An Agent-Based Population Model for Wolverhampton, UK: a spatio-temporal activity based approach to population modelling

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Summary:

This study presents the development of a prototype model representing the dynamic population across a 24 hour period using an agent-based model, using an activity-based approach by assigning journeys and activities to agents representing different population groups within Wolverhampton, UK.
The model simulates dynamic movement of population throughout the day, which provide advantages over comparable traditional static mapping outputs by allowing the exploration of information on the dynamic movement of individuals within the population which cannot be done through static snapshots. Agent-based models, when integrated to geographic information, have potential to develop more advanced and complex representations of the population.

KEYWORDS: population modelling, agent-based, spatio-temporal, dynamic population, movement

1. Introduction

The use of population data has been important for public and private sector organisations in the development of specific policies and plans requiring an understanding of density, distribution and location of the population. Common approaches to representing the distribution of the population through Geographical Information Systems (GIS) often provide only the residential location as a proxy for measurement through a 'static snapshot' of time (Martin, Cockings, & Leung, 2009). However, in reality the distribution of the population is dynamic and the location of the population is continually changing throughout time and across space. These changes occur across the day and between different days of the week and also at different times of the year. By using the residential location of the population alone it is argued that we are in effect simply representing the night-time population of a given place (Bhaduri, Bright, Coleman, & Dobson, 2002). The spatio-temporal dynamic nature of the human population can have an impact on where and when certain services should be provided and thus the need to examine the ways in which this dynamic movement can be modelled has attracted interest in the field of Geography over the past 40 years (Kwan, 2004).

Traditional proprietary GIS has limitations in being able to accurately model the population due to their restrictive ability to model temporal changes. In addition, the lack of detailed data at the individual level of a continuous nature is also a contributory factor that has often hindered the development of spatio-temporal modelling (Kwan, 2004; Crooks, Castle, & Batty, 2008). Recent advances in computer modelling have increased the opportunity to use geographic information to model the population through a variety of spatio-temporal modelling techniques, such as agent-based modelling (ABM). ABM provides an appropriate modelling environment in which to examine and to simulate population dynamic movements across space and time with the inclusion of agents representing the population and its interaction with different land use types.

Many difficulties in representing the location of the population in GIS are due to the lack of continuous data that is able to accurately model population over space and time (Heywood, Cornelius, & Carver, 2006). The collection of individual activity data is often a challenge due to the extensive

costs and technology required to collect such datasets as well as data confidentially issues associated with monitoring the daily activities of individuals (Longley & Batty, 2003). This means that aggregated population datasets are the most commonly used data sources for studies of the population. Census data is the most comprehensive dataset available in terms of population data however in the case of the UK Census this only provides the residential, workplace and daytime (based on workers and residents) location of the population at a particular given point in time.

There are a number of factors which can impact on the population distribution and density of an area at any given time and therefore for the dynamic nature of the population needs to be considered in context of such requirements. Not only day and nighttime populations can be very different but also factors such as day of the week, whether it's the weekend or a holiday, and the season of the year can also have an impact. (Martin, Cockings, & Leung, 2009).

This study focuses on the development of an agent-based model representing the dynamic population across a 24 hour period. It uses data from the UK 2001 Census as well as other publicly available secondary data sources to create a basic prototype spatio-temporal population model of Wolverhampton, UK.

2. Modelling Population Dynamics in Wolverhampton

The prototype model for Wolverhampton population dynamics was developed using NetLogo. The choice for Netlogo was its GIS extension functionality available within the software as well as the basic level of programming skills required.

The table below summarises the data used in the project:

Table 1. Data sets and sources

2001 Census data for England and Wales (Office for National Statistics)	This dataset was used for output-area level data relating to overall resident population (Census table UV01), workplace population (Census table UV37) population by age group (Census table UV04), and data on economic status (economic activity Census table UV28)
National Travel Survey 2009 (Department for Transport	This information provides statistics on personal travel including modes of travel and trip lengths at a national and regional level. This information was used to develop factors to apply to the local population by type of trip and the distribution of start times of different trip types throughout the day.
Core Accessibility Indicators Database 2009 (Department for Transport)	This is a national database designed to develop the core accessibility indicators for England. It includes geographical location information for education, leisure, and shopping establishments as well as number of jobs available at a Super Output Area level.
Ordnance Survey Digital Mapping (Ordnance Survey) 2011	Output Area boundaries were used to capture Census data at the smallest geographical area available. OS raster based mapping has also been used within this report.

