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MODELLING PASSENGER DEMAND FOR PARKWAY RAIL STATIONS

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1. INTRODUCTION AND OBJECTIVES

Most of the stations which serve inter-urban, inter-regional and international rail networks are located in central urban areas. Although the distance travelled to stations is longer for longer distance journeys, since there tends to be less choice of stations providing direct services and the access time forms a lower proportion of the overall generalised cost, the majority of traffic originates from a relatively small catchment area. The average distance travelled to stations is around 10km for longer distance largely London based rail trips (Rail Operational Research, 1995) and around 5km for medium distance regional trips (Wardman and Tyler, 2000). On the other hand, suburban stations tend to serve distinct local populations and essentially provide for relatively short distance rail journeys typically into major urban centres and act as 'feeder' stations into the larger network. In addition, there are stations which act primarily as destinations, such as those serving shopping centres, sports facilities and airports, whilst yet others serve an important role in facilitating interchange between different routes and services.

Interest in a different type of station emerged in the 1980's. What has been termed a Parkway station does not necessarily serve a local population but does act as a convenient out-of-town station for inter-urban rail journeys, otherwise known as a "railhead". Easy road access combined with good parking facilities and an attractive rail service are deemed to be essential features of the Parkway product[1]. Transmark (1988) stated that, "The objective of Parkway stations is to increase car accessibility to the rail network" and they distinguished between three types of Parkway station. Firstly, a new station close to suburban populations located in a strategic position on the road network to complement existing urban stations where car access is impeded by road congestion. An example is Bristol Parkway. Secondly, a new station to serve remote population off the main line, such as Tiverton and Bodmin Parkways. Thirdly, the expansion of car parking at an existing station where road access is good and the station can be re-marketed as a Parkway, such as Didcot.

Whilst most stations serving inter-urban trips act as both an origin (generator) and destination (attractor) station in roughly equal measure, Parkway stations generate far more rail traffic than they attract. For example, the ratio of trips originating at Parkway stations to trips with destinations at Parkway stations was around 1.6 in 1999. Contrast this with ratios of 0.82 for London stations, 1.03 for the major regional commercial centre of Leeds, and 0.54 for the major tourist attraction of Stratford upon Avon.

Although the definition of exactly what is and is not a Parkway station is not a precise one, and indeed any station offering inter-urban services can attract travellers from quite remote origins, there were 13 so-called Parkway stations in Britain in 1999 and two have subsequently been opened. They range from major stations such as Birmingham International and Bristol Parkway with annual revenues in 1999 of £12m and £7.7m respectively through to Tame Bridge Parkway and Sutton Parkway with revenues around £100,000. To put these figures into context, the average revenue per station in Great Britain in 1999 was £1.4m.

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[1] Similar stations provided for shorter distance trips are known as 'park and ride' stations.

Rail Operational Research (1995) examined very large data sets containing the origins of rail travellers. Around 50% of travellers making long distance trips on key inter-city routes use a station that is not their closest. This figure falls to 10% in the South East where the much denser network is geared to serving the predominant London based flows. The main two railheading stations in Great Britain were both Parkway stations. The proportion of travellers categorised as railheaders was 92% at Birmingham International and 85% at Bristol Parkway. The figures at Bodmin Parkway, Didcot Parkway and Tiverton Parkway were 72%, 57% and 50% respectively. Compare these with figures for some principal stations on the rail network in Great Britain: Manchester Piccadilly (64%), Birmingham New Street (58%), Newcastle (56%), Leeds (48%), Edinburgh (40%), York (37%) and Bristol Temple Meads (34%). Table 1 provides figures drawn from Rail Operational Research (1995) which indicate the average distance travelled to the Parkway stations covered in that study and to a comparable station in the area. The expected longer access distances for Parkway stations are clearly apparent.

Table 1: Average Distances Travelled to Stations

Parkway Station	km	Reference Station	km
Tiverton Parkway	28	Taunton	20
Port Talbot Parkway	27	Swansea	21
Birmingham International	22	Birmingham New Street	12
Bodmin Parkway	16	Truro	9
Bristol Parkway	12	Bristol Temple Meads	7
Didcot Parkway	11	Oxford	10

Considerable interest in Parkway stations remains. Proposals to at least consider new Parkway stations have been a common feature of bids for train operating company franchises in Great Britain. The Midland Mainline franchise extension deal provides for a major new Parkway in the East Midlands linked to the M1 motorway and East Midlands Airport (SRA, 2002). This has also been investigated by multi-modal studies for the corridor (Atkins et al., 2002) and was an option in Railtrack's network management statement (Railtrack, 2000). As part of a recent extended franchise bid, the Great North Eastern Railway, which operates between London and West Yorkshire, the North East and Scotland, proposed three new Parkway stations: adjacent to the M25 orbital motorway near London; near the M62 motorway south of Leeds; and on the southern outskirts of Edinburgh. Other multi-modal studies are evaluating Parkway station proposals. For example, Arup and Scott Wilson Kirkpatrick (2002) in their West Midlands to North West multi-modal study evaluated three Parkway stations, with one recommended for implementation, whilst MVA et al. (2001) are considering three Parkway stations in their South and West Yorkshire multi-modal study.

The Strategic Rail Authority has commissioned a study to examine the costs and benefits of various options for a new North-South high speed line (SRA, 2002). A high speed line or small network of lines cannot serve as many locations as the existing network, and even directly serving those city centres which are in the vicinity of the route will have an adverse impact on average rail speeds which runs counter to the whole purpose of the scheme. Parkway stations providing remote access to the high speed network, particularly with rail feeder services, become an attractive option. The high speed rail link between the Channel Tunnel and Central London, which is due to be fully open by 2007, will include a Parkway station at Ebbsfleet in North Kent, about 40 kilometres from London. Studies have indicated that it will have a large catchment area and be particularly attractive to commuters.

Parkway stations which are strategically located and which possess suitable facilities can appeal to a much broader catchment area than traditional city centre sites. This can be expected to stimulate modal switch, helping to satisfy both the commercial objectives of rail operators and the strategic interests of central, regional and local government. In addition, Parkway stations can also provide a means by which a train operator can better compete with a rival operator. For example, the study into the now opened Warwick Parkway on the Chiltern Line between Birmingham and London (Steer Davies Gleave, 1997a) forecast that much of the new traffic would be abstracted from Virgin West Coast services on a parallel route.

