

Testing the ability of Multivariate Hybrid Spatial Network Analysis to Predict the Effect of a Major Urban Redevelopment on Pedestrian Flows

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Summary

This paper explores a new approach to pedestrian modelling using multivariate hybrid spatial network analysis. Using a case study of Cardiff, Wales it demonstrates how the approach can be used to predict pedestrian flows after a major development of the city centre including the construction of a new purpose built shopping mall. The model is tested by comparing predicted flows against footfall counts before and after the development. The results show that the model works sufficiently well to inform policy makers about the potential impact of redevelopment on footfall and pedestrian movement.

KEYWORDS: Pedestrian modelling, network analysis, betweenness, footfall

1. Introduction

Predicting how changes to the urban environment will affect pedestrian flows is important for numerous reasons. Substitution of motorized trips with walking is not only beneficial for our ecological and carbon footprint, but also reduces congestion and air pollution, increases community cohesion, and - in the face of an obesity crisis - improves public health. Pedestrian activity is also crucial to economic sustainability, with footfall being a key determinant of the success of retail developments in generating revenue, for instance. Finally, it affects social sustainability, with the design of urban spaces having a significant impact on the vibrancy of the communities that live in them.

There are three main types of pedestrian models:

1. Area-based regression models, which predict aggregate pedestrian volumes based on the aggregate characteristics of an area e.g. Ewing et al. (2014).
2. Microsimulation models, which are often employed in commercial projects e.g. planning of subway stations, or stadium evacuation plans but are not yet employed for city-scale modelling (King, Srikukenthiran, and Shalaby 2014).

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3. Origin-destination and route choice models, which are simulate origins, destinations and flows between them. We note two types in particular:

(a) Traditional four-stage vehicle transport models, which have been adapted to model pedestrian mode choice (e.g. Guo and Ferreira 20087) and more recently flows (e.g. Clifton et al. 2016);

(b) Spatial Network Analysis (SpNA) models, which simulate flows through the network, but discard detailed consideration of trip generation and distribution in favour of a focus on the structure of the network itself (e.g. Cooper, 2015).

In this research we describe our own model as Multivariate Hybrid Spatial Network Analysis (MHSpNA). It aims to fill a gap between traditional transport models and existing SpNA models, i.e. categories (3a) and (3b) above.

Not all published pedestrian models include an empirical test against observed pedestrian flow data. Those which do, invariably test model fit at a single point in time as a cross-sectional study. Longitudinal studies, which track changes over time, are considered more reliable (Greenhalgh 1997) but have not been used in this field. In this respect the recording of pedestrian flows before and after a major change to the urban environment brings the opportunity to raise the bar: given a model calibrated on data prior to the change, can the effects of the change be predicted correctly? We thus test the model's ability to extrapolate across time. To our knowledge this is the first time any pedestrian flow model in the above category (3) has been tested in this way. We also, using generalized cross-validation, test our ability to extrapolate across space.

2. Case Study and Data

The case study area is Cardiff, the capital and largest city in Wales, UK. In terms of urban morphology and demographic characteristics it is typical of a medium size British city. However, its capital city status means that it is a major retail and tourist destination and over the past 10 years the city centre has undergone a major regeneration programme. A new shopping mall, St David's Centre opened in 2009, and the surrounding shopping streets were pedestrianised. The city Centre also includes Victorian and Edwardian shopping arcades and a civic centre to the north which hosts the University, Law Courts and Government buildings. To the south of the city centre is the main bus station and Central railway station and there are a number of car parks to the north, east and south. Bordering the city centre to the south west is the national stadium for Wales, the Millennium Stadium, which opened in 1999 and to the north-west is Cardiff Castle and Bute Park – See Figure 1.

Cardiff Council collected pedestrian flow data for years between 1999 and 2011. Each year comprises data collected on Thursday evening, Friday, Saturday and Sunday daytimes (10am-4pm i.e. not including peak commuting times). We calibrate the pedestrian model to summer 2007, the last snapshot available before work on the St David's Centre began in winter 2007. We test the model on the years 2010 and 2011, the only years available after completion of the development. Historic OS Mastermap (Ordnance Survey 2017) in ArcGIS was used to model the outdoor and indoor pedestrian network for 2007 and 2011. The network extends into the surrounding area via a 1.2km buffer to serve as source for trips from the surroundings. Retail floor area was derived from Business Rates data held by the Valuation Office Agency (VOA) and added to the network. The description of the use of the property was used to identify retail and leisure outlets. Carparks were also identified and added to the model. The Business Rates data did not contain information on buildings that had been demolished before 2010, which included the re-developed area. Here building layout and floor area were reconstructed via other data sources including historic OS Mastermap, historic Google Earth aerial photographs and local knowledge. This allowed a before and after model of the St David's 2 development to be constructed.

