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CityMobil

Alternative Patronage Estimator

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SIXTH FRAMEWORK PROGRAMME

EXECUTIVE SUMMARY

This document presents deliverable D2.2.6 as part of Work Package 2.2, Sub-Project 2, in the CityMobil project. The main objective of this sub-project is to develop analysis tools to assess the transport and land-use implications of innovative transport technologies if applied now or over the next 30 years.

Deliverable 2.2.6 concerns a model for travel demand prediction which is referred to as 'Alternative Patronage Estimator'. The objective of this model is to be able make quick rough estimates of travel demand for a particular public transport service. This tool allows for a first analysis and quick comparison of several schemes for a new automated public transport service. It is particularly useful in the design process of a new system.

The alternative patronage estimator is a simplified version of the more classical four-step approach. It focuses on the use of one particular public transport system, without estimating demand for other modes. The tool is a GIS-based application that predicts the use of an automated public transport system. The demand for the system is calculated based on socio-economic data (number of inhabitants, jobs, schools, etc) in the GIS-map of your region and the properties of the service.

The developed demand predictor is applied on a case study. Three High-Tech bus routes are considered in the Tyne and Wear region. Trip amounts predicted by the Alternative Patronage Estimator are compared to those predicted by the MARS model. Results of both models have the same order of magnitude.

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1 Notation

i,j,x,y	index for public transport (PT) station
n	total amount of PT stations in the considered area
S	Set of all PT stations
zone i	Zone around PT station i
area	Area around all PT stations
d_{zone}	Zone radius (km)
d_{area}	Area radius (km)
d_{ij}	distance between station i and station j
ρ	Percentage of trips from a station that have their origin within the zone around this station (%)
σ	Percentage of trips towards a station that have their destination within the zone around this station (%)
π	Percentage of trips from a zone around a station that have their destination within the area around this station (%)
c	index for household category
$\alpha^{cat\ c}$	Daily trip production per household in household category c (-)
p	index for trip purpose
β_p	Daily Trip Attraction per household for trip purpose *p* (-)
γ_p	Daily Trip Attraction per retail employee for trip purpose *p* (-)
δ_p	Daily Trip Attraction per non-retail employee for trip purpose *p* (-)
μ	Percentage of trips that are accommodated by the new mode, given that $\|origin\text{-}station\| < d_{zone}$ and $\|station\text{-}destination\| < d_{zone}$ (%)
ε	First parameter of distribution function (-)
ζ	Second parameter of distribution function (-)
o	midpoint (geographical centre) of all PT stations
$P_{zone\ i}^{TOT}$	Total production from zone around station i (-)
$N_{zone\ i}^{hh}$	Number of households in zone around station i (-)
$a_{zone\ i}^{cat\ c}$	Percentage of households in zone around station i belonging to household-category c (%)
$P_{zone\ i}^{within-area}$	Production from zone around station i of trips that have their destination within the area around this station (-)
$A_{zone\ j}^{TOT}$	Total attraction to zone around station j (-)
$N_{zone\ j}^{retail-empl}$	Number of retail employees in zone around station j (-)

$N_{zone\ j}^{non-retail-empl}$	Number of non-retail employees in zone around station j (-)
A_{area}^{TOT}	Total attraction to the considered area j (-)
$P_{zone\ i}^{to\ other\ zones}$	Production from zone around station i to all other zones (as a whole) (-)
m	index for mode of transportation
$P_{zone\ i}^{to\ other\ zones;\ \mathrm{mod}\, m}$	Production for the new mode m from zone around station i to all other zones (as a whole) (-)
$P_{station\ i}^{to\ other\ zones;\ \mathrm{mod}\, m}$	Production for the new mode m from station i to all other zones (as a whole) (-)
$P_{station\ i}^{to\ other\ stations;\ \mathrm{mod}\, m}$	Production for the new mode m from station i to all other stations (as a whole) (-)
$A_{station\ j}^{from\ other\ stations;\ \mathrm{mod}\, m}$	(balanced) Attraction for the new mode m of station j from all other stations (as a whole) (-)
$F(d_{ij})$	Distribution function of trips (as a function of trip distance)
k	index for iteration number
$T^{k\ ((n+2)\times(n+2))}$	OD-matrix for k^{th} iteration step; dimensions (n+2) x (n+2)
t_{ij}	Amount of trips from station i to station j
g_x^k	grow factor for x^{th} row in k^{th} iteration step (-)
g_y^k	grow factor for y^{th} column in k^{th} iteration step (-)

2 Introduction

The alternative patronage estimator is a GIS[1] based application that predicts the use of a public transport system. Travel demand can be estimated for both existing systems and for new technologies (e.g. automated services).

The objective of this model is to be able make quick rough estimates of travel demand for a particular public transport service. This tool allows for a first analysis and quick comparison of several schemes for a new automated public transport service. It is particularly useful in the design process of a new system.

The approach deviates from the classical four-step approach[2] which includes a mode choice logit model that estimates the use of a specific mode as a part of the total amount of trips. The reason for this is that the calibration of mode choice logit models is far from evident

[1] GIS : A Geographical Information System captures, stores, analyzes, manages, and presents data that is linked to location. Technically, GIS is geographic information systems which includes mapping software and its application with remote sensing, land surveying, aerial photography, mathematics, photogrammetry, geography, and tools that can be implemented with GIS software.

[2] 1) Production/attraction 2) Distribution 3) Mode choice 4) Assignment

when certain modes only accommodate a small percentage of the total amount of trips (e.g., for a constant total amount of vehicles, an increase of a small percentage of cars could correspond to a decrease of large percentage of city buses, since the vehicle park contains far more cars than city buses). Because the share of automated public transport in a city will – at least in a first stage - be limited, we suggest another approach.