This paper reports the development and application of a new Parkway forecasting model which was conducted for the Association of Train Operating Companies (ATOC). The research was undertaken as part of an extensive update to the Passenger Demand Forecasting Handbook (ATOC, 2002), which recommends demand forecasting frameworks and associated parameters that are widely used in the railway industry in Great Britain. The objective was to develop a new Parkway station forecasting model that had more desirable properties and was more straightforward to apply than the existing recommended procedure. The focus is entirely upon inter-urban journeys of over 80 kilometres.

2. BACKGROUND

2.1 Current Handbook Forecasting Procedure

The edition of the Passenger Demand Forecasting Handbook in place when this research commenced (ATOC, 1997) contained what was termed a Parkway Access Model. It was developed from a number of studies conducted in the early 1980’s. The catchment of the Parkway station is specified to be an area within a one hour drive time. This catchment area is split into zones and the number of rail trips from each zone to each destination station via existing stations has to be estimated. The access times from each zone to the existing stations and the new Parkway station are calculated. These are combined with the rail generalised journey times (GJT) between the origin stations and each destination. The GJT is the representation of timetable related train service quality and expresses the service frequency and interchange aspects of the journey in equivalent time units alongside the station-to-station journey time. Access costs and differences between fares at each station can be converted into time units using appropriate values of time and entered into the overall GJT measure.

The route with the lowest overall GJT to the relevant destination station is identified both with and without the Parkway station. When the Parkway offers a lower GJT between the origin zone and the destination station, all the demand is assumed to divert to the Parkway station. An elasticity to GJT is then used to calculate demand growth on the basis of the reduction in GJT offered by the Parkway. This process is repeated for each combination of origin zone and destination station.

There are a number of deficiencies with this forecasting approach. Firstly, it requires a large amount of information that train companies do not routinely have at their disposal. Train companies do not know the precise origins of their travellers, only the origin stations, and acquiring the necessary origin-destination data can be an expensive task. Secondly, little guidance is provided on the number of competing stations to consider or the zoning system to use, whilst the one hour catchment area is a matter of judgement rather than an empirical finding. Thirdly, the introduction of a Parkway station can be expected to improve the overall attractiveness of rail, and indeed it cannot make it less attractive. Although the attractiveness of rail is improved, it will not be allowed to impact on rail demand unless a lower GJT is offered by the Parkway station than all existing stations. Even then, the impact on rail demand is forecast to be the entire GJT reduction and this will clearly overstate the benefits of the Parkway station since not all individuals would regard it to be better. A more sophisticated measure of the attractiveness of rail after the opening of a Parkway station, consistent with utility maximising behaviour, is required to form the basis of the forecasting model. Finally, Parkway stations are likely to appeal to a different type of traveller, particularly business travellers and those accessing by car. The use of demand parameters estimated to rail travellers in general cannot be expected to be appropriate to this distinct market segment.

2.2 Other Forecasting Procedures and Previous Research

Forecasting the effects of changes in accessibility to the rail network have been addressed either through the use of aggregate approaches which generally make use of elasticity measures or by the application of disaggregate models which have been calibrated upon individuals' choices amongst relevant alternatives. These two approaches are discussed in turn.

Aggregate Forecasting Procedures

The initial Parkway Access Model was based on deduced access time elasticities. Studies examining various potential Parkway stations at Tiverton, Barnstaple and Plymouth (Steer Davies Gleave, 1984), Iver (Steer Davies Gleave, 1985a), Hinksey (Steer Davies Gleave, 1985b), Springfield (Steer Davies Gleave, 1985c) and Patcham (Steer Davies Gleave, 1986) undertook SP exercises to determine, amongst other things, the value of access time (μ). The access time elasticity (η_A) was deduced from aggregate ticket-sales based evidence on the fare elasticity (η_F) as:

$$\eta_A = \frac{\mu A}{F}\eta_F \qquad (1)$$

where A and F are the levels of access time and fare respectively. Subsequently, the Parkway forecasting approach used in the railway industry in Great Britain was amended to be based on an elasticity to GJT, as outlined in section 2.1 above

Other studies have directly estimated access elasticities. Wardman and Tyler (2000) developed a model based on post-code origins data to explain how inter-urban rail trip rates vary with, amongst other things, distance from the station. The access distance elasticity was found to be –0.47 for leisure trips and –0.53 for business trips. In a model estimated to ticket sales data, which was the first of its type to explicitly include variables relating to access times to and egress times from the rail network (Wardman et al., 2002), the access elasticity was estimated as –0.61 and the egress elasticity as –0.82 on Non London inter-urban routes for which leisure trips dominate. The latter model has been used to forecast potential demand for a new Parkway station 8km east of Manchester as part of an evaluation conducted for the Strategic Rail Authority of a new inter-urban train company franchise in the North of England (Lythgoe, 2001)

The degree of correspondence between the access time elasticities in these two studies based on different techniques is encouraging. Nonetheless, these elasticity based approaches cannot handle the fundamental issue of overlapping station catchment areas, since station choice is not explicitly addressed, and they cannot provide an adequate measure of the increased attractiveness of rail travel resulting from a new Parkway station.

Disaggregate Forecasting Procedures

The application of disaggregate forecasting tools to potential Parkway stations is generally characterised by consideration of only a subset of all relevant choices. Some studies have focused on choices within the rail mode. For example, Babtie (1993) restricted their SP based analysis to the choice between a new Parkway station and an existing station, Rail Operational Research (1995) also examined just the choice of station in their railheading analysis, whilst Wardman and Whelan (1999) additionally included access mode choice alongside station choice in a joint revealed preference and stated preference model. Other studies have covered the mode choice dimension. Steer Davies Gleave (1997b) included a new Parkway station within an SP exercise dealing with choices between air and rail for trips between London and Paris/Brussels whilst Halcrow Fox (1998) used an SP exercise which offered choices between an existing car journey and travelling by train via a new Parkway station. Multi-modal studies tend to use mode choice models, effectively treating the Parkway station as a new mode (Atkins et al., 2002; Arup and Scott Wilson Kirkpatrick, 2002) whilst in a similar vein

Oscar Faber (1995) considered Parkway stations within a simultaneous treatment of main mode choice and station choice. Indeed, the vast proportion of the very many disaggregate mode choice studies conducted contain terms relating to out-of-vehicle time.

