DynaPop – Population distribution dynamics as basis for social impact evaluation in crisis management

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ABSTRACT

In this paper ongoing developments regarding the conceptual setup and subsequent implementation logic of a seamless spatio-temporal population dynamics model are presented. The *DynaPop* model aims at serving as basic input for social impact evaluation in crisis management. In addition to providing the starting point for assessing population exposure dynamics, i.e. the location and number of affected people at different stages during an event, knowledge of spatio-temporal population distribution patterns is also considered crucial for a set of other related aspects in disaster risk and crisis management including evacuation planning and casualty assessment. *DynaPop* is implemented via a gridded spatial disaggregation approach and integrates previous efforts on spatio-temporal modeling that account for various aspects of population dynamics such as human mobility and activity patterns that are particularly relevant in picturing the highly dynamic daytime situation.

Keywords

Population dynamics, spatio-temporal modeling, spatial disaggregation, population exposure

INTRODUCTION AND CONTEXT

In the context of proactive disaster risk as well as immediate situational crisis and emergency management the quality of available models and corresponding input data in all terms of spatial, temporal, and thematic accuracy and reliability is among the most important factors for risk mitigation and disaster impact minimization. With regard to information on population patterns, census data usually available in inhomogeneous spatial reference units (e.g. census tracts) are commonly considered the standard information input e.g. for assessing potentially affected people in case of an emergency. However, as has been increasingly pointed out for the last decade or so there is a strong demand on population data that are independent from enumeration and administrative areas. Raster representations can meet this demand but are not available on local scale for many parts of the world in neither sufficient spatial nor thematic consistency. Re-allocating population counts from administrative areas (aggregated due to privacy reasons after initial address-based compilation) to a regular grid requires areal interpolation methods such as dasymetric mapping. This technique accounts for ancillary data to disaggregate spatially heterogeneous population information to areas where it is effectively present, at a finer resolution (Eicher and Brewer, 2001).

The spatial distribution of population, and in a disaster risk and crisis perspective its exposure to natural hazards and other stressors, is strongly time-dependent. Due to human activities and mobility, both distribution and density of population vary greatly in the daily cycle, particularly in metropolitan areas. Therefore, a more accurate assessment of population exposure requires going beyond residence-based census data (merely representing a nighttime situation) in order to be prepared for events that can occur any time and day (Freire and

Aubrecht, 2012). In an attempt to address those issues of population dynamics the recently developed LandScan USA product follows a multi-dimensional dasymetric modeling approach to create a high-resolution spatio-temporal population distribution dataset (Bhaduri et al., 2007). At a 90 m resolution (3 arc-seconds) LandScan USA contains both nighttime residential and daytime population distribution information incorporating movement of workers and students. The development of LandScan USA as a nation-wide dataset represents a major improvement over previous static modeling methods. However, it is not openly accessible to the public or the scientific community due to its formal classified initiation through the U.S. Department of Homeland Security. The presented study builds upon the needs of the applied scientific community and shows ongoing developments regarding the conceptual setup and subsequent implementation logic of a seamless spatio-temporal population dynamics model – *DynaPop* – that aims at serving as basic input for social impact evaluation in crisis management.

FIRST STEPS IN THE CONCEPTUAL SETUP OF A SEAMLESS SPATIO-TEMPORAL POPULATION DYNAMICS MODEL

In the following a preliminary version of a conceptual model is presented that facilitates a general implementation of population disaggregation processes. It is based on the assumption that population data, aggregated to a region, can be redistributed within the region by means of local parameters. These local parameters are usually represented by information on land use (residential housing densities, commercial areas, transport lines etc.). Depending on the level of detail of these proxy parameters the actual spatial distribution of population can be estimated with more or less accuracy. The most straightforward approach to population disaggregation is the estimation of refined residential population distribution patterns. Population data available per administrative unit (census tract, municipality, etc.) is disaggregated to actual settlement areas as e.g. identified in remote sensing imagery. This approach is based on the assumption that settlement and, in a more refined perspective, housing density is correlated with population density. The resulting population data set still represents *nighttime population*.