The alternative methodology, suggested below, will focus on the use of the considered public transport system, without explicitly estimating demand for other modes. The use of mode choice logit models, that are hard to calibrate, is avoided. Furthermore, the alternative tool only estimates travel demand for zones in the immediate surroundings of public transport stations. Zones that are outside the range of influence of public transport stations are not considered.

Based on a tractable number of parameters, the alternative patronage estimator efficiently predicts travel demand for (only) the considered public transport system.

The approach of the alternative patronage estimator is summarized below. Section 4 reports the complete methodology of this GIS based application. The alternative patronage estimator is tested on a case study in Section 5. Finally, conclusions are formulated in Section 6.

3 Approach

Based on the characteristics of the considered public transport system (network infrastructure: location of public transport stations & network connections and qualities of the system: frequency, mean trip speed, capacity,…) and based on the characteristics of the local population (population density, employment, local travel behavior/trip distribution characteristics,…), the use of the public transport service is estimated directly by the GIS application.

Note that the methodology focuses on the use of the considered public transport system, without explicitly estimating travel demand for other modes. This simplified approach is introduced to allow for a quick rough estimate of travel demand for a particular public transport system. Furthermore, only zones in the immediate surroundings of a public transport station are considered.

3.1 Overview of methodology

The procedure starts by creating (influence) zones around the different public transport stations and by creating an area that contains all zones. Subsequently, the following variables are determined:

$P_{zone\ i}^{TOT}$: the production from a zone around station *i* to the rest of the world, for all modes

$P_{zone\ i}^{within-area}$: the production from a zone around station *i* to all destinations within the considered area, for all modes

$P_{zone\ i}^{to\ other\ zones}$: the production from a zone around station *i* to all other zones (as a whole), for all modes

$P_{zone\ i}^{to\ other\ zones;\ \mathrm{mod}\,m}$	:	the production from a zone around station *i* to all other zones (as a whole), for the new mode
$P_{station\ i}^{to\ other\ zones;\ \mathrm{mod}\,m}$	:	the production from station *i* to all other zones (as a whole), for the new mode
$P_{station\ i}^{to\ other\ stations;\ \mathrm{mod}\,m}$	:	the production from station *i* to all other stations (as a whole), for the new mode
T(i,j):		the production from all stations *i* to all other individual stations, for the new mode (i.e. OD-matrix)

The above variables are determined based on

- Geographical data (network infrastructure)
- GIS related data (population density, employment rate, number of workplaces, car-ownership)
- Production and Attraction related data (daily trip productions for different household-categories, daily trip attractions for different trip-categories
- Travel behavioural parameters:
  - π: trip distribution of all modes as a function of trip distance
  - μ: mode choice as a function of proximity origin-station and proximity destination-station
  - ρ: trip distribution of new mode as a function of proximity origin-station
  - σ: trip distribution of new mode as a function of proximity destination-station
  - ε,ζ: trip distribution of new mode as a function of trip distance

3.2 Modelling existing systems and new automated services

The above-mentioned travel behavioural parameters are dependent on the quality and characteristics of the considered public transport system (frequency, mean trip speed, capacity, mean trip length,…). For existing public transport systems, travel behavioural parameters are derived from empirical data in literature. For new systems (e.g. automated services) these parameters can be determined or calibrated based on the results of surveys and stated preference research. Such research should reveal how the considered travel behavioural parameters are affected by the properties of the new service.

4 Methodology

4.1 Division of study area into zones and areas

Around each PT station, create a zone with zone radius d_{zone} and an area with area radius d_{area}.

4.1.1 Zone radius d_{zone}

Zone radius $d_{zone\ i}$ around station i should have one of the following standard lengths: 250m, 500m, 1km, 2km or 5km. The length should be the maximum of these standard lengths for which $d_{zone} \leq \frac{d_{ij,\min}}{2}$ where $d_{ij,min}$ is the shortest of all distances between the considered station i and its adjacent stations j.

Remark:

- Zone radius d_{zone} can be different for different public transport stations. In a first approximation however, the length of d_{zone} would be a constant for all stations.

4.1.2 Area radius d_{area}

An area should include all considered zones (around all considered public transport stations), as shown in Figure 1:

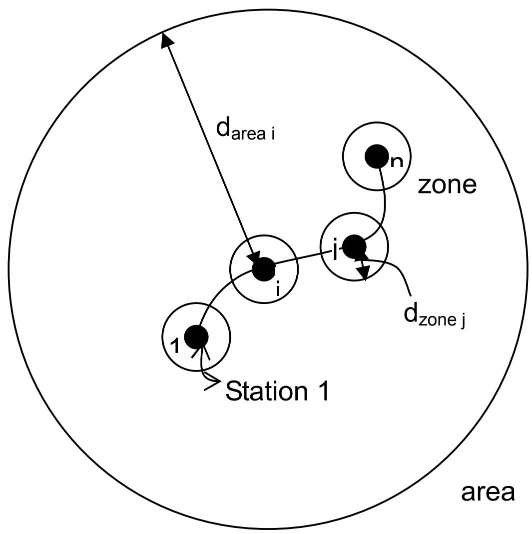


Figure 1: Stations, zones, areas

The area radius d_{area} may have one of the following standard lengths (though this is not mandatory): 1km, 2.5km, 5km, 7.5km, 10km, 15km, 20km, 30km, 50km. The length should be the minimum of these standard lengths for which $d_{area} \geq d_{ij,\max}$ where $d_{ij,max}$ is the longest of all distances between any two different stations. The midpoint *o* of this circular area should be the geographical centre (midpoint) of all stations.

