Creation of a System of Functional Areas for England and Wales and for Scotland

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ABSTRACT

Geographers and planners today place an emphasis on spatial organisation. One of the key concepts in spatial organisation is Functional Areas – areas defined by business and economic activities rather than by administrative or historic boundaries. We define the Functional Areas as areas which have high level of self-containment in terms of travel-to-work patterns. To create the potential functional areas for England and Wales and for Scotland we carried out some analysis using a hierarchical clustering algorithm called Intramax procedure which is incorporated in the FLOWMAP software. The data used in this study comes from the flow dataset in the 2001 UK Census and it consists of the journey-to-work statistics for all wards in Britain, resulting in a sparse flow matrix with origin-destination pairs. The Functional Areas analysis provides a catalogue of possible zoning systems for land-use/transport modelling and planning. Any justification for using any particular set of Functional Areas as the basis for any particular model must depend on other characteristics such as the perception of what constitute the alternatives for different types of locational decisions.

1. INTRODUCTION

In June 2004 the Department for Transport (DfT), UK, commissioned a project to use 2001 Census journey-to-work data in two streams of work: the creation of a system of Balancing Areas for use in the next version of the National Trip End Model (NTEM); and creation of a system of Functional Areas/Regions to form the basis for future research on household and business location choice modelling. This paper presents the methods which were used to obtain a system of Functional Areas/Regions, and shows some results of the project. The project was carried out by a consortium of MVA and David Simmonds Consultancy Ltd (MVA and DSC, 2005).
The selection of a suitable functional regionalization technique raises both technical and practical problems. Even though there is an agreement amongst specialists as to what is meant by a functional region in general, there is significant diversity of judgement about how exactly it can be specified in practice. The main decisive factor is the strength of interaction between spatial units, which mean that the functional regions can be defined as “areas or locational entities which have more interaction or connection with each other than with outside areas” (Brown and Holmes, 1971).

The best-established technique for a functional approach to area grouping is to identify boundaries across which relatively few people commute. Although commuting distances have increased in length over time, and have become very long for a minority of people, distance still has a substantial deterrence effect and, as a result, for almost all areas the majority of journey to work flows are to and from nearby areas.

To create the potential Functional Areas for England and Wales and for Scotland we carried out analysis using a hierarchical clustering algorithm, which was already coded in the FLOWMAP program developed by the University of Utrecht (Van der Zwan et al., 2003). The Functional Areas analysis provides, in effect, a catalogue of possible zoning systems based on identifying areas of relatively high self-containment in terms of the travel-to-work patterns in 2001. In this study we refer to the basic input units – wards as zones, to small groups of zones as areas and to larger groups of zones as regions.

The data used in this study comes from the journey to work flow dataset in the 2001 UK Census. Census participants were asked to for their usual workplace, their main mode of travel to work and details about their work. In Scotland the question was broadened to include ‘location of workplace or course of study’. Due to these differences in questions, the 2001 census is provided as a single dataset for England and Wales and a separate dataset for Scotland. It consists of the statistics for all wards in Britain (the average ward size in England is about 6000 resident persons, in Wales – 3000 and in Scotland – 4000 resident persons), resulting in a sparse flow matrix with origin-destination pairs. To avoid releasing information that may identify particular individuals, families, households or dwellings, all UK Census tables were subjected to random error so that the minimum number of people reported in any single cell is 3.

The other input to this project was separate boundary files for England and Wales and Scotland.

Analysis of the England and Wales Census journey to work matrix was carried out for the data for the ‘all people’ category. Given the different census question in Scotland we assumed that the full time students in employment would give their student address, and therefore efforts were concentrated on the people aged 16-74 in employment; not full time student for the Scotland dataset.
Following this Section, the paper is structured as follows. Section 2 is a brief overview of the Intramax analysis and the FLOWMAP software. Section 3 discusses the main results on Functional Areas for England and Wales and Scotland. Finally, Section 4 gives some conclusions on the research.

