transport side by intervening and manually removing any delay seen by the bus at a junction within the two corridors. This can be done with the use of a file created during the public transport assignment in the defined time periods.
**Results of Model**

**Table 1 North Clondalkin zone summary results**

<table>
<thead>
<tr>
<th></th>
<th>Modal Split %</th>
<th>Travel Time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PT</td>
<td>SM¹</td>
</tr>
<tr>
<td>TSP</td>
<td>24.25</td>
<td>33.95</td>
</tr>
<tr>
<td>Base</td>
<td>24.21</td>
<td>33.95</td>
</tr>
<tr>
<td>Increase above base</td>
<td>+0.04</td>
<td>0</td>
</tr>
</tbody>
</table>

North Clondalkin zone, socially disadvantaged area – the area saw minimal change in modal split, less than 1% from the base results of public transport (PT) = 24%, slow modes (SM) = 34% and highway (HW) = 42%. There was a clear change in travel time with PT seeing an approximate 10 minute travel time reduction, and SM and HW receiving less than 1 minute increase each.

**Table 2 Stillorgan zone summary results**

<table>
<thead>
<tr>
<th></th>
<th>Modal Split %</th>
<th>Travel Time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PT</td>
<td>SM</td>
</tr>
<tr>
<td>TSP</td>
<td>21.47</td>
<td>23.71</td>
</tr>
<tr>
<td>Base</td>
<td>21.47</td>
<td>23.70</td>
</tr>
<tr>
<td>Increase above base</td>
<td>0</td>
<td>+0.01</td>
</tr>
</tbody>
</table>

Stillorgan zone, socially advantaged area – the area saw minimal change in modal split, less than 1% from the base results of public transport (PT) = 21%, slow modes (SM) = 24% and highway (HW) = 55%. The lower use of PT and SM and higher use of HW coincides with this zone being further away from the city centre than the North Clondalkin zone and being socially advantaged. There was a clear change in travel time with PT seeing an approximate 8 minute travel time reduction, and SM and HW receiving less than 1 minute decrease each.

**Table 3 Modal split total user increase above base**

<table>
<thead>
<tr>
<th></th>
<th>HW</th>
<th>PT</th>
<th>SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dublin City Centre (destination)</td>
<td>-16</td>
<td>+43</td>
<td>-6</td>
</tr>
<tr>
<td>GDA</td>
<td>-58</td>
<td>+72</td>
<td>-12</td>
</tr>
</tbody>
</table>

Overall the modal split into the city centre changed with 43 people more travelling in by PT and a reduction in HW users by 16 people and SM users by 6 people.

**Sub-mode**²

There is a clear net growth in city bus passenger kms of +2293 pax/kms which represents a net growth of +0.1% when TSP is introduced on the two bus routes. This would translate directly into a 0.1% growth in fare revenue.

**Equity results**

The travel time and modal splits found for the base and TSP cases are used as input to the Lorenz curve and Gini index to determine visually and numerically the change in equity once TSP is introduced in the two areas.

---

¹ SM includes cycling and pedestrian movements. Cycling represents approximately 4% of GDA movements in 2006, the rest representing pedestrian movements. As a result the SM values are modified to only represent cyclists and not pedestrians.

² Sub modes include regional and city bus, DART, Luas and commuter train.
Proceedings of the ITRN2015
27-28th August 2015
NUI Galway

IVERS: Evaluating TSP, with a focus on equity

It can be seen in the above Figures (1 and 2) and Table 4 that both routes receive an increased equality: -0.08 for the North Clondalkin area and -0.03 for the Stillorgan area. It can also be seen that introducing TSP on both routes balances the level of equality from 0.14 for North Clondalkin and 0.09 for Stillorgan to 0.06 and 0.06 respectively (Table 4). The zones with lower equity value, the North Clondalkin zone sees a higher change in the Gini index of 57% rather than 36% for the Stillorgan zones.

Cost Benefit Analysis (CBA)
A simple CBA was conducted to find the cost of implementing TSP through a combination of investment, maintenance and operational costs and travel time savings. The input in the CBA is considered sufficient as all other components are not (negatively) affected and it is the interaction between travel time and investment, maintenance and operational costs that are the most significant.
In order to determine the travel time savings for the CBA, the input values for the Lorenz curve and Gini index cannot be used as they are at disaggregate level and are too small for the CBA. Consequently the overall travel time savings and modal split results generated by the GDA transport modal had to be used.