Transmark (1988) provided one of the most complete analyses of the demand for Parkway stations using disaggregate methods. Access mode and station choice were simultaneously considered in a hierarchical logit model. The alternatives covered were two stations and the five access modes of car, rail, bus, taxi and walk. A composite cost term was constructed and converted into equivalent journey time to allow the introduction of the Parkway station to increase rail demand using a journey time elasticity.

This study provided advances in dealing with access mode as well as station choice, in using a probabilistic rather than all-or-nothing procedure for allocating travellers to the available alternatives and in implicitly allowing rail demand to grow from both mode switching and the generation of new trips. However, the journey time elasticity used was not specific to the type of traveller expected to be attracted to Parkway stations whilst the data requirements necessary for forecasting were not trivial.

Systems of disaggregate models dealing with several choice contexts have been developed. For example, in an international travel context, a system dealing with trip generation, mode choice, station choice and access mode choice was developed to forecast demand for the channel tunnel rail link (Hague Consulting Group, 1995). However, the choice sets and type of traveller are not typical of domestic travel whilst a considerable amount of data would be required to apply this model to forecast Parkway demand.

2.3 A Way Forward

There are a number of desirable features that a model which is used to forecast demand at a Parkway station should possess. These are:

- Station choice is appropriately modelled, since Parkway stations rarely cater for ‘freestanding’ locations but instead will provide competition of varying degrees to existing stations. This dimension will influence the degree of abstraction from existing stations, which must be taken into account in appraisal, and the extent to which new trips are generated.

- Generation of new rail trips as a result of the new station must be allowed for in an appropriate manner and be capable of being separately identified. These trips should cover existing trips attracted from other modes and the creation of new trips.

- The forecasting procedure should not require the use of a large amount of data which is not readily available to train companies or which is unreliable. In particular, there is little reliable information in Great Britain on inter-urban travel by car, which is the main competitor to rail, coach data is not readily available, and air data must in some way be allocated to specific competing rail station-to-station movements.

- The demand parameters should be suitable to the market of travellers who are attracted to use Parkway stations

None of the modelling procedures outlined in section 2.2 address all these requirements satisfactorily. The aggregate models outlined tend not to deal with station choice adequately and hence cannot exploit their usual advantage of readily allowing for changes in the size of the rail market. On the other hand, station choice is readily addressed using disaggregate methods. However, issues of trip generation are not easily handled whilst application often involves large and expensive data sets. Hence a new method is required.

There are several attractions of using ticket sales data to develop rail demand models. Large amounts of data are readily available to train operating companies, it is regarded to provide a reliable account of travel between stations and variations in it across routes and over time reflect both mode switching and trip generation elements. However, ticket sales data only relates to travel between stations and tells us nothing directly about access and egress. This would seem to be a serious shortcoming in this context. A way forward is to follow the procedure set out in Wardman et al. (2002).

The basic approach is to specify a gravity model for the demand (V) between a zone (a) around the origin station (i) and zone (b) around the destination station (j). This takes the form:

$$V_{aijb} = \kappa P_a^{\alpha} P_b^{\beta} A_{ai}^{\gamma} E_{bj}^{\delta} f(GC_{ij} .....) \tag{2}$$

where P_a is the population at the origin zone, P_b is the population at the destination zone, A_{ai} is the access time from zone a to the origin station, E_{bj} is the egress time from the destination station to zone b, and GC_{ij} is the generalised cost of travel by rail between stations i and j.

Obviously, the number of rail trips from each zone around a station is unknown; only the number between the origin station and the destination station is known. However, we know that the total number of trips between i and j is the sum of the trips from all the zones around the origin station to all the zones around the destination station. Thus the rail demand between two stations i and j can be specified as:

$$V_{ij} = \sum_a \sum_b V_{aijb} \tag{3}$$

By substitution, we can express the known demand between stations (V_{ij}) in terms of observed variables:

$$V_{ij} = \kappa \left(\sum_a P_a^{\alpha} A_{ai}^{\gamma} \sum_b P_b^{\beta} E_{bj}^{\delta} \right) GC_{ij}^{\lambda} \tag{4}$$

This model is intuitively reasonable, involving as it does the weighting of population according to its distance from the station. It can be estimated using non-linear least squares to provide estimates of the parameters. Thus by substitution of terms that are unobservable by observable variables, we can proceed to examine access and egress issues which at first sight appear to be beyond the scope of a model based on ticket sales data. A serious limitation of the above model is that it does not address the crucial issue in this context of competition between stations. However, there is no reason in principle why it cannot be enhanced to obtain a Parkway Forecasting Model possessing the desirable properties outlined above. This model is outlined below.

3. MODEL DEVELOPMENT

The probability that an individual on a single occasion chooses to travel from their origin zone a to a destination station j using origin station i can be expressed as[2]:

$$\Pr\left(rail_{aij}\right) = \Pr\left(rail_{aij} \mid rail_{a.j}\right) \times \Pr\left(rail_{a.j}\right) \tag{5}$$

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[2] Destination zone b could in principle be included but is not the focus of this study

The first term on the right hand side is the probability of using the origin station i conditional that a rail journey is made and the second term represents the probability of making a rail journey to destination j rather than travelling by another mode or not travelling at all.

Adopting a hierarchical logit approach, with the choice of origin station in the lower nest and the choice of whether to make a rail journey or not in the upper nest, $\Pr(\text{rail}_{aij})$ can be expressed as:

$$\Pr(rail_{aij}) = \frac{e^{U_{aij}}}{\sum_k e^{U_{akj}}} \times \frac{e^{\left\{\theta \ln\left(\sum_k e^{U_{akj}}\right) + U_{..j}\right\}}}{e^{\left\{\theta \ln\left(\sum_k e^{U_{akj}}\right) + U_{..j}\right\}} + e^{U_{0a.j}}} \tag{6}$$

U denotes the utility of an alternative, and thus U_{akj} is the utility for a journey from origin zone a to destination station j using origin station k. This includes both the rail and the access components. The choice of station is a multinomial logit model, with k indicating any origin station. The choice of whether to make a rail journey or not is dependent upon the overall attractiveness of rail, represented by an expected maximum utility across the various origin stations, the utility of the location served by destination station j ($U_{..j}$) and the utility of not travelling by rail ($U_{0a.j}$).