2. INTRAMAX ANALYSIS USING FLOWMAP

Spatial aggregation by means of the Intramax procedure is incorporated in the software called FLOWMAP. The software was developed at the Faculty of Geographical Sciences in Utrecht University, the Netherlands. The software is specialised in analyzing interaction data, like migration and commuting flows, network analysis, interaction analysis like accessibility analysis, and interaction modelling (van der Zwan et al., 2003).

FLOWMAP uses any data which can be grouped into three classes, namely, flow data, distance tables and maps. Flow data give observed interactions like commuter flows and migration flows from certain origins to certain destinations. A distance table is a matrix which contain distances for all possible combinations of interactions between origins and destinations (for example, in meters or minutes). Such tables can be calculated and built within FLOWMAP. Maps usually include a base map, which is either an area map or a network, a point map containing flow origins, and a point map containing flow destinations. These points are often centroids of the base area map. In the software, maps are called Location data, data with regards to flows are called Flow Data and distances are called Distance Matrices.

The original authors of Intramax (Masser and Scheurwater, 1980) are not clear whether or not it is necessary/correct to use some form of a contiguity criterion. In FLOWMAP no contiguity criterion is used. The higher level results are usually automatically almost completely contiguous and most non-contiguous mergers observed in the results could be traced back to a data error or unsuitable data. The detailed explanation on how to use the software can be found in the software manual (see van der Zwan et al., 2003).

Interaction between various locations can be considered as a degree of functional distance, namely, the more interaction, the shorter the distance. FLOWMAP uses the Intramax procedure which carries out a regionalisation of an interaction matrix. According to Masser and Scheurwater (1980), “the objective of the Intramax procedure is to maximize the proportion within the group interaction at each stage of the grouping process, while taking account of the variations in the row and column totals of the matrix”. Each step in FLOWMAP looks at every pair of zones which might be combined at that step, and merges the pair for which the objective function has the highest value. That mean that those two areas are grouped together for which the objective function is maximised:
\[
\frac{T_{ij}}{O_i \cdot D_j} + \frac{T_{ji}}{O_j \cdot D_i} \rightarrow \text{max},
\]

where \( T_{ij} \) is the interaction between origin location \( i \) and destination location \( j \), \( O_i = \sum_j T_{ij} \), \( D_j = \sum_i T_{ij} \). Note that the objective function can only be calculated for all \( D_j > 0 \) and for all \( O_i > 0 \), i.e. a zone which has either no jobs or no resident workers will be ignored. In practice, with ward-level data, this is not a problem.

The Intramax procedure incorporated in FLOWMAP is a stepwise analysis. In each step two areas are grouped together and the interaction between these two areas become intrazonal interaction for the new resulting area. Then the process is repeated, and after \( N-1 \) steps with \( N \) areas all areas are grouped together into one area and all interaction becomes intrazonal.

**Figure 1. Example of Intramax Analysis by FLOWMAP for Journey-to-Work Data for England and Wales, 2001.**
As an example, Figure 1 represents part of the output from the Intramax Analysis for Scotland. The header of the output denotes the data files which were used in the analysis as well as the initial output. The total number of interactions is the total number of zonal trips. The process merges at each stage the zone which does most to increase the proportion of the intrazonal interactions in absolute terms irrespectively from the size of the zones. In each step each area in the first column is to be merged to the corresponding area from the second column. The total intrazonal interaction (the total number of the intrazonal trips) after this merge is shown in the third column. The forth column shows a percentage increase (the percentage of the intrazonal trips in the total number of trips in the network) which will occur after this merge. The last column represents the percentage cumulative intrazonal interaction after the merge. The initial intrazonal interaction is 23.59%. At the very first step area 004S19 is added to area 004S18, at the second step area 008S21 is added to area 008S20, then area 004S18 is added to area 004S17, and so on. The cumulative intrazonal interaction is gradually increasing. After 1175 steps all areas are merged into a single area and the cumulative intrazonal interaction becomes 100%.