It was found that there was a total net present value benefit of +€285,066,40 eur and a cost benefit ratio of 1.8 when TSP is introduced on two bus routes.

Conclusion
Both methods, CBA and Lorenz curve and Gini index, generate a positive result when TSP is implemented in the study area. However one clear difference between these methods is the scale at which they gather their input values. For the Lorenz curve and Gini index it was possible to see the effect that TSP had at a disaggregate level and how much that affected the equity within and between the study areas. The CBA is at aggregate level and only the overall result could be found. This has the potential to hide negative effects of introducing such transport changes when specific areas are being considered.

The Lorenz curve and Gini index is a good analysis and visualisation tool to see the effects that transport policies have in different areas. It also has the potential to be used in conjunction with a CBA to highlight the distribution of social benefits and costs with study area. Through the step by step methodology outlined in identifying the necessary components the results of the CBA can be used to conclude that the equitable transport innovation is financially feasible.

Discussion
A perfectly even distribution of transit supply does not imply that demand for transit service is being perfectly met. A transit system can receive a “perfect” score of zero (Gini index) regardless of how well the system is able to meet the total demand [15]. It is not only travel time fairness that is important but also modal split balance which relates to mode availability that is important for equitable transport.

For there to be equitable transport every mode needs to have a similar travel time. However it is not only travel time is important; secondly there needs to be a more balanced modal split, for example every mode (highway, public transport and cyclist) should aim to represent 33% modal split and have equal travel times, such as 30 minutes. This would create a line of equality on the Lorenz curve. Thirdly is the distance to destinations. This can be seen through the Stillorgan zone (socially advantaged zone) which has a longer distance of 15km, a cycle travel time of approximately 60 minutes and a highway and public transport travel time of approximately 30 minutes. Creating a public transport and highway network having a similar travel time to cycling would not be advantageous and it would require increasing in the current public transport and highway travel time; however it would create a more equitable transport. Therefore having a transport policy that aims to increase the number of cyclists in this area could decrease transport equality. A transport policy that would be more equitable in this area would be to create a greater modal split towards public transport and highway modes in order to compensate for the large cycle travel time. It can be seen that a mixture of transport measures could be required in a city depending on the varying socio-economic distribution, distance to destinations, current modal split, mode availability, and current travel times in areas.

The proposed equitable transport appraisal method has the ability to influence policy, network and local level.

- At policy level the use of the Lorenz curve and Gini index enables different transport proposals to be tested to see the effects it has on different users and helps policy makers decide a proposal that generates the most equitable result. This high level approach has the ability to directly impact the lower level users in the most positive way.
- At network level it can determine which routes gain the best results and which routes do not benefit. This is important for two reasons. First that transport is there to improve society and so the benefits can be seen. Secondly areas where the
A transport proposal generates the greatest benefit can be identified. Therefore if the introduction of TSP is required in stages then the 16 QBCs can be prioritised in order of who benefits the most from it.

- At local level this method identifies the current equality level in transport provision and enables policy makers to pin point what is required to achieve a more equitable transport. It delivers real benefits to areas by focusing on specific modes per area that increase accessibility and reduce travel time to key destinations. It prioritises areas in terms of investment in order to reduce the level of inequality both within areas and between areas by implementing proposals that reduce the Gini index.

This approach has the ability to see the effects a transport proposal has at a disaggregate level rather than the aggregate level of a cost benefit analysis which has the ability to hide negative results in one area with large positive results in another area therefore increasing the level of inequality.

What the Lorenz curve and Gini index is unable to do is deal with the health or environment benefits of using a particular mode. Taking the example of the Stillorgan zone with a cycle travel time of 60 minutes and bus and car travel time of approximately 30 minutes, in order to make this zone completely equitable car and bus travel times must increase to that of the bike or cyclists must be removed as a mode as their speed is unlikely to reach that of motorised vehicles. Both options have the potential to cause a negative effect on both the health of citizens and the environment.

References