Urban.Access:
High-Resolution Estimation of Urban Accessibility

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1. Comparative Accessibility Measurement

Accessibility, understood as the ability of people to reach and participate in activities (Garb and Levine 2002), is increasingly identified as a key criterion to assess transport and land use policies (Bristow et al. 2009). Comparison of car and transit accessibility is considered more important than ever, from an environmental (assessment of car-dependency) and social perspective (assessment of the ability of car-less households to participate fully in society) (Benenson et al. 2009).

Most large-scale accessibility analyses in the literature measure accessibility at the level of neighborhoods or traffic zones and use rather rough estimates of travel time (e.g., Shen 1998; Blumenberg and Ong 2001; Hess 2005; Kawabata and Shen 2006; Kawabata 2009). This may be sufficient for car accessibility, but for transit accessibility an accurate assessment of travel time requires geo-information at the resolution of buildings and road segments in order to accurately incorporate access, egress and waiting times in the measurement of total travel time. In this paper, we present a practically applicable tool for a high-resolution comparative analysis of accessibility at a large scale. Such a detailed and large-scale analysis of accessibility is important from a scientific and practical perspective. From a scientific perspective, large-scale accessibility data would enable a systematic analysis of the relationship between accessibility and actual travel behavior (in terms of, e.g., trip distances, frequencies and mode choice). From a practical perspective, large-scale, comparative, analyses would provide the necessary input for the development of strategies towards a more sustainable transport system.

2. Accessibility Measures

Following other studies, we use a traditional cumulative opportunity measure of accessibility (e..g Geurs and Ritsema van Eck 2001). In line with the literature, our measures of accessibility are based on an estimate of the *travel time* between (O)rigin and (D)estination. We define them for a given transportation (M)ode: public (B)us and private (C)ar. Bus travel time (BTT) includes access time by foot from origin to initial bus stop, waiting time, in-vehicle time, transfer time including walking, and egress time by foot. Car travel time (CTT) includes access time from origin to parking place, in-vehicle time, and egress time by foot to the destination.

Given origin O, transportation mode M and travel time τ, Mode Access Area, $MAA_O(\tau)$□, is defined as the area containing all destinations D that can be reached from O with M during Mode Travel Time (MTT) $\leq \tau$. Similarly, Mode Service Area, $MSA_D(\tau)$, is defined as the area containing all origins O from which a given destination D can be reached with M during MTT $\leq \tau$.

Subsequently, we use Bus to Car (B/C) Access and Service Areas (AA and SA) ratio as the key comparative accessibility measure. Given an origin O, the *Access Areas ratio* and *Service Area ratio* are defined as:

$$AA_O(\tau) = BAA_O(\tau)/CAA_O(\tau) \text{ and } SA_D(\tau) = BSA_D(\tau)/CSA_D(\tau) \qquad (1)$$

These measures are further specified for a particular type k of destinations D_k or origins O_k of capacities $D_{k,Capacity}$, $O_{k,Capacity}$, for instance, high-tech enterprises with destination capacity defined as a number of jobs. E.g., the Access Area ratio to destinations of type k can be defined as the sum of capacities of the destinations (e.g., the number of high-tech jobs) that can be accessed during time τ with Bus and Car:

$$AA_{O,k}(\tau) = \sum_{Dk}\{D_{k,Capacity} \mid D_k \in BAA_O(\tau)\}/\sum_{Dk}\{D_{k,Capacity} \mid D_k \in CAA_O(\tau)\} \qquad (2)$$

The presentation introduces a series of comparative accessibility measures, the corresponding software and then applies the proposed measures to analyzing accessibility in the Tel Aviv metropolitan area. We consider comparative measures as an important component of the human estimate of accessibility.

Note that the accessibility measures proposed here are intentionally of a relatively simple nature, in comparison to recent advances in the field (e.g. Kwan 1999; Dong, Ben-Akiva et al. 2006; Doi, Kii et al. 2008). However, we uphold that the measure is sufficient from a sustainability perspective. From that perspective, the capability of an accessibility measure to identify *disparities* in accessibility levels by car and transit is of key importance. It is by no means certain that other accessibility measures will provide additional dimensions of these disparities that may result in the identification of other areas or neighborhoods where transit accessibility is essentially lower than car-based accessibility.