Required input data:

- Exact location of all public transport stations
- Distances between different stations.

4.2 Total Production from zone

$P^{TOT}_{zone\ i}$ **: production from a zone around a station to the rest of the world, for all modes**

Initially, it is assumed that all trips starting in a specific public transport station exclusively originate from within the considered zones. Later on (Section 4.6), a factor ρ is introduced to account for productions from outside of these zones.

- For all stations $i \in S$, determine:

  $$P^{TOT}_{zone\ i} = N^{hh}_{zone\ i} \sum_{c=1}^{9} a^{cat\ c}_{zone\ i}\ \alpha^{cat\ c}$$

  where

  c = index for household-category

  $N^{hh}_{zone\ i}$ = Number of households in zone around station i (from GIS)

  $a^{cat\ c}_{zone\ i}$ = Percentage of households in zone around station i belonging to household-category c; $\sum_{c=1}^{9} a^{cat\ c}_{zone\ i} = 1$ (from GIS)

  $\alpha^{cat\ c}$ = Daily trip production per household in category c (Required Input)

There are 9 different household-categories (income: low, medium or high; car-ownership: 0, 1 or 2+). Default values for daily trip productions are derived from literature (source: US Department of Transportation, 1977a*)* and summarized in Table 1:

Table 1: Default values for Daily trip productions for different household-categories

	0 cars	1 car	2+ cars
low income	$\alpha^{cat\ 1} = 1$	$\alpha^{cat\ 2} = 6$	$\alpha^{cat\ 3} = 10$
medium income	$\alpha^{cat\ 4} = 2$	$\alpha^{cat\ 5} = 8$	$\alpha^{cat\ 6} = 13$
high income	$\alpha^{cat\ 7} = 3$	$\alpha^{cat\ 8} = 9$	$\alpha^{cat\ 9} = 15$

Required input data:

- Detailed GIS-map containing data on the above socio-economic factors (household/population densities, income, car ownership).
- Daily trip productions for different household categories.

4.3 Within-area Production from zone

$P_{zone\ i}^{within-area}$ **: production from a zone around a station to all destinations within the considered area, for all modes**

- For all stations $i \in S$, determine:

  $$P_{zone\ i}^{within-area} = \pi P_{zone\ i}^{TOT}$$

where

π = Percentage of trips from a zone around a station that have their destination within the area around this station (%) (Required Input).

4.4 Production from zone to all other zones (as a whole)

$P_{zone\ i}^{to\ other\ zones}$ **: production from a zone around a station to all other zones (as a whole), for all modes**

4.4.1 Determine Total Attraction to zone

Initially, it is assumed that all trips ending in a specific public transport station exclusively have their destination within the considered zone. Later on (Section 4.7), a factor σ is introduced to account for attractions outside of these zones.

- For all stations $j \in S$, determine:

  $$A_{zone\ j}^{TOT} = \sum_{p=1}^{3} \beta_p N_{zone\ j}^{hh} + \gamma_p N_{zone\ j}^{retail-empl} + \delta_p N_{zone\ j}^{non-retail-empl}$$

  where

  p = index for trip-purpose

  $N_{zone\ j}^{hh}$ = Number of households in zone around station j (from GIS)

  $N_{zone\ j}^{retail-empl}$ = Number of retail employees in zone around station j (from GIS)

  $N_{zone\ j}^{non-retail-empl}$ = Number of non-retail employees in zone around station j (from GIS)

  β_p = Daily trip attraction per household for trip purpose p (Required Input)

  γ_p = Daily trip attraction per retail employee for trip purpose p (Required Input)

  δ_p = Daily trip attraction per non-retail employee for trip purpose p (Required Input)

There are 9 different trip-categories (purpose: Home-Based Work (HBW), Home-Based Other (HBO) or Non-Home-Based (NHB); attraction-type: per household, per non-retail employee and per retail-employee). Default values for daily trip attractions are derived from literature (source: US Department of Transportation, 1977b) and summarized in Table 2:

Table 2: Default values for Daily trip attractions for different trip-categories

	per household	per non-retail employee	per retail employee
Home-Based-Work	$\beta_1 = 0$	$\gamma_1 = 1.7$	$\delta_1 = 1.7$
Home-Based-Other	$\beta_2 = 1$	$\gamma_2 = 2$	$\delta_2 = 7.5$
Non-Home-Based	$\beta_3 = 1$	$\gamma_3 = 1$	$\delta_3 = 4$

<u>Required input data:</u>

- Detailed GIS-map containing data on the above socio-economic factors (household/population density and employment (retail and non-retail)).
- Daily trip attractions for different trip-categories.

4.4.2 Determine Total Attraction to area

- For the considered area, determine:

$$A_{area}^{TOT} = \sum_{p=1}^{3} \beta_p N_{area}^{hh} + \gamma_p N_{area}^{retail-empl} + \delta_p N_{area}^{non-retail-empl}$$

where

N_{area}^{hh} = Number of households in the considered area (<u>from GIS</u>)

etc…

4.4.3 Determine Production from zone to all other zones (as a whole)

The production to other zones is determined as the within-area production, multiplied by the ratio of zonal attractions to area attraction:

- For all stations $i \in S$, determine:

$$P_{zone\ i}^{to\ other\ zones} = P_{zone\ i}^{within-area} \frac{\sum_{j \in \{S|i\}} A_{zone\ j}^{TOT}}{A_{area}^{TOT}}$$

4.5 Production for the new mode from zone to all other zones (as a whole)

$P_{zone\ i}^{to\ other\ zones;\ \mathrm{mod}\, m}$ **: production from a zone around a station to all other zones (as a whole), for the new mode**

A certain amount of all trips to and from the considered zones will be accommodated by the considered mode:

- For all stations $i \in S$, determine:

$$P_{zone\ i}^{to\ other\ zones;\mathrm{mod}\ m} = \mu\, P_{zone\ i}^{to\ other\ zones}$$

where

μ = Percentage of trips that are accommodated by the new mode, given that the distance between origin & station < d_{zone} and the distance between station & destination < d_{zone} (%), i.e. given that the origin and destination of the trips are located within the zones around the considered stations (Required Input).