To convert to the total number of journeys per annum from origin zone a to destination station j that use origin station i (V_{aij}), we multiply by the population in zone a (P_a) and by an unknown average number of decisions (n) to travel (by any mode), or not to travel, made by an individual in one year.

$$V_{aij} = n \times P_a \times \frac{e^{U_{aij}}}{\sum_k e^{U_{akj}}} \times \frac{e^{\left\{\theta \ln\left(\sum_k e^{U_{akj}}\right) + U_{..j}\right\}}}{e^{\left\{\theta \ln\left(\sum_k e^{U_{akj}}\right) + U_{..j}\right\}} + e^{U_{0a.j}}} \tag{7}$$

Finally, we sum across all the zones a around the origin station to obtain a representation of the number of rail trips between stations i and j ($V_{.ij}$) as:

$$V_{.ij} = \sum_a V_{aij} = n \times \sum_a \left(P_a \times \frac{e^{U_{aij}}}{\sum_k e^{U_{akj}}} \times \frac{\left\{\left(\sum_k e^{U_{akj}}\right)^{\theta} \times e^{U_{..j}}\right\}}{\left\{\left(\sum_k e^{U_{akj}}\right)^{\theta} \times e^{U_{..j}}\right\} + e^{U_{0a.j}}} \right) \tag{8}$$

Section 5 which reports the results also outlines how the utility terms in equation 8 are represented by observed transport variables.

4. DATA COLLECTION

The dependent variable to be explained is the number of trips in 1999 between Parkway stations and other stations. This information was obtained from the rail industry's CAPRI system which is regarded to provide a reliable account of trips between stations and which has for many years and in numerous instances supported the development of robust rail demand models (see ATOC, 2002). Table 2 lists the 11 Parkway stations for which all relevant data was available and also indicates how the 3413 observations of station-to-station flows available for modelling purposes were distributed across these stations.

Table 2: Parkway Stations Used and Number of Observations for Each

Station	Obs	Station	Obs
Alfreton	287	Port Talbot Parkway	326
Birmingham International	395	Southampton Airport Parkway	369
Bodmin Parkway	350	Sutton Parkway	83
Bristol Parkway	402	Tame Bridge Parkway	160
Didcot Parkway	369	Tiverton Parkway	373
Haddenham and Thame Parkway	299	Total	3413

The number of rail trips between stations i and j depend upon the generating potential of the zones around the origin station, the attracting potential of zones around the destination station, the attractiveness of making the journey by rail using origin station i, and the attractiveness of competing stations.

In this study, the generating potential is represented by the population in zones around the origin station. Population data from the 1991 census was obtained through MIMAS/Casweb at enumeration district level for England and Wales, and output area level for Scotland, together with the Ordnance Survey grid references of their centroids. There are on average 181 households in an enumeration district and 53 households in an output area (Leventhal et al., 1993). Each Parkway station has a grid of 16 zones around it and the population units over a 40km radius are allocated to those zones (Lythgoe and Wardman, 2002a). This number of zones appeared to be adequate to represent the distribution of population without making the data too unwieldy, or the estimation process too slow. Different radii had been examined, but 40km provided the best model fit (see 5.3, below).

The model here simply specifies dummy variables to represent the relative attractiveness of 431 different destinations. Although not all possible destinations on the Great Britain railway network are represented, which is a potential problem for forecasting, the included destinations cover 94% of inter-urban rail revenue.

The attractiveness of making a journey by rail via any particular station is represented by the generalised cost (GC_{akj}) from an origin zone a via an origin station k to the destination station j. This is composed as:

$$GC_{akj} = \mu GJT_{kj} + F_{kj} + \mu T_{ak} + C_{ak} \tag{9}$$

T_{ak} and C_{ak} are the time and cost involved in accessing the origin station from the origin zone a, F_{kj} is the fare for the journey between stations and GJT_{kj} represents what is termed the generalised journey time between stations. The rail fare is represented by revenue per trip contained in the CAPRI data. GJT is a measure of timetable related service quality that is widely used in the railway industry in Great Britain. It is composed as:

$$GJT_{kj} = TT_{kj} + \tau_1 H_{kj} + \tau_2 I_{kj} \tag{10}$$

where TT is the station-to-station travel time, H is the headway between trains and I is the number of interchanges required. Weights are attached to the latter two terms to convert them into equivalent time units. GJT for each station-to-station movement was obtained from the MOIRA system and provided by ATOC.

GJT and access time are weighted by the value of time (μ) for inclusion into the overall GC. This used the value of time formula derived from meta-analysis of a very large amount of British data (Wardman, 2001) and which now forms Handbook recommendations (ATOC, 2002). The key features are that the value of time varies with journey purpose and distance. A weighted value of time is used to reflect the business and leisure journey purpose split, which is taken to be 50:50 on Non London journeys and 75:25 on London flows. The proportion of business travellers amongst Parkway users is higher than for typical stations.

The road network for the whole of Great Britain was downloaded in the form of 1:250,000 Ordnance Survey ‘Strategi’ tiles from EDINA/Digimap, and converted for input to MapInfo GIS software. Associated software known as RouteView is then used to calculate drive time and distance matrices from zonal centres of population to the Parkway station and to each of the competitor stations. Road access distances are multiplied by a cost of 7 pence per kilometre to obtain a car operating cost measure.

The model could in principle be extended to cover a range of other variables, and particularly competition from other modes, but these issues were beyond the scope of the study.

5. EMPIRICAL FINDINGS

5.1 Model Form

Equation 8 represents the demand relationship derived using a hierarchical logit relationship covering the choice of station and the choice of whether to make a journey by rail or not to destination j. Whilst this equation can in principle be estimated by non-linear least squares, subject to substitution of relevant explanatory variables into the utility terms, taking a logarithmic transformation makes the model comparable with more conventional ‘double-log’ constant elasticity rail demand models and also served to facilitate the iterative estimation process.