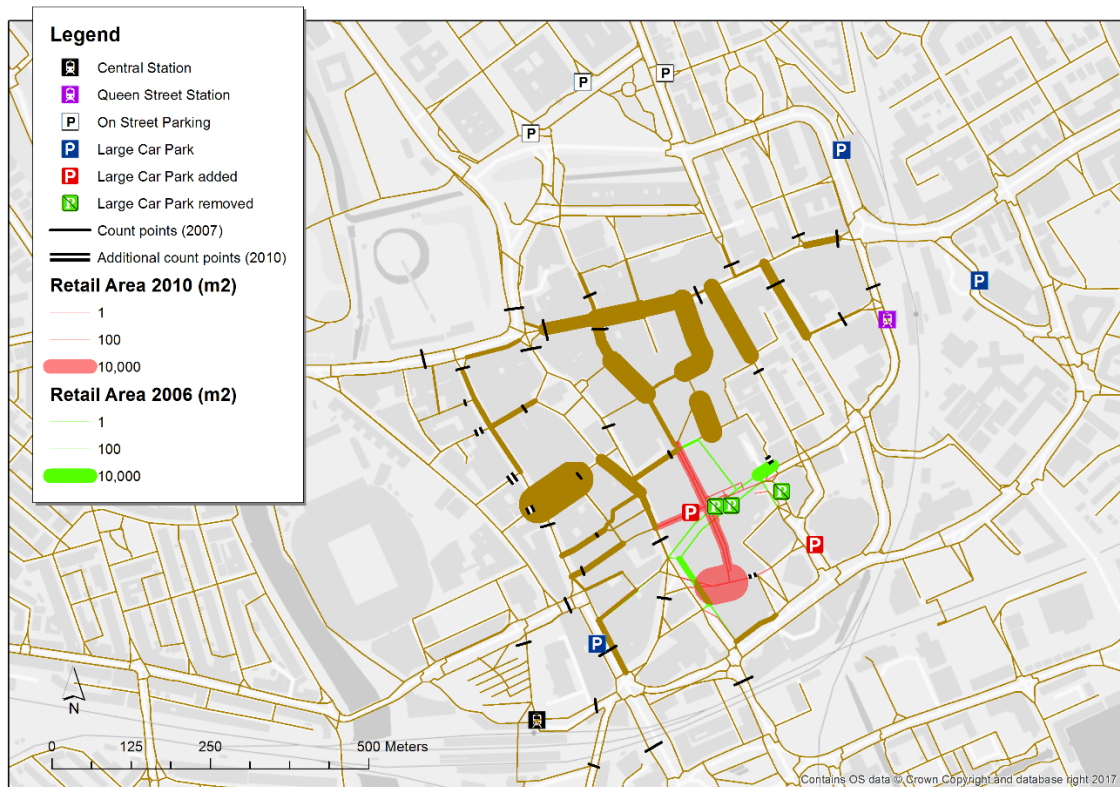


Figure 1 Cardiff City centre study area

3. Method

The building block for the MHSpNA model is the SpNA measure of Betweenness. In simple terms, this is a flow model derived by summing ‘shortest’ paths from ‘everywhere to everywhere’ subject to a constraint on maximum trip distance. We modify our definition of ‘shortest’ to incorporate distance that is neither angular nor Euclidean, as with SpNA tradition (Hillier and Iida 2005), but instead a hybrid of both distance types also including a random component. We modify ‘everywhere’ to specific sets of origins and destinations, but repeat this process for multiple trip types, hence making the model multivariate. In the current study we also introduce ‘Two Phase Betweenness’ which is computed in two phases; (1) determine total accessible destinations; (2) distribute origin weight across available destinations. We also make use of Continuous Space Betweenness (Cooper and Chiaradia 2015) to improve accuracy for the smallest (200m) trip distances. All analyses use the ‘Polyline weighting’ option in sDNA to interpret weight rather than per unit length.