Figure 1 provides a diagram of the main components of the conceptualised model. This shows that the model components consist of; agents representing the population (represented by 'turtles in Netlogo) and the land (represented by 'patches' in Netlogo), and the environment which represents the types of land use or activities.

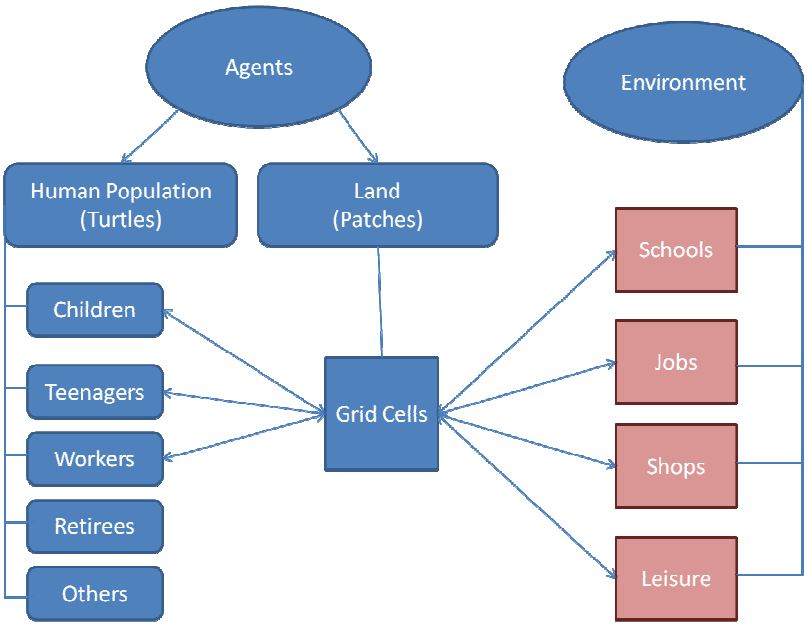


Figure 1. Model Flowchart

The agents in the model represent both the population and the land on which the population move around. The population is represented by of different types of agents which reflect different groups of people within society, each undertaking different travel patterns and activities throughout the day. These groups are described below with a description of their actions within the model.

Table 1. Population Types

Population Types	*Definition*	*% of population*	*Main activities*
Children	People aged 5-10 years old	8%	If no school in output area then will travel to a primary school. The NTS 2009 records that 41% of education trips leave between 8:00 and 8:59 and 32% are made between 15:00 and 15:59. Therefore the main procedure for children will be travel to and from school between these hours and then return to their home patch.
Teenagers	People aged 11-16 years old	8%	If no secondary school home patch then will travel to a secondary school. As with children teenagers will leave their home output area to head to secondary school between 8:00 and 9:00. Therefore the main procedure for teenagers will be to travel to and from school between these hours – and then return to their home patch.
Workers	Population aged 16-64 in full or part time employment	34%	Will travel to town centre or a patch with a minimum number of jobs or to the town centre. The leaving time for commuting trips (NTS0503) associated with workers is distributed across the day. However most trip occur between 7:00 and 8:59 and between 16:00 and 17:59

Retirees	All People aged 65 and over	19%	Involved in leisure and shopping journeys and activities throughout the day. Most shopping trips start and end between 10:00 and 12:59 and as such the main journeys involving this group of the population will take place during these hours.
Others	Includes all people not included within above groups	31%	Involved in leisure and shopping journeys and activities throughout the day. Most shopping trips start and end between 10:00 and 12:59 and as such the main journeys involving this group of the population will take place during these hours.

The environment within the model represents types of land use within the city. The types of land use are represented by variables 'attached' to 'patches' in the model. Each patch represents a land parcel in Wolverhampton. Census data at the OA level is disaggregated to the grid level in ArcGIS and then this is applied to the patches within the NetLogo model to provide population data. Data from the Core accessibility indicators including location of primary schools, secondary schools, retail and numbers of jobs were disaggregated to patch level.