In order to account for population dynamics and estimate *daytime population* the model needs to be conceptually extended. First, the total population per administrative 'input' unit may change in basic terms over the day due to people commuting in and out of the area. The disaggregation approach therefore requires a daytime dependent variable (temporal unit) in order to consider the diurnal variation of total population to be redistributed (e.g., hourly time steps). In addition to the varying total population numbers implicit information on the dynamic changes of people's location is required. Freire and Aubrecht (2012) presented a sort of binary approach assuming that people are in their workplaces/schools during the day and at home during the night, thus coming up with a basic nighttime/daytime population distribution model. In a slightly modified approach that binary work-home model can be extended to include the transition periods in the morning and evening in its output. In addition to work and home, commuting is therefore included as additional model parameter:

- *Work (W)*: represents the percentage of people working at a certain time unit
- *Commuters (C)*: represents the percentage of people commuting at a certain time unit
- *Home (H)*: represents the remaining percentage of people

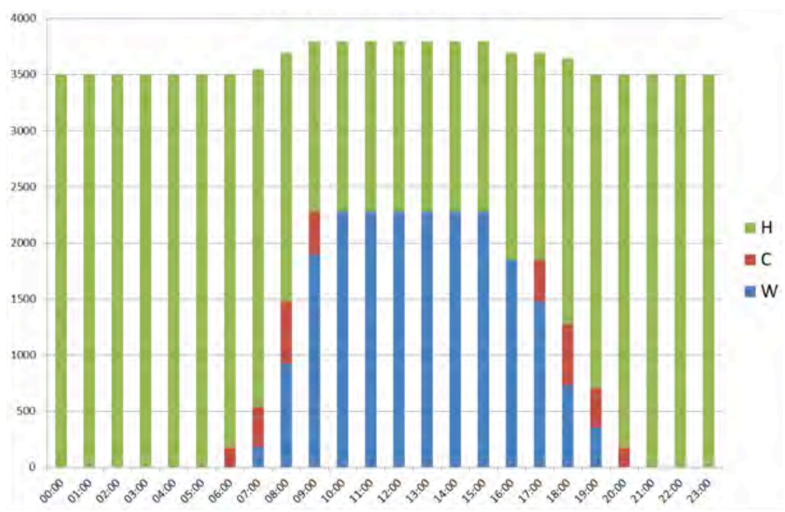

Figure 1. Simplified diurnal variation of total population per input location

Figure 1 shows the temporal patterns of people's locations over a day in a generalized and simplified way as outlined above. The variation of total population per temporal unit is combined with the relative locational activity ratios resulting in the dynamic distribution of absolute population per input location. Basic activity ratios can be derived from statistical enquiries and do not necessarily differ per administrative unit. For reasons of simplification, in the presented preliminary *DynaPop* model version, the Home class (H) also comprises people who are out for shopping, leisure, etc. This will be further refined in the follow-up model version by using comprehensive time use statistics as implemented e.g. in the UK Population 24/7 model (Martin et al., 2010). Information on time usage e.g. in terms of weekly and seasonal variations also provides a basis for deriving more accurate input for casualty modeling (Zuccaro & Cacace, 2011) as outlined later on (referring to the issues of occupancy rates during working days vs. weekends and holidays as well as touristic influence).

For the actual distribution of population each activity pattern requires a spatial representation, i.e. target zone. For 'Home' the residential areas are a useful proxy, for 'Commute' transportation networks are appropriate references and for 'Work' commercial, business and industrial areas can be used. While the mere spatial distribution of these proxy data may be sufficient for a basic disaggregation, density measures significantly improve the local estimates. For the residential areas housing densities can be used as an estimate for population density at 'Home'. For the transportation networks traffic counts on roads or passenger counts in trains and undergrounds can provide a basis for average density measures. The estimation of population densities for work places is generally more challenging due to limited consistent data availability. On a very large scale workplaces per company can be used assuming that the precise location of companies is available and the list of companies is complete. The final step is a weighted distribution of the population per location (H, C, W) accounting for the corresponding target zones and density parameters (housing, transportation, workplaces). This step can be repeated for each temporal unit, thus the resulting temporal granularity or resolution is depending on the temporal units defined in the input data.

DYNAPOP MODEL IMPLEMENTATION LOGIC

Following the preliminary basic conceptual setup of *DynaPop* this section will provide some more details on the model implementation logic. Further steps such as the inclusion of time use statistics and related derivation of more seamless spatio-temporal patterns are current work-in-progress. Generally, the above-described basic simplified conceptual model to calculate dynamic spatio-temporal population patterns consists of two steps:

(1) Calculate the total amount of population per class (W, C, H) being present in a given area at a specific point in time (*temporal domain*).