Three models are formed and tested against each year 2010 and 2011:

1. The null model assumes no change in pedestrian flow between years, and is thus only applicable to points where pedestrian counts have been recorded all years.
2. The incremental model works by adding predicted change between years to the flows for the baseline year.
3. The direct model uses regression outputs directly for prediction. This is the most useful model in practice as it extrapolates data across both space and time.

In each case, the models are calibrated to the year 2007, and the coefficients derived applied to the changed map data for 2010 (adding/removing links, altering floor area and car park locations). All modelling is undertaken with the publicly available sDNA+ toolbox for ArcGIS and QGIS (Cooper,

Chiaradia, and Webster 2011; Cooper 2016). Calibration via ridge regression is conducted using the open source sDNA *Learn* and *Predict* tools which in turn make use of the *glmnet* R package (Friedman, Hastie, and Tibshirani 2009).

4. Results and Conclusions

Figure 2 shows pedestrian flows fitted to the footfall count data for 2007. This reveals progressively higher pedestrian flows from the edge of the city to the centre with the highest flows occurring in and around the pedestrianised streets, as would be expected. It is also clear how side streets off busy streets can have much lower pedestrian flows despite linking streets with high levels of flows. The car parks and the Central station do not appear to influence larger flows, probably due to the latter being quite evenly distributed around the periphery

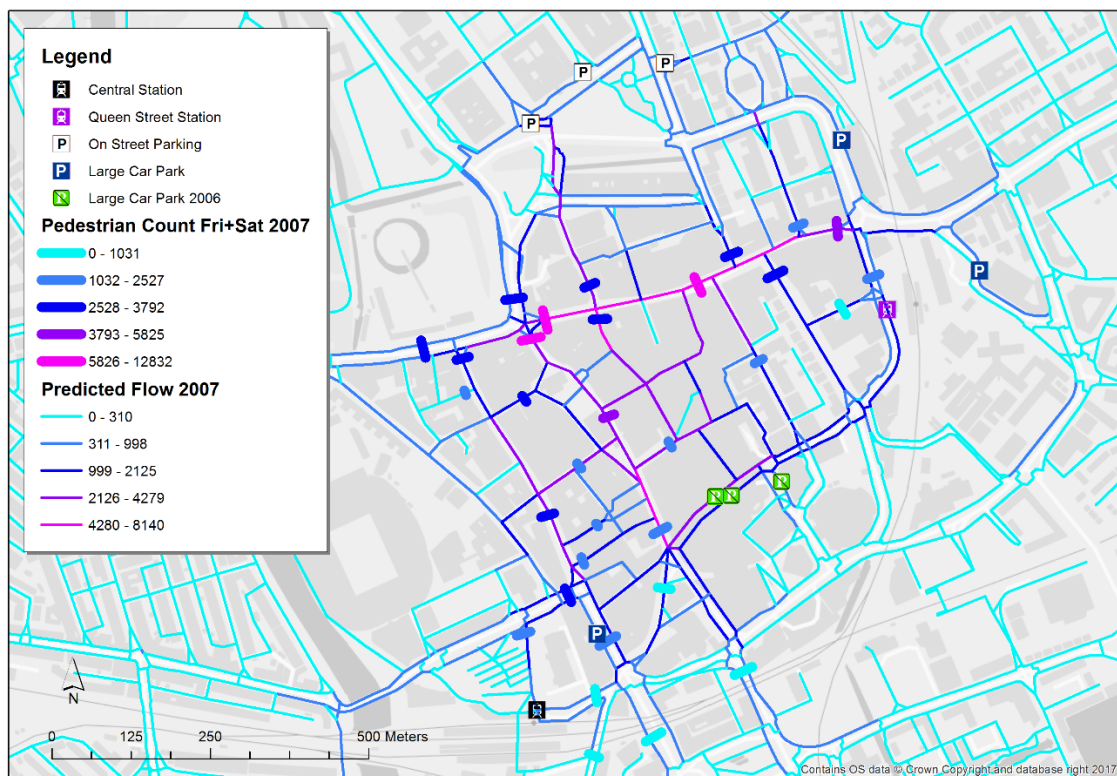


Figure 2 Extrapolation across space: predicted flows for 2007 calibrated to 2007 counts

Figure 3 shows the predicted change in pedestrian flows between 2007 and 2011. The thick red lines show the greatest increase in flows with blue showing a decrease; white reveals no substantial change. This predicts the increase in flows to the new St David's 2 development, in the bottom centre of the map, and the importance of the streets linking the new development to the two railway stations and bus station and also the main pedestrianised thoroughfare from the north of the city centre. The smaller side streets show no predicted change in flows except where close enough to the new development (400m) that they can capture 'shop-to-shop' traffic with their own retail area.