We have found that the method seems to show a strong tendency to produce areas which consist of parts of an urban area and their adjoining suburban/rural areas. We understand, through correspondence with Prof. Tom de Jong, one of the creators of the FLOWMAP software, that this is a normal Intramax result. Intramax of course does not know about rural/urban distinctions but looks at flows and total numbers of commuters per zone. In the initial stages of the Intramax procedure smaller zones (in terms of total in-commuting/out-commuting) with relatively strong links are merged (high $T_{ij}$ value compared to small $O_i$ and $D_j$ values.) In the middle stages small zones are linked to larger ones (high $T_{ij}$ value compared to a small $O_i$ and a high $D_j$ value or a small $D_j$ and a high $O_i$ value). In the final stages large zones are linked to other larger zones (high $T_{ij}$ value compared to high $O_i$ and $D_j$ values). With commuter data this has the effect of dividing the whole area into catchment areas around large urban centres instead of a split between urban and rural fields.

To analyse the Intramax data we have developed the InfoMap program. As discussed above, FLOWMAP uses the Intramax Procedure to group areas together such that total within-group interaction is maximised and outputs this data as a series of steps, with each step consisting of one area being merged into another. InfoMap, given a user input number of areas, reads these steps and produces a table displaying the area each zone belongs to, which MapInfo then uses to produce illustrative maps. For this project it has been important to display the data using Mapinfo software to be able to assess contiguity of the areas.
3. 2001 FUNCTIONAL AREA RESULTS

To create the potential Functional Areas for England and Wales and for Scotland we carried out analysis using the FLOWMAP Intramax function. We produced databases containing a number of snapshots at different steps of the process using ward data. Note that the method is not constrained to respect administrative or other regional boundaries.

![Figure 2. Part of the database for Scotland based on 2001 JTW data.](image)

An example of the final database for Scotland (2001) is presented in Figure 2. Each row in the database represents an original ward (in the alphabetic order) and each column is one stage in the FLOWMAP aggregation sequence. The values in the table are the identifier of the area to which the zone belongs at that stage. This identifier is simply the first zone, in alphanumeric order, within the area, and has no significance except to distinguish the different areas.

Table 1 shows aggregation steps and the corresponding cumulative intrazonal interactions for England and Wales, and Scotland based on the Intramax output for 2001 Census data. The intrazonal interactions are the intrazonal flows as a percentage of all flows with origins or destinations in that area.
Table 1. Cumulative intrazonal interaction (%) for the selected Intramax steps for England and Wales, JTW 2001 ward data.