To estimate the model, we must enter into the utility functions terms which influence the attractiveness of the various alternatives. The overall attractiveness of travelling by rail from origin zone a via any origin station k to destination j (U_{akj}) is represented by its generalised cost (GC_{akj}) as defined by equation 9. However, GC could enter the utility function in many different forms. The form that provided the best fit and the most sensible results was:

$$U_{akj} = \lambda \ln GC_{akj} \tag{11}$$

It can be surmised that the utility of not travelling by rail ($U_{0_{akj}}$) is much larger than the utility of travelling by rail. This was confirmed by the early model results, and effectively simplifying the denominator of the second ratio term in equation 8 to $e^{U_{0_{a.j}}}$ made no difference to the estimates of the parameters.[3]

The simplified model form allows $e^{U_{..j}}$, which represents the attractiveness of the destination, to be taken outside the summation, meaning that the relative attractiveness of each destination can simply

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[3] This can be understood by noting that:

$$\frac{\left\{\left(\sum_k e^{U_{akj}}\right)^{\theta} \times e^{U_{..j}}\right\}}{\left\{\left(\sum_k e^{U_{akj}}\right)^{\theta} \times e^{U_{..j}}\right\} + e^{U_{0_{a.j}}}} \xrightarrow[\frac{\left\{\left(\sum_k e^{U_{akj}}\right)^{\theta} \times e^{U_{..j}}\right\}}{e^{U_{0_{a.j}}}} \longrightarrow 0]{} \frac{\left\{\left(\sum_k e^{U_{akj}}\right)^{\theta} \times e^{U_{..j}}\right\}}{e^{U_{0_{a.j}}}}$$

This indicates that a binary logit curve can be approximated by an exponential curve when the proportion choosing one of the alternatives is very small.

be represented as the exponential of destination specific dummy variables ($U'_{..j}$), where, by introducing an unknown constant K:

$$U'_{..j} = U_{..j} + K \tag{12}$$

The following substitution can also be made:

$$U'_{0_{a.j}} = U_{0_{a.j}} + K - \log(n) \tag{13}$$

A series of models were estimated including ones using dummy distance variables to describe $U'_{0_{a.j}}$. These variables indicated very clearly that $U'_{0_{a.j}}$ was a linear function of the rail distance (D_{ij}) in kilometres between stations i and j (Lythgoe and Wardman, 2002a), and can therefore be expressed in the form[4]:

$$U'_{0_{a.j}} = \zeta + \eta \times D_{ij} \tag{14}$$

The final estimated model therefore took the form:

$$\ln(V_{.ij}) = \ln\left(\sum_a \left\{ P_a \times \frac{GC^{\lambda}_{aij}}{\sum_k GC^{\lambda}_{akj}} \times \frac{\left(\sum_k GC^{\lambda}_{akj}\right)^{\theta}}{e^{(\zeta + \eta \times D_{ij})}} \right\}\right) + U'_{..j} \tag{15}$$

5.2 Model Results

Non-linear least squares has been used since its purpose is to estimate the coefficients of models which are non-linear in parameters, and in independent variables, which is the case here. It is an acceptable method and relatively straightforward to apply.

Equation 15 was estimated to 3413 observations using a non-linear least squares procedure available in SAS (SAS Institute, 1999). For each Parkway station, ten competing stations were identified. These had to be within 40km of the centre of any of the 16 zones around the Parkway and possess the largest population and distance weighted revenue (Φ_k) defined as:

$$\Phi_k = R_k \sum_a \frac{P_a}{D_{ak}} \tag{16}$$

where P_a is the population of Parkway zone a, R_k is the revenue of station k and D_{ak} is the distance from zone a to station k. The rationale for using this formula is that the number of journeys accessing a competitor station k can be broadly expected to increase with the revenue at the station, as a measure of its attractiveness, and with the population of the zone as a measure of its generating potential, but to diminish with distance.

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[4] The final model using the distance function given in Equation (14) was estimated with an adjusted R^2 of 53% (see Section 5.2) whereas a comparable model using a series of distance band dummies was estimated with a very slightly lower adjusted R^2.

Table 3 reports the estimated parameters other than those associated with the destination specific dummy variables. The model is estimated with an adjusted R^2 of 53%, which in our experience is typical of cross-sectional models of this form, and the parameters have the expected signs and are all very precisely estimated. The goodness of fit can be compared with a value of 80% for a model which contained dummy variables to represent the generating potential of each Parkway station in addition to the destination specific dummies, and with a value of 31% for a model which contained no variables at all to represent the Parkway station generating potential.

Table 3: Parameter Estimates

Parameter	**Estimate**	**t Value**
λ	-8.429	-49.82
θ	0.498	37.07
ζ	-26.699	-18.45
η	-0.009	-16.72
Adjusted R^2	**0.5318**	

λ is a spread parameter associated with the share that each station captures and hence determines cross-elasticities between stations. θ approximately represents the proportion that newly generated trips form of all trips from the Parkway station (Lythgoe and Wardman, 2002a). This is 50% in our model, which in itself seems reasonable to us[5], but a limitation is that it is constant and we might expect this ratio to vary according to the location of the new Parkway station relative to existing stations.

Taking the two parameters together, $\lambda\theta$ is the elasticity of rail demand from all stations in response to a proportionate change in GC at all stations (Lythgoe and Wardman, 2002a)[6]. The GC elasticity is -4.2. Comparison with other rail evidence is restricted because rail demand models are rarely estimated in terms of GC but typically disaggregate at least into fare and generalised journey time (GJT).

Wardman et al. (2002) in analysis of Non London inter-urban flows report a GC elasticity of –1.71, with a 95% confidence interval of ±3%, and a separate access time elasticity of –0.61 (±28%). Taking the latter to represent access generalised cost, because of the correlation of access time and cost, the

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[5] Train Operating Companies were not able to provide survey based evidence to validate this figure, and we are not aware of other evidence.

[6] The total demand from zone a to destination j is given by:

$$V_{a.j} = \sum_i V_{aij} = \sum_i n \times P_a \times \frac{GC_{aij}^{\lambda}}{\sum_k GC_{akj}^{\lambda}} \times \frac{GC_{a.j}^{\lambda\theta}}{e^{U_{0_{a.j}}}} \times e^{U_{..j}}$$ where $GC_{a.j} = \left(\sum_i GC_{aij}^{\lambda}\right)^{1/\lambda}$ is the 'composite generalised cost' from a to j through all stations k. This reduces to $V_{a.j} = n \times P_a \times \frac{GC_{a.j}^{\lambda\theta}}{e^{U_{0_{a.j}}}} \times e^{U_{..j}}$ so that the elasticity of $V_{a.j}$ with respect to $GC_{a.j}$ is λθ (Lythgoe and Wardman 2002a).