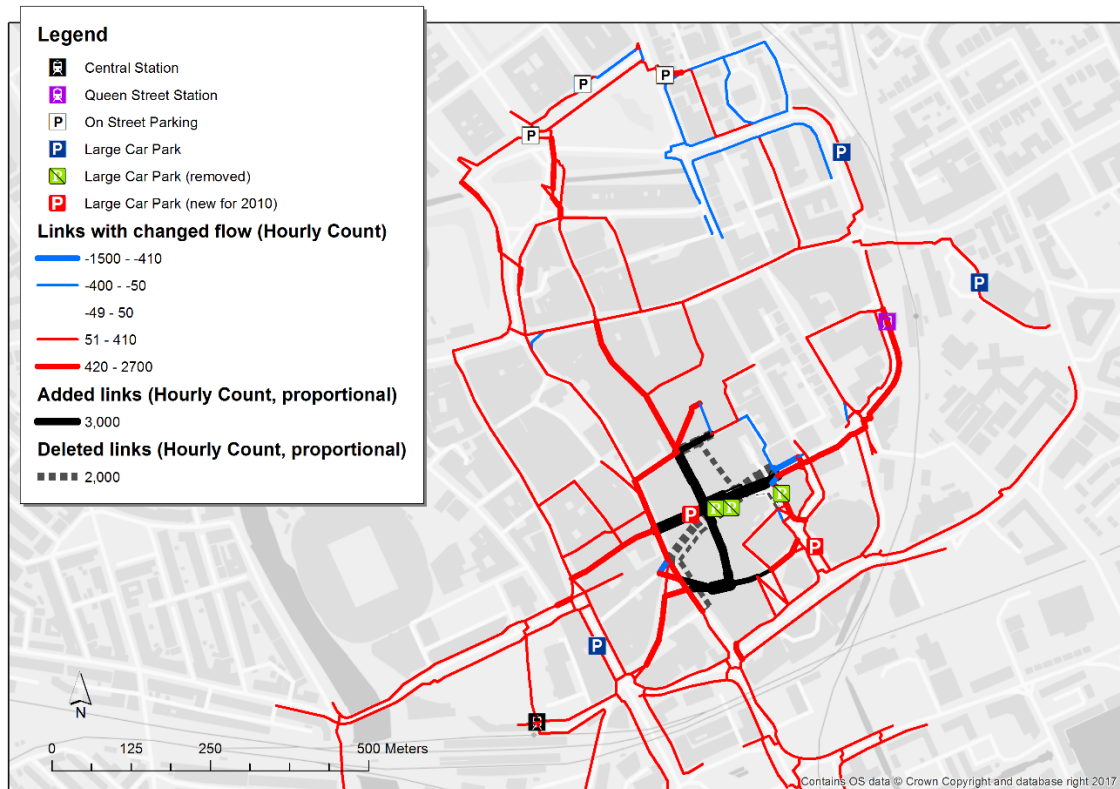


Figure 3 Extrapolation across time: predicted changes for 2010 based on calibration from 2007

The results have shown that the MHSpNA modelling approach can be used to predict future footfall based on changes to the network and previous footfall. A key limitation is the method used for pedestrian counts, which were manual. Modern counting techniques include video analysis and Wi-Fi sensors, with the hope of producing more accurate and voluminous data. There is also no pedestrian flow measurement from inside the new St Davids 2 shopping centre, which would have been beneficial to include if present. Finally it would be fruitful to employ MHSpNA techniques in the prediction of pedestrian mode choice (the decision to walk rather than take motorized transport) as well as flows, as mode choice is the key measure of success in implementing sustainable transportation.

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6. Biography

Dr Crispin Cooper is a Research Associate at the Sustainable Places Research Institute and is currently working on sDNA (Spatial Design Network Analysis). His primary role is to create the next generation of spatial network analysis software, and look for new ways to apply it in research.

Ian Harvey is a Research Software Engineer at the Cardiff University Data Innovation Research Centre. His research interests include interoperability of experimental and production data and computing resources, and development of tools useful to the research community.

Dr Scott Orford is a Reader in GIS and spatial analysis at Cardiff University School of Geography

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