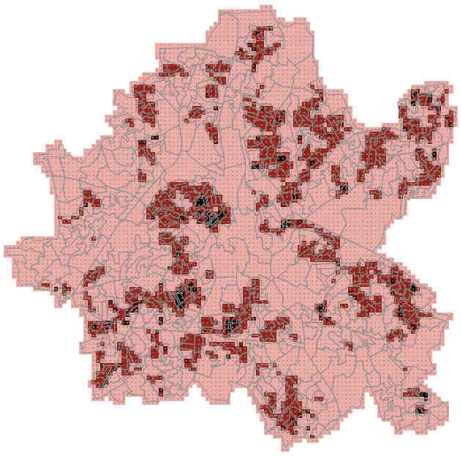
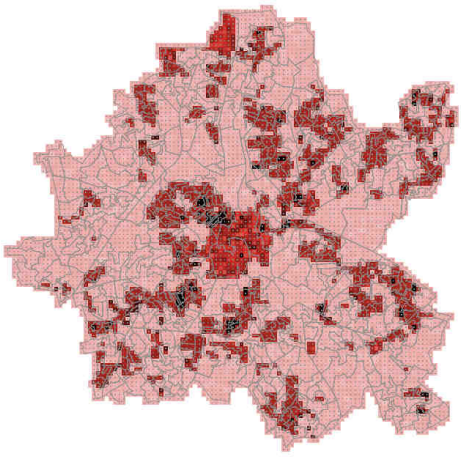
Table 2. Environment Variables within model

Land-Use Type	***Comments***
Education (Primary Schools & Secondary Schools)	The geographical coordinates of the schools located in Wolverhampton were taken from the Core accessibility indicator dataset from the DfT and verified using the Wolverhampton City Council website1. Each primary school, secondary school and place of further and higher education was plotted in ArcGIS. Information on the number and type of school in the city was to each patch to in the model.
Jobs	The number of jobs at a Super Output Area level is available as collected through the DfT's Core Accessibility Indicator data set. This data was aggregated to a 100m2 grid level for use at the patch level in NetLogo
Retail (Supermarkets and shops)	The geographical coordinates of supermarkets and shops located in Wolverhampton were taken from the Core accessibility indicator dataset. Information on the number of retail outlets in the city was disaggregated at patch level in the model.

2.1 Model outputs and results

Following the completion of the model development the model was run to simulate population movement over a 24-hour period in Wolverhampton. The outputs from this model included graphical output at each hour of the day showing the density of the population through a sum of all population located at each patch. Figure 2 shows the output views for selected hours of the day, with the darker patches representing denser populated areas and lighter patches reflecting lowest population density. This shows that through the early hours of the morning those population densities are highest in the residential areas especially those built up areas with multi-occupancy buildings. Between 7am and 6pm the most populated areas are within the city centre.