GC elasticity would be –2.32. The larger GC elasticity for Parkway station users may be because this largely car based market segment has distinctly different preferences with, for example, stronger requirements for good train service quality and a particular aversion to access time, whilst by definition there is strong competition from car.

Further light can be shed on this issue by decomposing the GC elasticity estimated here into the elasticities implied to each constituent variable. The implied elasticities to GJT, rail fare, access time and access cost depend upon the proportions that these variables form of overall GC. Taking the averages of these values for the Parkway Stations yields elasticities for these four variables of -2.27, -1.10, -0.66 and -0.17 respectively.

Wardman et al. (2002) estimated an access time elasticity of –0.61 (±28%) whilst Wardman and Tyler (2000) using a different technique obtained very similar figures of -0.53 (±12%) and -0.47 (±17%) for access distance elasticities for inter-urban business and leisure travel respectively. The combined access elasticity estimated here is broadly comparable given a stronger preference towards good access amongst Parkway station users and the strong car competition.

The implied fare elasticity for Parkway users is broadly in line with other evidence. There is a considerable amount of empirical evidence pointing to a fare elasticity of around one on both London and Non London routes, with the most recent evidence indicating an overall fare elasticity of –1.0 on London flows and –0.9 on Non London flows (ATOC, 2002).

The most significant difference between the results for Parkway users and the empirical evidence for rail travel in general is in terms of the GJT elasticity. The conventional wisdom in Great Britain has long been that the GJT elasticity is -0.9. There is much evidence to support it, and also some evidence for slightly stronger effects (ATOC, 2002). The implied GJT elasticity is here –2.27, presumably because of the strong preference for service quality and strong competition from car in this market segment.

The two terms ζ and η indicate that the non-rail utility decreases with distance D_{ij}. Given that this utility includes the utility of making the journey from origin zone a to destination j by another mode, usually car, then the decreasing utility is to be expected. The effect of this decrease is small since, even with D_{ij} equal to 300, the non-rail utility only decreases by 10% from its value when D_{ij} is zero.

430 destination specific dummy variables were estimated, with Wrexham Central serving as the arbitrary base, and of these 96 (22%) had |t| values greater than 2 with a further 120 (28%) between 1 and 2. Table 4 illustrates the findings for a number of destination stations. It provides the estimated values of $U'_{..}$,and associated t values. The exponential of this term indicates the relative attractiveness of the destination. Although these do not correlate exactly with the relative populations around the destination and what we expect to be the relative attractiveness of these locations, in general the results appear to be plausible. As expected, London is by far the most attractive destination, with Birmingham and Manchester being more significant attractors of rail trips than Leeds, Liverpool and Bristol. The final eight coefficients reported are for two sets of broadly comparable locations with the exception that Cambridge, Durham, Canterbury and York are major tourist attractions whereas Grantham, Rugby, Bedford and Lancaster are not. It is therefore not surprising that the model predicts, other things equal, that the former locations will attract far more rail trips than the latter. Specifying a set of variables that could adequately represent differences in the attracting potential of each destination would be a formidable task.

Table 4: Estimates of $U'_{..j}$ for a Selection of Stations

	$U_{..j}$	t value	$exp(U_{..j})$
London	6.51	8.72	675.2
Birmingham	3.71	4.89	40.9
Liverpool	3.33	4.53	28.0
Manchester	3.75	5.09	42.6
Newcastle	2.52	3.41	12.4
Leeds	3.29	4.48	26.9
Bristol	2.61	3.49	13.5
Grantham	1.78	2.36	5.9
Rugby	1.12	1.46	3.1
Bedford	-0.52	-0.48	0.6
Lancaster	1.50	2.04	4.5
Cambridge	3.08	4.14	21.8
Durham	1.83	2.44	6.2
Canterbury	2.32	3.08	10.2
York	3.14	4.27	23.1

5.3 Tests of Different Model Forms

The preferred model specifies GC in logarithmic form. Using instead the more conventional linear relationship between utility and GC resulted in an appreciable reduction in model fit to 46%. We regard this to be a desirable finding since the latter functional form forces a strong relationship between the GC elasticity and the level of GC yet rail demand models have rarely found convincing empirical support for strong elasticity variation with regard to the level of the variable (Wardman, 1997; Lythgoe and Wardman, 2002b).

The reason usually given for specifying a combined GC variable is that of high correlation between various component variables. In the sort of cross-sectional model under consideration here, train fare and GJT are strongly correlated as are access time and cost. When attempts were made to separate GC into its component parts, the model produced a wrong sign coefficient for access time which we attribute to multicollinearity.

The sensitivity of the model to the specified number of competitor stations was examined. The reported model contains 10 competitor stations and achieved an adjusted R^2 goodness of fit of 53%. This provided the best fit to the data. Increasing the number of competitor stations to 15 reduces the fit to 52% whilst reducing the number to 5 reduces the fit to 51%. However, the most significant finding is that when no competing stations are specified, which corresponds to conventional rail demand models based on ticket sales data, the goodness of fit falls considerably to 38% and the GC elasticity is less plausible at -5.17. Whilst the issue of station choice is expected to be more critical in the analysis of demand at Parkway stations than at standard stations, the results do seem to suggest that enhancement of conventional demand models to include station choice should be a priority.

We also examined the impact of changing the size of the area across which populations are aggregated. The reported model specifies a circular area with a radius of 40km. Tests were conducted with radii of 30km and 50km but these gave lower adjusted $R^{2'}$s of 50% and 49% respectively.

The forecasting parameters in the Passenger Demand Forecasting Handbook distinguish between London and Non London flows, largely on the grounds that the journey purpose mix and service quality vary markedly between the two. The parameters in the model were allowed to vary so as to produce different elasticities for London and Non London flows but no significant variations could be detected. However, a problem that arose here was the strong correlation between the London destination specific dummy variable and other London specific terms. Nor were any significant variations in the GC elasticity by distance discerned. Additional dummy terms were specified for Southampton Parkway and Birmingham International because they also serve as a means of egress for those arriving at their airports but the effects were not significant.

