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Network-based GIS accessibility metrics: A technical guide to geographical access scores available on the WISERD Data Portal

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This technical document is an accompaniment to the network-based accessibility scores generated as part of work package 3.2 of the ESRC-funded WISERD Civil Society research programme[1]. These data are freely available through the WISERD Data Portal[2]. The purpose of this document is to provide additional clarity, beyond the metadata already provided, on the computational steps that underpin these scores. Geographical accessibility scores were computed for all lower super output areas in Wales (LSOA, n=1,909) and for nine services: public libraries; leisure centres; post offices; primary and secondary schools; petrol stations; general practice surgeries; pharmacies; and food shops. All computations are based on a transport model that assumes travel is exclusively by private car passing through a road network model constructed with Ordnance Survey's Open Roads[3] product. Travel times along each road network link is based on national speed limits being applied according to the road's classification.

For the purposes of comparison, access scores have been generated using three alternative approaches to measuring geographical accessibility; (1) minimum distance to nearest provider, (2) local cumulative opportunity, and (3) enhanced two-step floating catchment area (E2SFCA) accessibility. A more detailed discussion of the strengths and limitations of each method is available elsewhere.[4] In order to improve spatial accuracy, in all cases the LSOA-level accessibility score is itself derived from a population weighted mean of the equivalent score computed at output area level (OA, n=10,036). Thus, population distribution is effectively modelled using the ONS supplied OA population weighted centroids, and each LSOA level score is derived from those OA level scores that nest within the LSOA. A freely available bespoke ArcGIS™ Add-In tool performed the E2SFCA calculations.[5] It requires the availability of the Network Analyst extension in ArcGIS.

[1] https://wiserd.ac.uk/wiserd-civil-society-research-centre

[2] https://wiserd.ac.uk/research/research-projects/wiserd-dataportal

[3] https://www.ordnancesurvey.co.uk/business-and-government/products/os-open-roads.html

[4] Page, N., Langford, M, Higgs, G. (2018) An evaluation of alternative measures of accessibility for investigating potential 'deprivation amplification' in service provision, *Applied Geography*, 95: 19-33.

[5] https://www.researchgate.net/publication/287198887_USW-FCA2_An_ArcGIS_add-In_tool_to_compute_Enhanced_Two-Step_Floating_Catchment_Area_accessibility_scores

1. Minimum distance ("min_dist")

Minimum distance to nearest provider (in meters) Z_k^M was measured as the shortest network journey time *d* from each population weighted centroid *k* to its nearest service supply point *j*:

$$Z_k^M = \min\left|d_{kj}\right| \quad (1)$$

2. Local cumulative opportunity ("cum_opp")

The local cumulative opportunity score Z_k^C was measured as the sum of those supply points S_j that fall inside a network-based maximum travel time catchment threshold (in this case, 15-minutes by private transport) d_0 from each population weighted centroid *k*:

$$Z_k^C = \sum_{j\in(d_{kj}\leq d_0)} S_j \quad (2)$$

3. Enhanced Two-Step Floating Catchment Area ("E2SFCA")

Floating Catchment Area (FCA) accessibility scores are widely considered to be an enhancement over traditional 'container' and 'travel cost' approaches to accessibility measurement. Container approaches evaluate accessibility only as the service supply capacity relative to potential demand volume inside a fixed geographical unit. Travel cost estimates focus on the travel impedance (e.g. time, distance, or cost) associated with reaching a service from a given point of origin. The FCA technique incorporates elements of both of these approaches, and involves two fundamental computational steps. In Step 1, a catchment area based on a maximum travel time (e.g. 15-minutes) is constructed around each service supply point (a GP surgery, for example). A supply-to-demand ratio is computed based on the supply capacity at this point relative to the number of potential users falling within the catchment. A key strength of defining geographical service areas in this way is that it circumvents many issues surrounding cross-border flows, which is a limitation of the container approach. In order to evaluate potential overlaps in the service provision areas of supply points, and to account for the fact that most demand centres have multiple supply centres 'in reach', a second calculation is required. In Step 2, equivalent catchments are placed around each demand centre (most commonly, the population weighted centroid of a census tract) and a final FCA score is computed as the sum of all supply-to-demand ratios within this catchment. To further account for the influence of travel cost, or geographical friction, a distance-decay function was applied to all distances used within the two-step FCA approach, to yield the so-called Enhanced Two-Step Floating Catchment Area (E2SFCA) method.

In Step 1, R_j, is a supply-to-demand ratio computed for each service point *j* based on its supply capacity S_j (always 1 in these calculations)[6] relative to the total OA population, P_k, that falls

[6] In the scores supplied, all supply capacities used a value of 1. This accounts for the presence of a service, and assumes that all service supply points have equal relative capacity. This value can be replaced by a meaningful supply characteristic (e.g. opening hours of library, or bed spaces in a hospital) if such data are available.

within the network-based maximum travel time catchment threshold d_0 (i.e. a 15-minute journey by private transport) (3). The linear weighting factor W_kj provides for the distance-decay effect; the actual population using a service centre is modelled to decline linearly with distance, reaching the value 0 at the limits of the defined catchment area (4).

$$R_j = \frac{S_j}{\sum_{k\in(d_{kj} \le d_0)} P_k W_{kj}} \quad (3)$$

$$W_{kj} = \frac{(d_0 - d_{kj})}{d_0} \quad if \quad d_{kj} \le d_0 \quad (4)$$

$$W_{kj} = 0 \qquad otherwise$$

The E2SFCA score A_k for each OA is computed as the sum of the supply-to-demand ratios, R_j, that fall inside the travel time catchment drawn around the population weighted centroid. Again all distances are weighted by a linear-decay function, so the value of a service provision point declines uniformly to become 0 at the limits of the defined catchment area (5).

$$A_k = \sum_{j\in(d_{kj} \le d_0)} R_j \, W_{kj} \quad (5)$$

Input data

Service supply-side data were obtained for the nine services recorded from a variety of sources (briefly summarised in Table 1). E2SFCA scores for these services were originally computed as part of a larger study exploring the implications of using FCA methods within indices of multiple deprivation[7], which informed the selection of the services chosen.

[7] Page, N., Langford, M., Higgs, G. (2017) Measuring spatial accessibility to services within indices of multiple deprivation: implications of applying an enhanced two-step floating catchment area (E2SFCA) approach, *Applied Spatial Analysis and Policy*. https://doi.org/10.1007/s12061-017-9246-2.

Table 1: Service points underpinning GIS accessibility metrics

Service	Source
Public library (n=207)	OS Points of Interest (Digimap), December 2016
Pharmacy (n=714)	Extracted from NHS sources, February 2017
Secondary school (n=205)	Welsh Government, January 2016
GP surgery (n=453)[8]	Welsh Government, November 2015
Food shop (n=3,444)[9]	OS Points of Interest (Digimap), December 2016
Leisure centre (n=195)[10]	Welsh local authorities (complied by Sport Wales), February 2015
Primary school (n=1,093)	Welsh Government, January 2016
Petrol station (n=540)	OS Points of Interest (Digimap), December 2016
Post office (n=807)	OS Points of Interest (Digimap), December 2016

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[8] Not including branch surgeries.

[9] Defined as any shop where it is possible to purchase bread and milk.

[10] Non-commercial (i.e. community or council operated) multi-activity facilities