[1] http://www.wolverhampton.gov.uk/education_learning/schools/list/ checked 1/12/2011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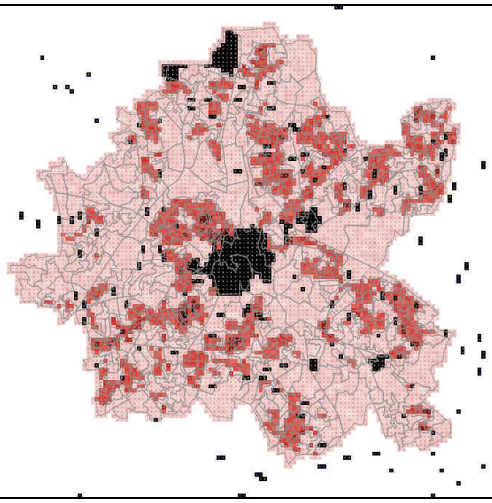
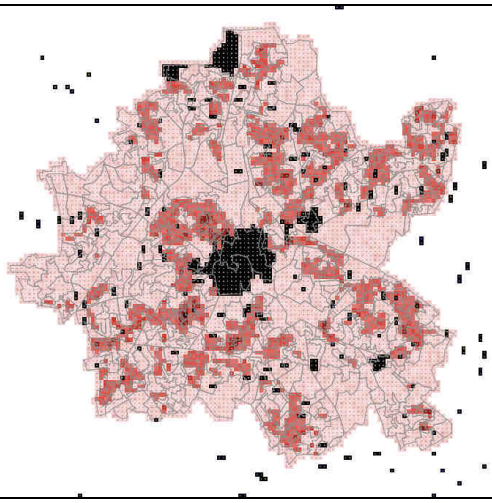
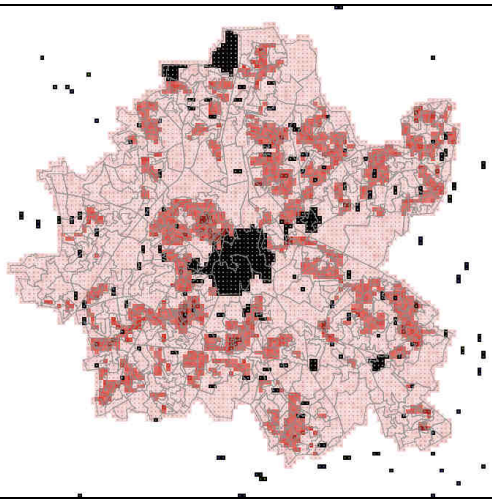
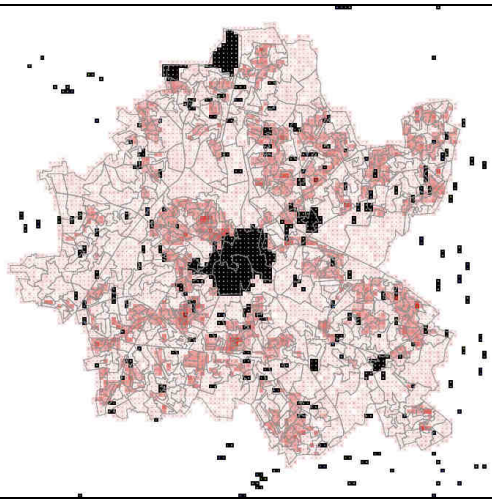
	