(2) Use invariant weighted distribution grids to calculate (class-dependent) population densities in the respective area (*spatial domain*).

Processing the temporal domain requires two input parameters. The first one is the absolute number of people present in a certain source zone (administrative unit) within a given time slot. The second parameter refers to the relative activity ratios per location that are also time-dependent. Multiplying both parameters returns an estimate of class size in terms of absolute numbers. Figure 2 illustrates this process by means of the '12:00 h' time slot.

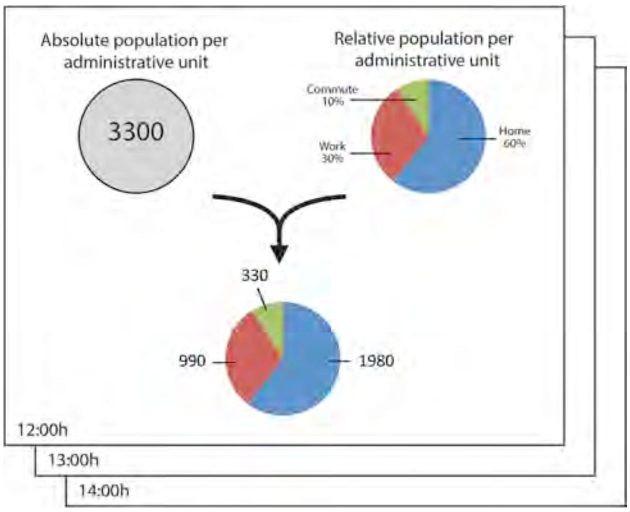

Figure 2. Calculating absolute population numbers for each class per source zone (administrative unit)

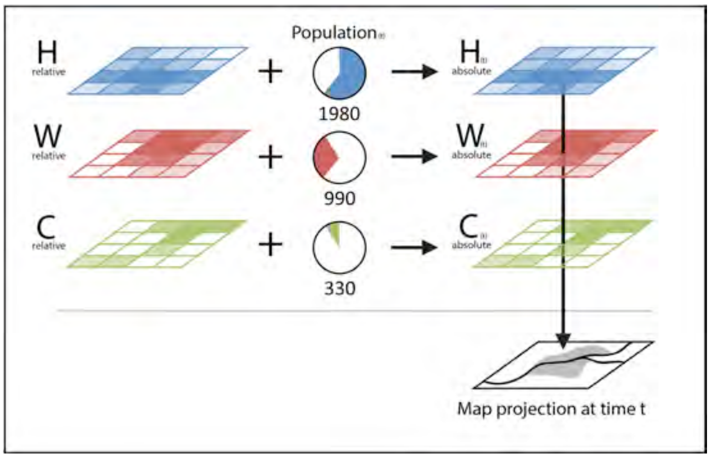

Figure 3. Density distribution for each activity class (H, W, C) at a specific point in time (t)

To proceed with spatial disaggregation from source to target zones, weighted density grids for each class belonging to a specific administrative unit are combined with the total amount of people being present in this spatial unit (see figure 3). The density grid is a square raster with each n^2 grid cell representing an area with a pre-defined side length between 100 and 500 m (according to input data granularity and required output resolution). Each square holds a relative density value d with

$$\sum(d(n^2)) = 100\%$$

The model can be enhanced by optionally offering different spatial formats for the density measures and target zones, such as triangular meshes as sometimes used specifically in hydrological models (e.g. flooding, runoff). Spatial disaggregation is achieved by multiplying the absolute population numbers (in the given administrative source unit at a specific time slot) with all values of $d(n^2)$. This leads to spatial depictions representing the total amount of people being present in each spatial entity of the grid at a specified point in time.

NEXT STEPS FOR DYNAPOP

As outlined in this short-paper, the integration of commuting information and locations of work and study enables modeling basic population distribution pattern variations between the residential nighttime situation and the ‘working’ situation during daytime including respective transition periods in the mornings and evenings. Furthermore, being disaggregated to uniform grid cells this constitutes a huge advancement compared to the use of standard census information (i.e., mere residential) based on heterogeneous administrative units.