<table>
<thead>
<tr>
<th>Intramax step</th>
<th>Number of zones</th>
<th>Cumulative intrazonal interaction (%)</th>
<th>Intramax step</th>
<th>Number of zones</th>
<th>Cumulative intrazonal interaction (%)</th>
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</thead>
<tbody>
<tr>
<td>England and Wales</td>
<td></td>
<td></td>
<td>Scotland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial data</td>
<td>8850</td>
<td>23.09</td>
<td>Initial data</td>
<td>1176</td>
<td>23.59</td>
</tr>
<tr>
<td>3851</td>
<td>5000</td>
<td>29.41</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6351</td>
<td>2500</td>
<td>38.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6851</td>
<td>2000</td>
<td>41.27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7851</td>
<td>1000</td>
<td>50.75</td>
<td>177</td>
<td>1000</td>
<td>27.07</td>
</tr>
<tr>
<td>8351</td>
<td>500</td>
<td>59.10</td>
<td>677</td>
<td>500</td>
<td>36.38</td>
</tr>
<tr>
<td>8475</td>
<td>376 (District level)</td>
<td>62.37</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>8526</td>
<td>325</td>
<td>63.98</td>
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<tr>
<td>8642</td>
<td>209</td>
<td>68.78</td>
<td>927</td>
<td>250</td>
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<tr>
<td>8676</td>
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<td>8763</td>
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<td>60</td>
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<td>48</td>
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<tr>
<td>8786</td>
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<td>81.16</td>
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<tr>
<td>8807</td>
<td>44</td>
<td>83.95</td>
<td>1145</td>
<td>32 (Council level)</td>
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<tr>
<td>8810</td>
<td>41</td>
<td>84.89</td>
<td>1147</td>
<td>30</td>
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<tr>
<td>8816</td>
<td>35</td>
<td>86.36</td>
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<td>28</td>
<td>78.76</td>
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<tr>
<td>8821</td>
<td>30</td>
<td>88.15</td>
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<td>25</td>
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<td>8834</td>
<td>17</td>
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<td>94.39</td>
<td>1163</td>
<td>14</td>
<td>91.41</td>
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<tr>
<td>8841</td>
<td>10 (Region level)</td>
<td>95.68</td>
<td>1167</td>
<td>10</td>
<td>93.03</td>
</tr>
<tr>
<td>8842</td>
<td>9</td>
<td>95.74</td>
<td>1169</td>
<td>8</td>
<td>94.68</td>
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<tr>
<td>8846</td>
<td>5</td>
<td>96.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8847</td>
<td>4</td>
<td>97.34</td>
<td>1173</td>
<td>4</td>
<td>96.52</td>
</tr>
<tr>
<td>8849</td>
<td>2</td>
<td>98.14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final</td>
<td>1</td>
<td>99.29</td>
<td>Final</td>
<td>1</td>
<td>100.00</td>
</tr>
</tbody>
</table>
For England and Wales all the steps listed in Table 1 from 325 zones onwards represent natural break points in the output, namely, the steps when a zone that significantly increases the total cumulative intrazonal interaction was added. The exceptions are steps 8786 and 8841 which are not natural break points but correspond to the total number of counties and to the total number of regions respectively. For Scotland the steps from 104 zones onwards represent natural break points with exception of step 1145 – Council level.

As can be seen from the table, about 0.7 per cent of the population of England do not work in England. We do not have data on where these people work.

There are 376 administrative areas in England and Wales. We compared their boundaries with the function area boundaries at 376 zone level (see Figure 3). Based on this map, we have made three main observations.

- Some of the administrative district and functional area boundaries perfectly overlap, whereas some others do not coincide at all. Figure 4 picks out examples of administrative areas which correspond particularly well or badly with functional areas.
Most administrative districts seem to have part of their boundaries overlapping with functional area boundaries, given that both administrative and functional boundaries use wards as their building blocks. However, where an administrative area corresponds closely to an urban area (as is the case in Cambridge or Stevenage, for example) such a boundary is unlikely to be the edge of a functional region, as functional regions tend to link urban areas with their rural hinterlands.

Urban administrative areas tend to be bigger than urban functional areas, whereas rural administrative areas tend to be smaller than rural functional areas.

Figure 4. Comparison of administrative district and functional area boundaries, Greater London, 2001.

We have produced a map of Wales and nine regions in England overlaying with a boundary map of the corresponding Functional Areas obtained from the Intramax analysis at ten-zones level (See Figure 5). City names have been added for reference. As one can see:

- the boundaries of the functional area centred on Newcastle-upon-Tyne are fairly similar to the actual boundaries of the North East region;
- the functional area boundaries divide the North West Region into two – northern and southern parts;
• the functional area centred on Leeds and Sheffield includes nearly all of Yorkshire and the Humber, but in addition encompasses the northern half of East Midlands;

• the functional area boundaries suggest that the northern part of Wales has more interactions with the North West Region than with the rest of Wales. - this finding reflects the effect of proximity to major cities (Manchester and Liverpool in this case) on spatial interactions;

• the functional area of West Midlands with Birmingham as the central node extends to the west to include the central section of Wales and to the east to include the southern part of East Midlands;

• the functional area with London as the centre is much larger than Greater London itself, covering most of the South-East Region and part of the East Region; and

• the functional area boundaries divide the South-West Region into two – eastern and western regions.