Instead of using dummy variables for the attractiveness of the destination zone, we specified the attractiveness of the destination in the same manner as Wardman et al. (2002) and set out in equation 4. This involved the specification of 5 concentric rings around the destination station based on drive time bands of up to 4 minutes, 4-6 minutes, 6-8 minutes, 8-10 minutes and 10-15 minutes. This procedure effectively weights the trip attracting potential of population in a zone according to the distance from the station. That study estimated an egress time elasticity of –0.82 (±19%) for Non London inter-urban flows. The egress elasticity is expected to be higher than the access elasticity because of the generally greater unfamiliarity with the destination and the absence of car. Using the same specification of the attractiveness of destination stations, the egress elasticity was here estimated to be –1.47 (±27%) and the adjusted R^2 goodness of fit measure was somewhat lower at 47%. This elasticity can be expected to be higher for Parkway stations since the car users who are a large proportion of those using these stations would most likely drive if their ultimate destination is not relatively close to the destination station.

6. APPLICATION

Two case study applications are reported below which serve several purposes. They illustrate the properties of the estimated model, allow an assessment of the plausibility of the demand forecasts it produces, support comparison against other forecasting procedures and enable validation of the model against actual demand for a recently opened Parkway station.

6.1 East Midlands Parkway Case Study

As discussed in the introductory section, firm plans are in place for an East Midlands Parkway. The proposed location is 30km north of Leicester on the Midland Main Line, adjacent to East Midlands Airport and the M1 motorway, and within 15 km of the major centres of Derby and Nottingham. A population of 1,047,582 lies within 20 km and 2,415,061 within 40 km, which is in line with Leeds and Sheffield stations but around half of Manchester and Birmingham. It would attract from existing station catchments those who would not make a rail journey because of poor road access whilst its position near to where two routes to London join means that it could exploit the joint service frequency to provide an attractive service.

We have used the model developed here to examine the range of scenarios depicted in Table 5 for journeys to London. Scenario I represents a situation of offering the same service as is currently provided at Leicester, but with suitably longer journey times to London. Possibilities for a North-South high speed line in Great Britain are currently being evaluated and Scenario II represents a situation where East Midlands Parkway is the station on a high speed route that serves the East Midlands conurbation with trains offering an average speed of around 250kph. The services provided at existing stations would remain unchanged. The worsening of access to existing stations due to increased road congestion is depicted by Scenario III whilst Scenario IV represents a situation where East Midlands Parkway has failed to attract sufficient traffic to warrant a high quality service and is instead served by a lower frequency and somewhat slower service calling at most intermediate stations.

Table 5: East Midlands Parkway Forecasting Scenarios

Scenario	Journey Time	Frequency	Access Times
I	80 mins	2 per hour	As Now
II	45 mins	2 per hour	As Now
III	80 mins	2 per hour	Competitors +10 minutes
IV	100 mins	1 per hour	As Now

In all cases, the fare is based on revenue per trip applicable to Leicester with a pro-rata increase for the greater distance involved. The service quality and fare from competing stations is the same as in the current situation. The data necessary to apply the Parkway Access Model (ATOC, 1997) prohibited its use in this context.

Table 6 reports the demand forecasts for the scenarios described in Table 5 for the 1999/2000 year of calibration. It provides the forecast number of one-way trips originating at East Midlands Parkway along with, for comparison, the forecasts for competing stations. The latter are obtained as the current demand minus the trips forecast to be abstracted from that station[7]. The change in demand at the existing station is given, along with the proportionate change in demand that it constitutes.

Table 6: East Midlands Parkway Demand Forecasts (1999/2000)

(provided at end of manuscript – please insert here)

In Scenario I, East Midlands Parkway has only limited impacts on the existing stations and overall it is forecast to increase rail demand by only 3% compared to the do nothing situation across the stations that it is specified to compete with. Nonetheless, the annual number of trips from East Midlands Parkway to London seems plausible compared to the number of London trips from the three key local stations and would constitute a worthwhile addition to trips on the Midland Main Line.

The high speed link represented by Scenario II leads to a very large increase in demand compared to Scenario I. This is not unexpected given the large GJT elasticity for this category of travellers in our model. Significant inroads are made into the demand from Leicester to London and demand is forecast to increase by 14%. Not surprisingly, given the high quality service offered at no cost premium in this scenario, East Midlands Parkway is forecast to generate far more trips to London than any of the principal stations in the area.

Scenario III indicates that ten minutes longer access times to existing stations due to increased city centre congestion would lead to significant growth in the number forecast to use East Midlands Parkway but this would not be sufficient to offset the demand losses elsewhere. The large reduction in trips from Leicester stems from the additional ten minutes being a very much larger proportion of GC than the other stations considered and because of the large population affected by this relatively large change. The lost traffic due to worse access at existing stations would more than offset the revenue gains achieved by opening East Midlands Parkway. This problem is largely beyond the control of train companies but it does represent a serious future threat to rail revenue and would seem to further strengthen the case for conveniently located Parkway stations offering good access to the rail network.

The relatively slow and infrequent service specified in Scenario IV would have little impact on demand at existing stations and the demand forecast for East Midlands Parkway would be somewhat

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[7] It is a simple matter to identify separately journeys abstracted from rival train operators on other routes. However, the model cannot distinguish between the traffic of different operators on the same flow.

lower than the 'reference' case of Scenario I. Under such a scenario, it is doubtful whether the revenue benefits would be sufficient to justify the construction of a station of the necessary size and with the facilities required. The results serve to highlight the fact that to be successful in attracting custom Parkway stations must offer a level of service which at the least compares favourably with what is offered at existing stations.

Atkins et al. (2002) forecast demand for East Midlands Parkway using a hierarchical logit model which covered mode and station choice. The latter was based on the choice between East Midlands Parkway and the current station. Generation effects were not included but commuting trips were. The number of one-way trips is forecast to be around 185,000 if 33% of all trips are to London[8]. This is very similar to the forecasts for Scenario I in Table 6.

6.2 Warwick Parkway Case Study

The opening of Warwick Parkway, some 2km west of Warwick on the Chiltern line between Birmingham and London, provides an opportunity to test the accuracy of the forecasting model developed here. We can also compare the forecasts with those obtained using the Parkway Access Model which was replaced by the model developed here as the recommended forecasting procedure in the Passenger Demand Forecasting Handbook.