At this stage, it is still assumed that all trips from station *i* to station *j* are exclusively made by travellers who live/work/have their origin in the zone around station *i* and work/live/have their destination in the zone around station *j*. In the next Sections 4.6 and 4.7, correction factors ρ and σ are introduced to account for travellers choosing public transport, despite the fact that their origin or destination is outside the considered zone, i.e. despite the fact that their pre- and post-trip distances are high.

Remark:

It needs to be noticed that mode choice parameter *μ* is a crucial parameter in the suggested methodology. Parameter *μ* is a function of the quality and characteristics of the considered public transport system, including frequency, headways, mean trip speed, capacity, mean trip length, reliability, punctuality, image,… For new automated systems, this parameter *μ* would ideally be determined based on the results of surveys and stated preference research. An example of stated preference research that was performed in the framework of this project can be found in WP 2.3, D 2.3.1, Section 8 ('Stated Preference Survey'). Although the exact determination of parameter *μ* for different automated public transport modes is outside the scope of research on this alternative methodology, it needs to be stressed that an accurate estimate of this parameter *μ* is of major importance for the Alternative Patronage Estimator in order to produce reliable results.

4.6 Production for the new mode from station to all other zones (as a whole)

$P_{station\ i}^{to\ other\ zones;\ \mathrm{mod}\, m}$ **: production from a station to all other zones (as a whole), for the new mode**

So far, it was assumed that all trips of the considered mode exclusively originate from within the considered zones (this is what $P_{zone\ i}^{to\ other\ zones;\mathrm{mod}\ m}$ refers to). However, a certain percentage of all trips of the considered mode originate from outside of these zones. Factor ρ is introduced to account for these trips (note that the amount of these extra trips corresponds to $P_{station\ i}^{to\ other\ zones;\mathrm{mod}\ m} - P_{zone\ i}^{to\ other\ zones;\mathrm{mod}\ m}$):

- For all stations $i \in S$, determine:

$$P_{station\ i}^{to\ other\ zones;\mathrm{mod}\ m} = \frac{100}{\rho} P_{zone\ i}^{to\ other\ zones;\mathrm{mod}\ m}$$

where

ρ = Percentage of trips from a station that have their origin within the zone around this station (%) (Required Input)

4.7 Production for the new mode from station to all other stations (as a whole)

$P_{station\ i}^{to\ other\ stations;\ \mathrm{mod}\, m}$ **: production from a station to all other stations (as a whole), for the new mode**

- For all stations $i \in S$, determine:

  $$P_{station\ i}^{to\ other\ stations;\mathrm{mod}\ m} = \frac{100}{\sigma} P_{station\ i}^{to\ other\ zones;\mathrm{mod}\ m}$$

  where

  σ = Percentage of trips towards a station that have their destination within the zone around this station (%) (Required Input)

4.8 Production for the new mode from station to all other individual stations

T: OD-matrix: production from each station to all other individual stations, for the new mode

4.8.1 Determine balanced attraction for the new mode of station from all other stations (as a whole)

Over a long enough period of time, the total amount of produced trips should equal the total amount of attracted trips. To ensure this conservation-of-trips principle, production and attraction are balanced. Target value is the total amount of produced trips, since productions are usually more reliable than attractions (population density is more predictable than job density). The attraction from other zones is proportional to the total attraction, with proportionality factor = balancing factor C_1:

- For all stations $j \in S$, determine:

  $$A_{station\ j}^{from\, other\, stations;\mathrm{mod}\, m} = A_{zone\ j}^{TOT} \frac{\sum_{i \in S} P_{station\ i}^{to\ other\ stations;\mathrm{mod}\, m}}{\sum_{i \in S} A_{zone\ i}^{TOT}} = C_1\, A_{zone\ j}^{TOT}$$

  where C_1 = balancing factor

4.8.2 Trip distribution: Determine OD-matrix (individual trips)

Estimate Distribution function F(dij)

The distribution function $F(d_{ij})$ distributes Productions and Attractions over different zones, proportional to the values of the distribution function. It projects trip distribution of the new mode as a function of trip distance.

As indicated by Ben-Akiva M. and Lerman S. (1985), it is assumed that the distribution function has the following functional form:

$$F(d_{ij}) = (d_{ij})^{-\varepsilon} e^{-\varsigma d_{ij}}$$

Parameters ε and ζ are coefficients for the distribution function (Required Input).