3. Urban.Access as a Tool for Estimating Accessibility

To implement the aforementioned framework we have developed Urban.Access, an application that combines ArcGIS and SQL-server abilities. The Urban.Access geodatabase consists of several layers and non-spatial tables, available from a municipal GIS and transport authorities: road network; bus lines and stops; bus departure and arrival times; data on urban land uses including the number of residents and jobs. In case of the Tel Aviv region (2.5 million population, 1500 sq km), the database includes ca. 2500 variants of bus routes, 25,000 geometrically different stops and 27,000 bus departures a day.

Urban.Access can generate an accessibility map depending on day of the week, time of the day, travel time threshold, and maximum number of transfers between bus lines. The user has to choose if either Access or Service Areas are considered.

The car access area is estimated once for every origin, and stored in the Geodatabase. The focus of the application is on transit accessibility analysis. Due to the complicated shape of the urban area and the desired spatial resolution, every standard GIS operation, such as buffering and overlapping of layers, becomes a heavy computation task. Despite sufficiently fast calculations related to transit trips (less than 1 minute for a given set of origin or destination stops), the ArcGIS-based calculation of the urban areas that can be reached by foot at the final end of a trip and the overlap between this area and urban land-uses takes several minutes for a regular PC. As a result, even at the resolution of the 583 traffic zones of the Tel Aviv region, the GIS-based construction of a single accessibility map takes weeks. The construction of an accessibility map at the resolution of ca 80,000 buildings in the region becomes thus practically impossible.

Low performance of the direct GIS calculations essentially limits our ability to investigate the accessibility impacts of changes in the transit network. To accelerate the calculations we have approximated each of the GIS layers by a 60x60 m vector grid (30x30 grid is also investigated). The attributes of the features are transferred to the cells that cover them and the spatial database is thus substituted by a set of non-spatial tables that describe the properties of the cells and spatial relationships between them as inherited from the transit lines, timetables, and the areas that can be reached by foot from the stops. The urban area of Tel Aviv region is represented by ca. 160,000 60x60 m cells and ca. 700,000 30x30 cells, and the size of each of the aforementioned tables varies between several hundred thousand to several million records.

Nonetheless, substitution of the GIS spatial operations by the set of optimized SQL queries executed directly by the SQL server reduces the time necessary for constructing the accessibility map for the entire Tel Aviv region at a 60x60 m resolution to less than two hours. With an increase in spatial resolution, the performance of the application grows almost linearly. The paper presents the algorithm of transition from GIS- to SQL-based analysis of accessibility and the corresponding software.

4. Accessibility Gaps to Employment

Urban.Access makes it possible to estimate accessibility levels for any partition of the urban area. Here, we present the results regarding the average accessibility gap for employment.

The analysis shows a substantial gap between transit-based and car-based accessibility to employment for the Tel Aviv region. On average, transit travelers can reach, with one transfer, only about 30% of employment opportunities available to the car user at peak hours, and 22% during off-peak hours. Large gaps can be found in the peripheral areas, but also within the metropolitan core a number of urban pockets of low transit accessibility can be found (Figure 1).

5. Discussion

The results found for the Tel Aviv region contradict general views. Even in the USA, which is notorious for its poor transit network, the transit/car job accessibility ratio varies between 12% to 59% (Hess 2005). Based on the Urban.Access application, we find substantially lower values for many areas. We claim that this is not the result of a poorer transit system, but rather of a high-resolution description of travel by transit. In the lecture, we show how the proposed approach can be applied in transportation planning by analyzing the impacts of a number of transport scenarios on accessibility levels in the Tel Aviv region. The performance achieved with the Urban.Access application that forwards the heavy computational tasks to the non-spatial transactions proofs sufficient for this purpose.