8am	9am
	
10am	11am

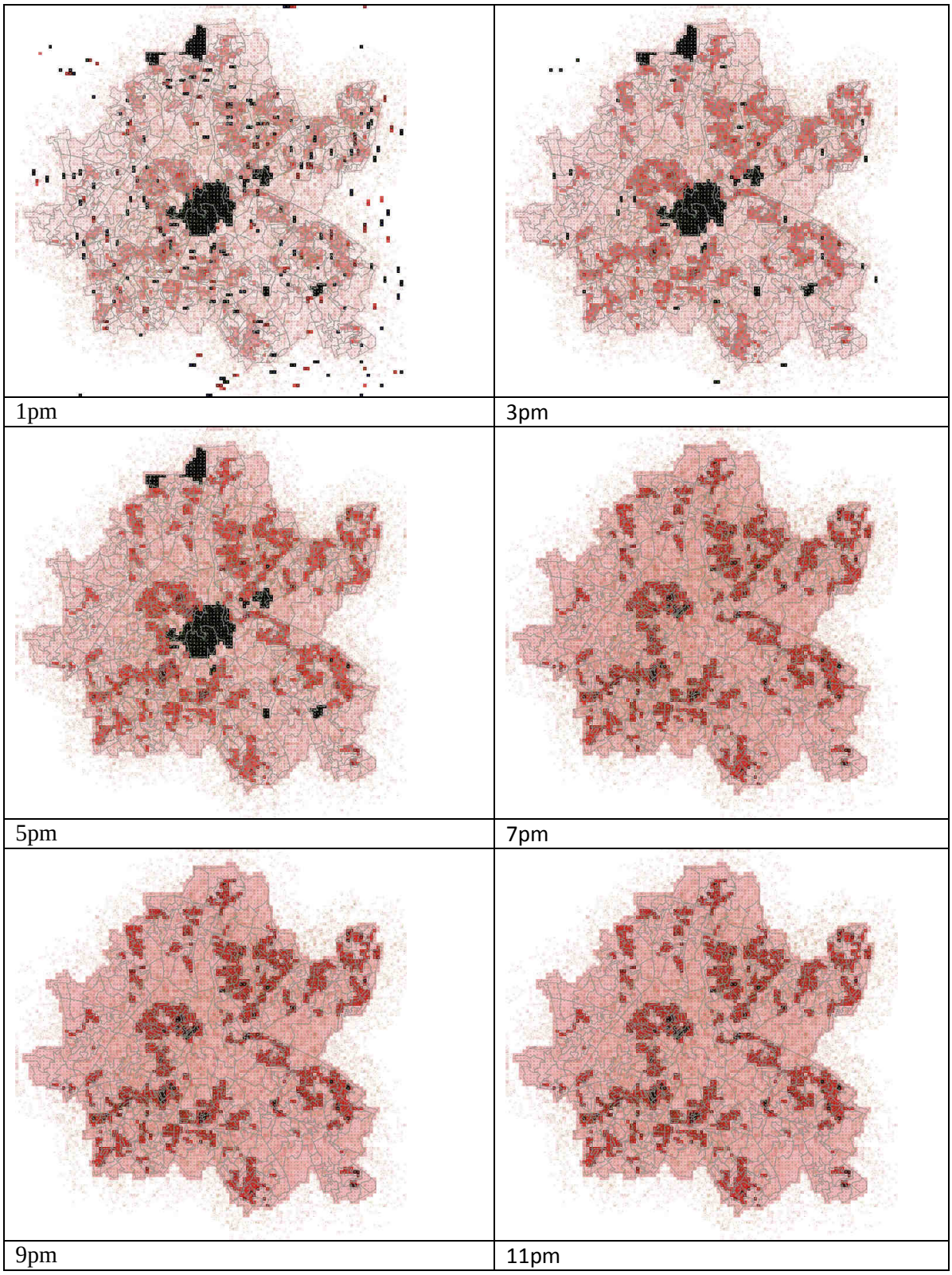
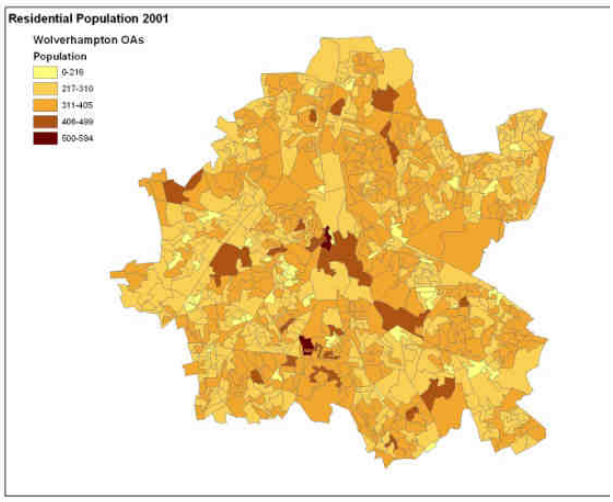
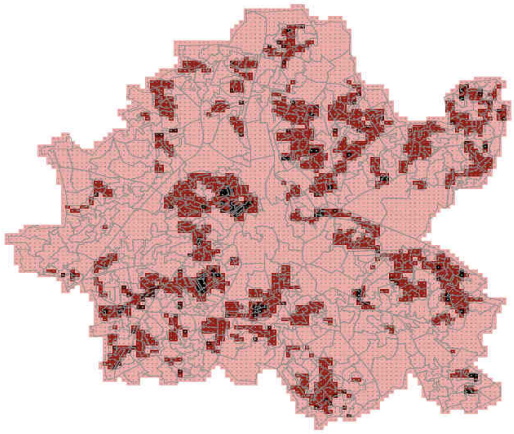


Figure 2. Snapshot sequence of Model Results – by hour of day

The model outputs have been compared with static snapshots of residential and daytime population data from Census to show similarities and differences in population distribution representation (see