For all OD-relations ij, determine amount of trips t_{ij}: Gravity model (distribution)
FOR ALL OD-RELATIONS IJ, DETERMINE VALUES OF DISTRIBUTION FUNCTION

Example:

Values of F(dij)					
	A	B	C	SUM	Prod Pi
A	34	18	4	56	100
B	18	34	9	61	100
C	4	9	34	47	200
SUM	56	61	47	164	
Attr Aj	200	150	50		400

FOR ALL OD-RELATIONS IJ, BALANCE PRODUCTIONS AND ATTRACTIONS

Since $\sum_j t_{ij} \neq P_i$ and $\sum_i t_{ij} \neq A_j$, Balance P's and A's using Furness algorithm:

Repeat:

adjust productions (apply 'correction factor' g_x on each element of row i, such that $\sum_j t_{ij} = P_i$)

adjust attractions (apply 'correction factor' g_y on each element of column j, such that $\sum_i t_{ij} = A_j$)

until convergence (i.e. until correction factors approximate 1.0)

Remarks:

- for most cases, this Furness-process converges to a stable solution
- $a_i = g_x^1 * g_x^2 * \ldots$ and $b_j = g_y^1 * g_y^2 * \ldots$ are referred to as "balancing factors"
  → $t_{ij} = a_i b_j F_{ij}(d_{ij})$
- Gravity model equivalent with discrete choice model:
  $t_{ij} = a_i b_j F_{ij}(d_{ij})$
  where $a_i b_j$ = K exp (V_i) exp (V_j)
  $F(d_{ij}) = e^{-\varsigma d_{ij}}$
  V_i = utility of an activity in i (e.g. living)
  V_j = utility of an activity in j (e.g. working)
  V_{ij} = utility for making trip ij

Example:

Amount of trips t_{ij} (gravity model)					
	A	B	C	SUM	a_i
A	78	22	0	100	1.01
B	50	48	2	100	1.23
C	72	80	48	200	7.85
SUM	200	150	50	400	
b_j	2.27	1.14	0.18		

4.9 Summary of required input data

4.9.1 Geographical data

- Exact location of all public transport stations
- Trip distances between different stations.

4.9.2 GIS related data

- Household/population densities, data on income and car ownership
- Employment rate and number of workplaces (both for retail and non-retail)

4.9.3 Production and Attraction related data

- Daily trip productions for different household-categories
- Daily trip attractions for different trip-categories

4.9.4 Travel behavioural parameters

- π: Percentage of trips from a zone around a certain station that have their destination within the area around this station (%)
- μ: Percentage of trips that are accommodated by the new mode, if the origin and destination of the trips are located within the zones around the considered stations (%)
- ρ: Percentage of trips from a certain station that have their origin within the zone around this station (%)
- σ: Percentage of trips towards a certain station that have their destination within the zone around this station (%)
- ε,ζ: First and second parameters of distribution function (-)

5 Case Study

The alternative patronage estimator will now be used to forecast travel demand for a public transport system in a practical case. We consider here the high-tech bus schemes of the Tyne & Wear case study as described in Chapter 3 of the 'Tyne and Wear MARS modeling results' document. For the location and description of the Tyne and Wear region, we refer to this Chapter 3. The considered high-tech bus routes and the proposed bus stops are illustrated in Figures 3.5 up to 3.7 of the previously mentioned document.

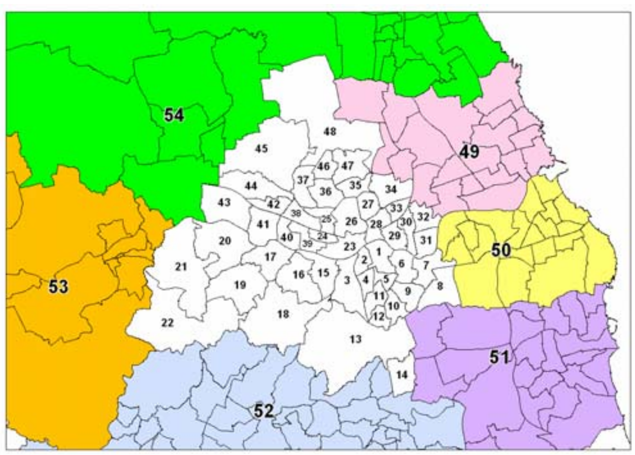
The demand for these 3 bus routes will now be predicted by the alternative patronage estimator. First, an overview of the model input is given. The results of the case study are discussed in Section 5.3.

5.1 Input

5.1.1 GIS-map

First, a Geographical Information System (GIS) map of the Tyne and Wear region is loaded into the model. The case study area is divided in 54 separate zones, as indicated in

Figure 2.



1	Bede	19	Winlanton	37	Blakelaw
2	Bensham	20	Ryton	38	Fenham
3	Teams	21	Crawcrook & Greenside	39	Benwell
4	Saltwell	22	Chopwell & Rowlands Gill	40	Scotswood
5	Deckham	23	West City	41	Lemington
6	Felling	24	Elswick	42	Denton
7	Pelaw & Heworth	25	Wingrove	43	Newburn
8	Wrekendyke	26	Moorside	44	Westerhope
9	Leam	27	Jesmond	45	Woolsington
10	High Fell	28	Sandyford	46	Fawdon
11	Low Fell	29	Byker	47	Grange
12	Chowdene	30	Monkchester	48	Castle
13	Lamesley	31	Walker	49	North Tyneside
14	Birtley	32	Walkergate	50	South Tyneside
15	Dunston	33	Heaton	51	Sunderland
16	Whickham North	34	Dene	52	Chester-le-Street
17	Blaydon	35	South Gosforth	53	Tynedale
18	Whickham South	36	Kenton	54	Castle Morpeth

Figure 2: Different zones of the Tyne and Wear case study region

For each of these zones, the GIS map includes data on

- Population
- Employment rate
- Number of workplaces
- Car ownership

These data are input for the patronage estimator.