Warwick Parkway station generated 148,871 one-way non-Season ticket trips in the financial year 2001/02. Our model, based on the actual fares charged and train service quality provided at Warwick Parkway and ten competing stations, forecast 80,255 non-season ticket trips after adjusting for income growth and significant fuel price increases between the calibration year of 1999/2000 and the out-turn year using Passenger Demand Forecasting Handbook recommendations (ATOC, 2002).

Steer Davies Gleave (1997a) used the Parkway Access Model to forecast demand for 2003. Adjusting their forecasts using Handbook recommendations to allow for income growth between the out-turn and their forecast year and removing season tickets for comparability results in 77,432 annual trips. However, these relate to all Southbound trips and not just to London, although the latter will form the majority, and furthermore contain around 13,000 trips due to a major housing development which are not included in our forecasts.

The model developed here therefore provides more accurate forecasts than the model it replaces, although the degree of correspondence between its forecasts and actual demand are disappointing. Nonetheless, we have not been able to forecast for a number of positive effects on demand. These include: the significant population growth due to major housing developments around Warwick Parkway (Warwick District Council 2001); the provision of a dedicated bus link from Warwick to the Parkway (which was a condition of granting planning permission); the limited car park capacities at Leamington Spa, Coventry and Warwick statios; the relative unreliability of the competing West Coast main-line and Cotswold line; and atypical targetted marketing of Warwick Parkway to potential users up to 50km away.

7. CONCLUSIONS

This paper has reported on the development of a model to forecast the demand for Parkway stations based solely on rail ticket sales data and it has illustrated its properties with two case study applications. Considerable interest remains in Parkway stations in Great Britain and the model developed forms the recommended forecasting procedure in the most recent version of the Passenger

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[8] Bristol Parkway is a similar distance from London as the East Midlands Parkway site, and around a third of all its trips are to London.

Demand Forecasting Handbook (ATOC, 2002) which is widely used in the rail industry in Great Britain. Since the model is based upon observed demand levels at existing Parkway stations and other readily available information, it is a far more straightforward approach to demand forecasting than the method it replaces and other methods which require detailed origin-destination data for other modes.

The model constitutes an advance in the methodology of rail demand models estimated to ticket sales data representing travel between stations. Of the very many demand models estimated to rail ticket sales data, we are only aware of one case where access time enters as an independent variable (Wardman et al., 2002) yet the model here additionally examines competition from other stations. The parameters which represent the competition between stations and the other parameters are all directly estimated by the model and require no behavioural data other than ticket sales.

The nature of Parkway stations forces consideration of competition, and we have demonstrated that the inclusion of the station choice component leads to a somewhat improved explanatory power and a more plausible generalised cost elasticity. Although competition between stations will not be as strong for non Parkway stations, the model offers the opportunity to obtain better results when applied to the analysis of rail demand in general and this should be a priority for future research.

The station choice feature of the model in its current form also represents the main limitation of the model. The use of a multinomial logit formulation for station choice implies that the proportion that new rail trips form of the total number of rail trips from a station is approximately constant. Further work, being undertaken as part of research applying the modelling approach to over 130,000 inter-urban rail flows in Great Britain, will address this problem. Possible solutions are to use a hierarchical logit model, cross nested logit model, paired combinatorial logit model, C-logit or other models recently developed in the context of route choice where there are different degrees of route overlap (Batley et al. 2001). Nonetheless, given that the generation ratio is constant, the estimated value of 0.5 seems reasonable. Moreover, it should be pointed out that it is likely that the model will be applied in situations similar to those upon which it was calibrated. There are no locations where a new Parkway station would offer such a significant improvement over existing services that newly generated trips would vastly outweigh trips abstracted from current stations whilst a new Parkway would not be located so near to an existing station that abstraction would form a large proportion.

In addition to the methodological developments, the model has provided generally reasonable elasticities and forecasts and shown that Parkway users have different preferences to rail travellers in general. In a test based around a newly opened Parkway station, its forecasts are more accurate than the procedure it replaces in the Passenger Demand Forecasting Handbook. Whilst the forecasts were disappointing compared with out-turn demand at Warwick Parkway, a number of possible contributory factors were not accounted for. It would be informative to undertake further research to examine the extent to which users of a Parkway station, or indeed users of any station in subsequent versions of the model, would switch to a competing station after a sufficient deterioration in service quality at their current station.

Issues other than station choice warrant further attention. A more detailed zoning system should be explored whilst a station’s generating potential is currently explained only in terms of population whereas a range of other socio-demographic and economic factors could be included. The use of a dummy variable approach to generation and attraction shows that there is considerable potential, as expected, to improve upon a specification based solely on population.

In addition, there is no reason in principle why the model cannot be enhanced by covering other aspects of choice. Including access mode choice would improve the explanation of station choice, and allow integration issues to be addressed, whilst choice of route, operator, class of travel and ticket type are further dimensions for consideration. In some of these cases, particularly ticket type, information would be available on the proportions choosing each option and this will broaden the modelling opportunities compared to the station choice which has been addressed in the research reported here. Should there be estimation problems as models become more complex, there remains the opportunity to use parameters obtained from complementary disaggregate choice modelling.

Ticket sales data is a very valuable resource for demand modelling, providing a reliable account of travel behaviour at relatively low cost. Efforts must therefore be made to enhance modelling capabilities to enable this resource to be exploited to the fullest possible extent.

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Table 6: East Midlands Parkway Demand Forecasts (1999/2000)

	Scenario I			Scenario II			Scenario III			Scenario IV		
	Forecast	Change		Forecast	Change		Forecast	Change		Forecast	Change	
E M Parkway	171,325	171,325		673,497	673,497		201,896	201,896		57,762	57,762	
Nottingham	390,740	-10,003	-2%	368,765	-31,978	-8%	372,740	-28,003	-7%	397,216	-3,527	-1%
Leicester	327,040	-32,749	-9%	244,682	-115,107	-32%	203,705	-156,084	-43%	348,472	-11,317	-3%
Derby	234,964	-7,243	-3%	218,999	-23,208	-10%	222,299	-19,908	-8%	239,648	-2,559	-1%
Other 7 Stations	1,857,323	-31,697	-2%	1,782,783	-106,237	-6%	1,785,814	-103,206	-5%	1,877,925	-11,095	-1%
Total	**2,981,391**	**89,632**	**+3%**	**3,288,726**	**396,967**	**+14%**	**2,786,454**	**-105,305**	**-4%**	**2,921,022**	**29,263**	**+1%**