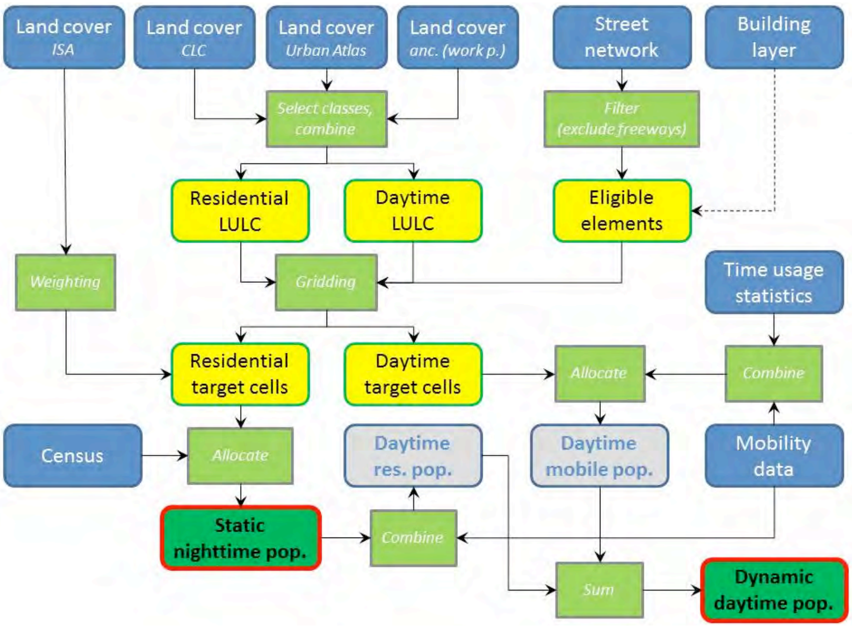

Figure 4. Conceptual framework for dynamic population modeling

Reality, however, shows a still much more diverse picture, particularly considering the daytime. Human activities naturally go far beyond mere commuting from home to work and back. Leisure activities and especially lunch and dinner habits add another important dimension to a usual working day, while weekends and seasonal holidays need to be regarded entirely separately. Work-in-progress on enhancing the *DynaPop* model focuses on that aspect by adding the option to integrate comprehensive time use statistics such as the European level HETUS (Harmonized European Time Use Survey) database as well as data on touristic flows. Figure 4 shows a conceptual flowchart how such a model can look like and operate (Aubrecht, 2013). Time usage is thereby integrated with mobility info in order to differentiate dynamic patterns during daytime.

DYNAPOP LINKED TO OTHER MODELS AND ASPECTS IN A CRISIS MANAGEMENT FRAMEWORK

Going beyond the use of *DynaPop* for the assessment of population exposure dynamics, knowledge of spatio-temporal population patterns is essential for a set of other related aspects in disaster risk and crisis management including evacuation and general response planning as well as casualty assessment. Evacuation models that are commonly either grid- or agent-based, have to consider both physical and social aspects of a study site for their setup. In that regard, in addition to situational aspects such as blocked roads and general conditions of the route network, population exposure information is one of the main input factors as it provides the basis to start with in terms of getting people out of danger. Temporal aspects including continuous updates on the speed of successful evacuation rates are considered essential for decision makers in a crisis situation. Accurate assessment in that regard is facilitated by considering appropriate dynamic input information as provided by *DynaPop*.

Casualty models eventually aim at estimating the number of actually affected people, thus being related to the initial starting basis of exposed population and accounting for the follow-up evacuation processes (also possibly accounting for first-impact casualties prior to evacuation). While population exposure models can be considered to a certain extent hazard-independent (population being exposed to any kind of hazard or stressor), evacuation models and particularly casualty assessments need to be closely linked to the respective hazard situation (particularly considering the speed of onset). Casualty modeling in case of earthquakes (i.e., rapid onset) does for example put a strong focus on the location of people in a temporally seamless and spatially explicit manner. As earthquakes can strike without any prediction and warning, it is crucial to know if people are inside or outside of buildings (occupancy ratios per building type) and where they are exactly within the affected area. In a further step this is then linked with physical aspects such as structural building safety (danger of collapse, etc.). *DynaPop* is tested in a pilot site in Italy using the 2009 L'Aquila event as reference scenario whereby all the above-mentioned relevant aspects will be considered during the model implementation.

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