5.1.2 High-Tech Bus Network

High-tech bus stations and routes

The following step consists of defining the different bus stops and network connections on this GIS map. **Figure 3** shows the result of this step:

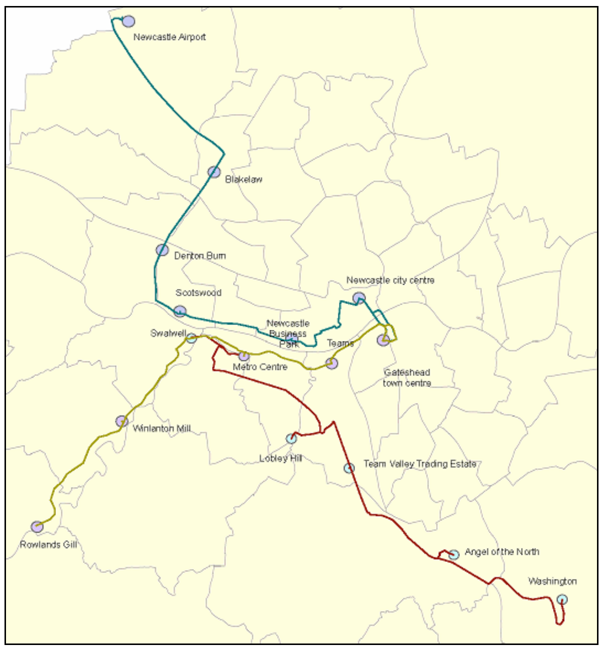


Figure 3: Bus stops and network connections of three high-tech bus schemes in Tyne and Wear

The key facts for these high-tech bus schemes are summarized below:

Table 3: Tyne and Wear high-tech bus schemes key facts

Scheme	Zones	Approximate route length (km)	Number of stops	Typical distance between stops (km)	Key areas/facilities on route
1	17,16,15, 3, 13, 51	18,3	6	3	Swalwell, Metro Centre, Lobley Hill, Team Valley Trading Estate, Angel of the North, Washington
2	45,37,42,41,40,39,23,21	18,6	7	2,5	Newcastle Airport, Blakelaw, Dneton Burn, Scotswood, Newcastle Business Park, Newcastle city centre, Gateshead town centre
3	22,19,17,16,15,3,2,1	14	5	3	Rowland Gill, Winlanton, Metro Centre, Teams, Gateshead town centre

Zones

Around each bus station, a zone with zone radius d_{zone} is created. Zone radius $d_{zone\ i}$ around station i is the maximum of the following standard lengths: 250m, 500m, 1km, 2km or 5km, for which $d_{zone} \leq \frac{d_{ij,\min}}{2}$ where $d_{ij,min}$ is the shortest of all distances between the considered station i and its adjacent stations j. In this case, all zones of each route have a radius of 500 m.

Areas

In this step an area is created around all zones of a specific route. The midpoint of the area is the geographical midpoint of the considered stations. The area radius d_{area} is the minimum of the following standard lengths (though this is not mandatory): 1km, 2.5km, 5km, 7.5km, 10km, 15km, 20km, 30km, 50km, for which $d_{area} \geq d_{ij,\max}$ where $d_{ij,max}$ is the longest of all distances between any two different stations. In this case study, the area radius equals 15 km for all three bus routes.

5.1.3 Production and Attraction related parameters

Households are differentiated towards income (low, medium, high) and towards car-ownership (0 cars, 1 car, 2 or more cars), resulting in 9 different household-categories. The daily trip productions per household are adopted from literature (US Department of Transportation 1977a) and summarized in Table 1 of Section 4.2.

Concerning trip attractions, trips are differentiated towards trip purpose (Home-Based Work (HBW), Home-Based Other (HBO) or Non-Home-Based (NHB)) and towards attraction type (per household, per non-retail employee and per retail-employee). The daily trip attractions per trip-category are adopted from literature (US Department of Transportation 1977b) and summarized in Table 2 of Section 4.4.1.

5.1.4 Travel behavioural parameters

For the new High-Tech bus service, travel behavioural parameters would ideally be determined based on Stated Preference Research. For this case study, it seems reasonable to assume that the new High-Tech bus service operates in a similar way to existing bus services. Zone/area-related parameters and parameters of the distribution function for High-Tech bus will be adopted from those for a regular bus service, which are derived from empirical data in literature. The mode choice related parameter will be adopted from MARS modeling results.

Zone-radius related parameters

Parameter ρ (%) reflects the percentage of trips from a certain station that have their origin within the zone around this station. This parameter is derived from trip distribution characteristics of the considered bus mode as a function of the proximity between origin and bus station. For public transport mode bus, values for ρ are derived from literature (source: Research on bus transportation behaviour in Belgium, (PHL, 2001a) and (Toint et al., 2001)) and summarized in **Table 4**:

Table 4: Values for ρ as a function of d_{zone}

d_zone (km)	ρ (%)
0,25	52,7
0,5	80,7
1	98,4
2	99,8
5	100
5+	100

Given a zone radius of 500m around each bus station in this case study, parameter ρ equals 80.7%.

Parameter σ (%) reflects the percentage of trips towards a certain station that have their destination within the zone around this station. This parameter is derived from trip distribution characteristics of the considered bus mode as a function of the proximity between destination and bus station. For public transport mode bus, values for σ are derived from literature (source: Research on bus transportation behaviour in Belgium, (PHL, 2001a) and (Toint et al., 2001)) and summarized in **Table 5**:

Table 5: Values for σ as a function of d_{zone}

d_zone (km)	σ (%)
0,25	60,2
0,5	86,7
1	96,8
2	99,5
5	100
5+	100

Given a zone radius of 500m around each bus station in this case study, parameter σ equals 86.7%.