Figure 5. Functional Area boundaries and Region Boundaries

There are 32 council areas in Scotland. These 32 council area boundaries have been compared with the function area boundaries at 32-zone level (see Figure 6).
Figure 6. 2001 Functional Areas and Administrative Areas, Scotland
According to the functional area boundaries, some existing council areas could be broken down into sub-areas, and some other council areas could be combined to form larger conurbations. Some areas are consistent with function area boundaries. We give examples of each case below.

Examples of council areas that are broken down include:

- Highland council is divided into five sub-areas;
- Aberdeenshire is divided into three sub-areas, namely, north, middle and south; and
- Dumfries and Galloway area is divided into two sub-areas, namely, east and west.

Examples of council areas that are combined include South Ayrshire, East Ayrshire and North Ayrshire; and Inverclyde, Renfrewshire, and a small part of Renfrewshire. Only three mainland council areas are consistent with the corresponding functional areas: Moray, Argyll and Bute, and Scottish Borders. The three island authorities (Shetland Islands, Orkney Islands, and Eilean Siar) also appear as functional units.

Additionally, particular attention was paid to the big cities – Glasgow, Edinburgh, Dundee and Aberdeen, and we observe that (see Figure 7):

- Glasgow is “dissolved” in the functional area map. It is broken down into four sub-areas, which are merged with the surrounding councils, such as East Dunbartonshire, North Lanarkshire, East Renfrewshire, and a small part of South Lanarkshire;

Edinburgh is combined with the entire Midlothian Council - however, the north-western part becomes separated from the city, and is combined with West Lothian instead;

- Dundee is merged with the southern half of Angus as well as with a part of Perth and Kinross; and
- Aberdeen is merged with the mid-section of Aberdeenshire.

The overall observation is that, comparing local authority units with the equivalent number of functional areas, the major urban authorities tend to be smaller than the functional areas, whilst the most rural authorities tend to be substantially larger. This probably reflects the political pressure within the process of defining local authorities (which in the UK are created by central/national government) to create more equal-sized authorities (in population numbers) than the functional analysis might suggest.
4. CONCLUSIONS

This paper reports on the Functional Area analysis, which provided a database of possible zoning systems based on identifying areas of relatively high self-containment in terms of the travel-to-work patterns in 2001.

What this analysis does not provide is a justification for using any particular set of Functional Areas as the basis for any particular model, either at a national level or for any particular region or sub-region. Any such justification must depend on other characteristics, such as – we suggest – the perception of what constitutes the alternatives for different types of locational decisions. These perceptions may well be very different for different types of actor – for example, the set of areas perceived as possible locations by a small, regional firm may be different from the set perceived by a large national firm.

Moreover, some decisions may well be hierarchical in nature, even before getting down to the choice of specific locations or properties within the lowest-level area. For example, a multinational firm seeking to set up an operation in England may make a choice at the regional level before making a choice – on different criteria – at the area level. Somewhat similarly, different categories of households may perceive areas differently – for example, a high-income household with two specialised, professional workers might perceive the North-West as a small number of large areas, whilst a household consisting of unskilled workers might
perceive the same region as a larger number of small areas (with perhaps only the closer ones being clearly perceived).

In addition, it is not suggested that any one zone system is in fact appropriate for all purposes, although a single zoning system forms the basis of the conventional approach to modelling. The present project has proceeded very much on the basis of taking a zoning system that is appropriate for the purpose. It is also likely that any set of functional units based on travel-to-work (or any other patterns of interaction) will change over time; it is therefore not strictly appropriate to use zones based on data for one point in time as the fixed units for long-term forecasting. Ideally, perhaps, the definitions of areas other than the smallest and most basic units would emerge as outputs of the forecasting approach rather than being fixed constraints upon it.

The word “ideally” needs to be emphasised in that sentence, and for present practical purposes we believe that the Functional Areas based on 2001 data will prove a valuable catalogue of possible system definitions. We have already started making use of this resource both in our household location modelling (Feldman et al., 2005) and in other work on possible model designs.

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REFERENCES