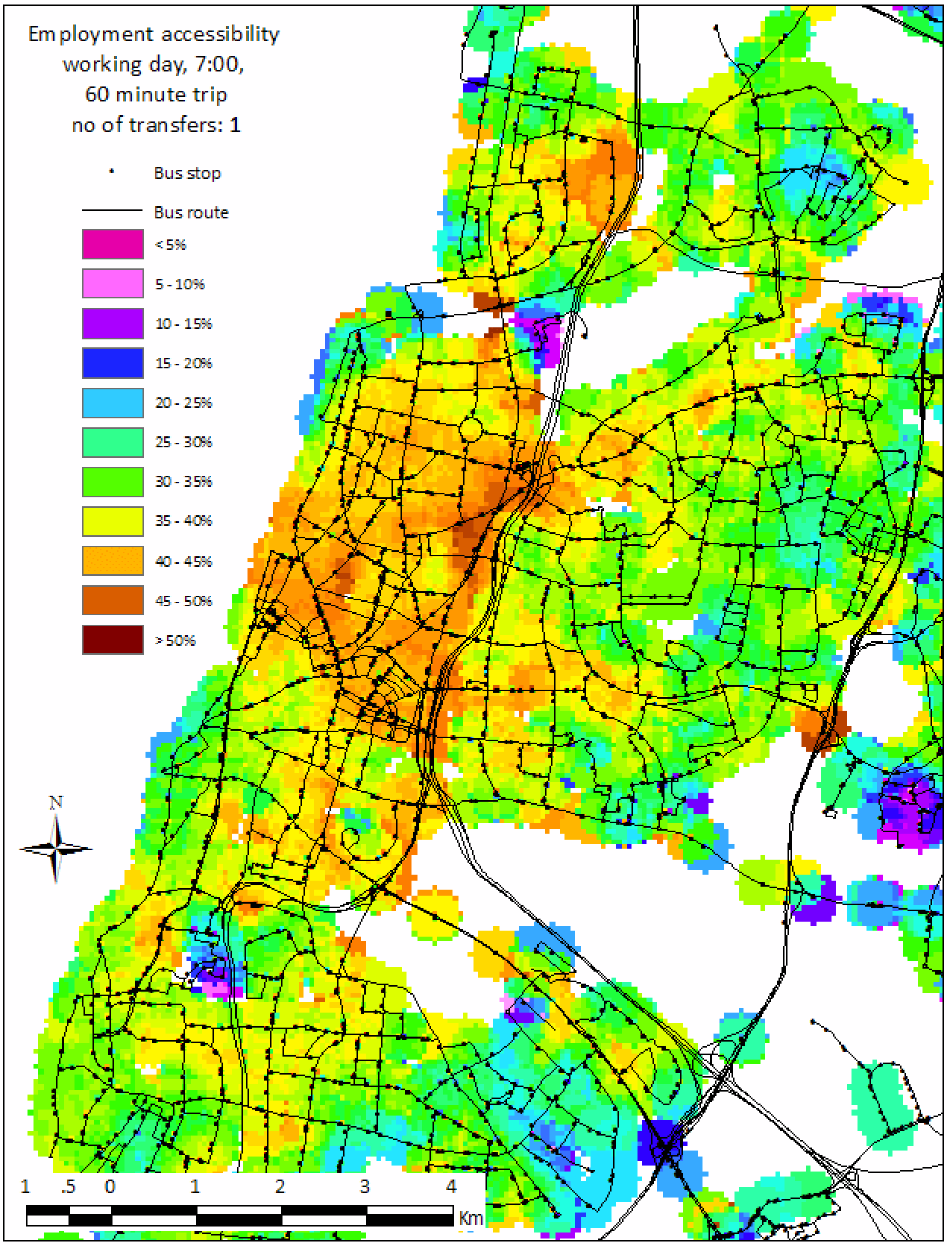

Figure 1. The center of the Tel Aviv region: Access Area index for employment for transit trips that allow one transfer.

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