Area-radius related parameters

Parameter π (%) reflects the percentage of trips from a zone around a station that have their destination within the area around this station. This parameter is derived from trip distribution characteristics of all modes as function of trip distance. For public transport mode bus, values for π are derived from literature (source: Research on bus transportation behaviour in Belgium, (PHL, 2001b)) and summarized in **Table 6**:

Table 6: Values for π as a function of d_{area}

d_area (km)	π (%)
1	1,9
2,5	6,6
5	22,6
7,5	36,6
10	52,2
15	66,9
20	75,3
30	83,3
50	95,2
50+	100

Given an area radius of 15 km in this case study, parameter π equals 66.9%.

Mode choice related parameter

Parameter μ (%) reflects the percentage of trips that are accommodated by the new mode, if the origin and destination of the trips are located within the zones around the considered stations. This parameter is adopted from MARS modeling results (Muir (2009)). A distinction is made between the M0 test, which represents a do-nothing scenario and the M4 test, which involves the introduction of High-Tech Bus.

Based on Tables 5.10, 5.11 and 5.12 of the 'Tyne and Wear MARS modeling results' document, the following values for μ were determined (cf. **Table 7**):

Table 7: Values for μ

scenario	μ (%)
M0 peak (2010)	16.7
M0 off peak (2010)	14.3
M0 daily (2010)	15.6
M4 peak (2010)	22.7
M4 off-peak (2010)	24.2
M4 daily (2010)	23.4

Parameters of the Distribution function

Parameters ε and ζ are the first and second parameters of the distribution function $F(d_{ij}) = (d_{ij})^{-\varepsilon} e^{-\varsigma d_{ij}}$. The distribution function $F(d_{ij})$ distributes Productions and Attractions over different zones, proportional to the values of the distribution function. It projects trip distribution of the new mode as a function of trip distance. For transport mode bus, the distribution function is derived from literature (source: Research on bus transportation behaviour in Belgium, (PHL, 2001c)).

In

Figure 4 the blue curve represents empirical results.

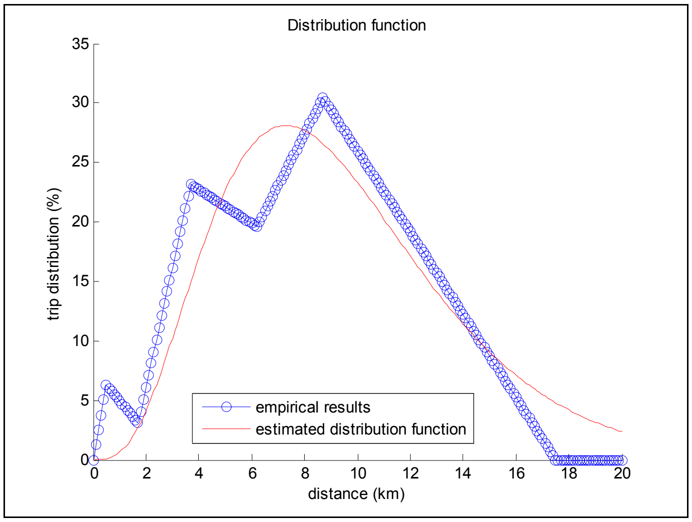


Figure 4: Distribution function for bus trips

The red curve is the function with functional form $F(d_{ij}) = (d_{ij})^{-\varepsilon} e^{-\varsigma d_{ij}}$ that most closely approximates the blue curve according to the method of the least square errors.

The resulting values for ε and ζ are as follows:

Table 8: Values for parameters of trip distribution function

ε	-3,38
ζ	0,46

The distribution function can be written as $F(d_{ij}) = (d_{ij})^{3.38} e^{-0.46 d_{ij}}$.

5.2 Model run

Based on the input described above, the patronage estimator now determines travel demand for each bus route. For all bus stations the following variables are determined:

$P_{zone\ i}^{TOT}$: the production from a zone around a station to the rest of the world, for all modes

$P_{zone\ i}^{within-area}$: the production from a zone around a station to all destinations within the considered area, for all modes

$P_{zone\ i}^{to\ other\ zones}$: the production from a zone around a station to all other zones (as a whole), for all modes

$P_{zone\ i}^{to\ other\ zones;\ \mathrm{mod}\, m}$: the production from a zone around a station to all other zones (as a whole), for the new mode

$P_{station\ i}^{to\ other\ zones;\ mod\,m}$: the production from a station to all other zones (as a whole), for the new mode

$P_{station\ i}^{to\ other\ stations;\ mod\,m}$: the production from a station to all other stations (as a whole), for the new mode

T(i,j): the production from a station to all other individual stations, for the new mode (i.e. OD-matrix)

5.3 Results

Output of the alternative patronage estimator is a travel demand forecast for each of the considered high-tech bus routes. The results are presented in the form of Origin-Destination matrices T_{ij} predicting the amount of trips on a daily basis from origin stations *i* (matrix rows) to destination stations *j* (matrix columns):

Table 9: Amount of bus trips on a daily basis for bus route 1 – scenario M0 (do-nothing):

Amount of trips (daily basis)							
From \ To	Swalwell	Metro Centre	Lobley Hill	Team Valley TE	Angel o.t. North	Washington	Prod's (sum)
Swalwell	0	3	289	183	94	24	585
Metro Centre	2	0	41	32	20	6	100
Lobley Hill	83	18	0	25	91	59	280
Team Valley TE	118	32	56	0	88	142	443
Angel of the North	68	22	232	100	0	171	595
Washington	18	7	159	170	181	0	531
Attractions (sum)	289	80	777	510	474	402	2533