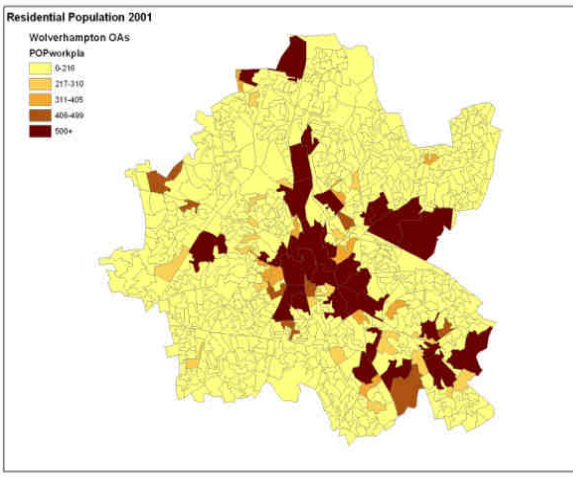
Figure 3 and Figure 4). The results show some variation in comparison between the density and distribution of the population throughout the day; however it is clear that the outputs being compared are illustrating different scenarios. The lack of continuous level individual data makes it difficult to validate or accurately evaluate the accuracy of the model outputs and detailed results are difficult to obtain. It is; however, clear that such a model can provide a more detailed representation of individual movements within the population where static maps may conceal the location of particular groups of the population at any given time.

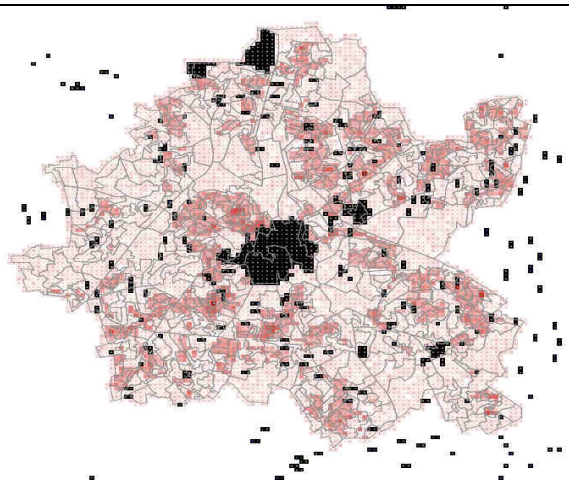




Census data output from ArcGIS – residential output	NetLogo output - 4am

Figure 3. Residential Population of Wolverhampton – representing night time population (Census 2001) choropleth maps from ArcGIS relating to the residential location of the population by output area in terms of number of population. This image reflects the 'night-time population'. This is compared to the output of the model (image B) showing the population at 4am. Source: 2001 Census Output Areas Boundaries. Crown Copyright material is reproduced with permission of Controller of HMSO.





Workplace Census Population 2001	NetLogo output 11am

Figure 4. Workplace Population of Wolverhampton choropleth map illustrating the distribution of the 'workplace population' for Wolverhampton. This is compared to the output showing the population at 10am from the agent-based model. Source: 2001 Census Output Areas Boundaries. Crown Copyright material is reproduced with permission of Controller of HMSO.

Conclusions

This study shows that agent-based modelling can be an appropriate technique for the use of modelling the dynamic of the population across time and space. The use of Census population data can be used as a base for which to understand the residential location of the population and secondary data sources such as the national travel survey can help to create a representation of the dynamic population.

Static snapshots showing residential, workplace and daytime population have been widely using in planning and policy formation and undoubtedly have their uses. However the outputs of the model show the dynamic movement of the population distribution throughout the day and allow the exploration of information on the dynamic movement of individuals within the population which cannot be done through static snapshots.

Limitations in terms of availability of appropriate data, restrictions in development time and programming ability and difficulties in validation and evaluation have all contributed to shortcomings in the model and therefore only a basic outline model has been developed for the purpose of this study. Further development of the model could include more detailed information on the transport network, the physical and psychological barriers impacting on movement as well as choice of destination (ie type of school or employment) and interaction between agents.

Although there are many additional features that could further enhance the developed model, this study has shown that agent-based models integrated with geographic information can be used to develop more advanced and complex representations of the population than traditional GIS methods.

4. References

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5. Biographies

Laura Walker is a senior planner at Atkins specialising in socio-demographic analysis and assessment of social and distributional impacts in the context of planning and transport related schemes. She has recently graduated from Birkbeck College with an MSc in Geographic Information Science.

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