Table 10: Amount of bus trips on a daily basis for bus route 1 – scenario M4 (introduction HT-Bus):

Amount of trips (daily basis)							
From \ To	Swalwell	Metro Centre	Lobley Hill	Team Valley TE	Angel o.t. North	Washington	Prod's (sum)
Swalwell	0	4	434	274	140	36	878
Metro Centre	3	0	61	49	30	8	149
Lobley Hill	125	27	0	37	137	89	420
Team Valley TE	177	47	84	0	133	213	664
Angel of the North	103	33	348	150	0	257	893
Washington	28	10	239	255	271	0	796
Attractions (sum)	434	121	1166	765	711	604	3800

On a daily basis, 289 trips are made from Swalwell to Lobley Hill, 183 trips from Swalwell to Team Valley Trading Estate etc…

Table 11: Amount of trips on a daily basis for high-tech bus route 2 – scenario M0 (do-nothing):

Amount of trips (daily basis)								
From \ To	NC Airport	Blakelaw	Denton Burn	Scostswood	NC Bus Park	NC city centre	Gateshead	Prod's (sum)
NC Airport	0	525	585	98	53	20	2	1277
Blakelaw	198	0	109	67	84	49	6	519
Denton Burn	261	129	0	18	81	73	11	580
Scostswood	295	537	119	0	49	95	18	1119
NC Business Park	165	699	571	51	0	34	14	1531
NC city centre	97	637	803	154	54	0	3	1741
Gateshead TC	9	67	95	22	13	1	0	206
Attractions (sum)	1025	2595	2283	410	335	272	54	6971

Table 12: Amount of bus trips on a daily basis for bus route 2 – scenario M4 (introduction HT-Bus):

Amount of trips (daily basis)								
From \ To	NC Airport	Blakelaw	Denton Burn	Scostswood	NC Bus Park	NC city centre	Gateshead	Prod's (sum)
NC Airport	0	787	878	147	79	30	3	1915
Blakelaw	297	0	164	101	127	74	10	779
Denton Burn	391	194	0	26	122	110	17	870
Scostswood	443	806	178	0	73	142	27	1678
NC Business Park	247	1049	857	76	0	51	21	2296
NC city centre	145	956	1205	232	81	0	4	2612
Gateshead TC	13	101	143	32	20	1	0	309
Attractions (sum)	1537	3892	3424	615	502	408	81	10457

Table 13: Amount of trips on a daily basis for high-tech bus route 3 – scenario M0 (do-nothing):

Amount of trips (daily basis)						
From \ To	Rowlands Gill	Winlanton	Metro Centre	Teams	Gateshead TC	Prod's (sum)
Rowlands Gill	0	396	246	31	10	699
Winlanton	259	0	113	26	12	413
Metro Centre	500	353	0	6	14	860
Teams	184	230	18	0	2	430
Gateshead TC	69	117	34	1	0	221
Attractions (sum)	1013	1096	411	65	39	2626

Table 14: Amount of bus trips on a daily basis for bus route 3 – scenario M4 (introduction HT-Bus):

Amount of trips (daily basis)						
From \ To	Rowlands Gill	Winlanton	Metro Centre	Teams	Gateshead TC	Prod's (sum)
Rowlands Gill	0	594	368	47	16	1048
Winlanton	389	0	170	38	19	620
Metro Centre	751	530	0	9	21	1291
Teams	276	345	27	0	4	645
Gateshead TC	103	175	51	2	0	332
Attractions (sum)	1519	1644	617	97	59	3940

5.4 Comparison with MARS modelling results

Based on Tables 5.10, 5.11 and 5.12 of the 'Tyne and Wear MARS modeling results' document, the following amounts of daily bus trips on all 3 bus routes were determined (cf. **Table 15**):

Table 15: Daily bus trips determined by MARS

scenario	bus trips	μ (%)
M0 peak (2010)	4507	16.7
M0 off peak (2010)	6040	14.3
M0 daily (2010)	15054	15.6
M4 peak (2010)	6545	22.7
M4 off-peak (2010)	11174	24.2
M4 daily (2010)	24264	23.4

M0 represents a do-nothing scenario; M4 involves the introduction of High-Tech Bus. Daily trip amounts are calculated as the sum of off-peak trips (off-peak lasts for 12 hours) and two times peak trips (peak lasts for 2 hours). Table 16 compares the daily amount of bus trips determined by MARS, with those determined by the Alternative Patronage Estimator (APE):

Table 16: Comparison bus trips MARS versus bus trips APE

scenario	bus trips MARS	bus trips APE	% difference
M0 daily (2010)	15054	12131	19%
M4 daily (2010)	24264	18196	25%

Compared to the MARS model, the Alternative Patronage Estimator predicts 19% to 25% less trips on a daily basis. Results of both models have the same order of magnitude.

6 Conclusions

The alternative patronage estimator is a GIS based application that predicts the use of a public transport system. Based on a tractable number of parameters, the alternative patronage estimator efficiently predicts travel demand for both existing systems and new technologies (e.g. automated services) of public transport. The use of other transportation modes is not explicitly estimated.

The developed demand predictor is applied on a case study. Three High-Tech bus routes are considered in the Tyne and Wear region. Travel behavioural parameters for this High-Tech bus system are adopted from those for a regular bus service which are derived from empirical data in literature. The mode choice parameter is adopted form Tyne and Wear MARS modeling results (Muir (2009)). Results of the case study are presented in the form of Origin-Destination matrices predicting the daily amount of trips from each origin station to each destination station. Trip amounts predicted by the Alternative Patronage Estimator are compared to those predicted by the MARS model. Results of both models have the same order of magnitude.

7 References

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