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Implementation of Accessibility-Based Evaluation of Transportation and Land-Use Planning

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DISCLAIMER

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Introduction

The concept of accessibility has made inroads into planning practice, largely at the system level. That is, accessibility is measured or modeled for current or future regional transportation and land-use scenarios for evaluation or broad policy guidance. Yet system-level scenarios cannot readily be applied to the project-by-project decision-making that characterizes the majority of land-use planning decisions. Accessibility evaluation of individual land-development projects differs from system-level analysis in essential ways and thus requires specialized tools.

Findings

This article proposes an elasticity-based metric of accessibility that can enable project-level evaluation as an accessibility-based alternative to traffic-impact analysis. The metric is demonstrated for three land-development projects in Ann Arbor, Michigan, USA. The metric is shown to be sensitive to the location of development and capable of distinguishing among the analyzed projects in accessibility terms. Where mobility-based evaluation tends to rank peripheral development highly, the proposed accessibility metric appropriately rates central development as contributing the most to regional accessibility even after accounting for the traffic delay it engenders.

Recommendations

The metric is recommended for adoption in local transportation and land-use planning practice in place of traffic-impact analysis. (More precisely, traffic-impact analysis is a needed input to the analysis presented here.)

The project developed a web-based tool-- http://aim.fau.edu/developments/--to enable planners in local practice to implement the methods outlined here. The user chooses the geographic unit of analysis and US counties to be included, and inputs the location, population, and jobs associated with the proposed development. The website returns the accessibility-elasticity calculations detailed here.

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1.1 Moving Beyond Mobility-Based Evaluation

Researchers since the 1970s have argued that accessibility is the proper rubric for planning and evaluating transportation investments and the transportation dimensions of land-use developments (Wachs and Kumagai 1973). This idea stands in contrast to two competing notions. The first is that transportation and land use are best guided by principles of mobility (or frequently, automobility), as embodied in tools such as highway level of service (Transportation Research Board 2010), value of time lost in congestion (Shrank et al. 2012), traffic-impact analysis (Institute of Transportation Engineers 2010) or cost-benefit analyses driven principally by travel-time savings (Laird et al. 2014). The second contrasting notion is the implicit idea that accessibility is principally a positive spatial descriptor, and hence a useful independent variable in predictive models of land value, travel behavior, or economic development. John Q. Stewart (1948), on whose work Hansen's (1959) seminal paper on accessibility was partly based, argued against the use of accessibility as a normative policy goal to be pursued consciously. While subsequent research did not echo Stewart's explicit cautionary note, it nonetheless tended toward accessibility as a positive descriptor; research into the use of accessibility as a normative goal for has been rare.

Rarer still has been the use of accessibility as a planning and evaluation framework in policy, a shift that has been referred to as a move from a mobility to an accessibility paradigm (Cervero, 1996). The shift from mobility-based to accessibility-based evaluation is logically compelled by the derived nature of transportation demand (Levine et al. 2012, Grengs et al. 2011): since a large majority of travel is for the purpose of reaching destinations rather than movement per se, mobility is an intermediate service whose demand is derived from the directly demanded objective of accessibility. Mobility is thus properly understood as a means and accessibility is its end; other means for promoting accessibility are proximity and remote electronic connectivity. Consistency with the idea that the demand for transportation is largely derived requires that transportation and land-use systems be planned and evaluated with accessibility, rather than mobility, as a goal. Yet the integration of measured accessibility into everyday planning practice has been limited to date. To the extent that accessibility planning has begun to permeate planning practice in North America, it has mostly done so at the scale of the regional transportation and land-use system (See for example: Ammiano et al., 2004; Chicago Metropolitan Agency for Planning, 2010; Puget Sound Regional Council, 2001; Anderson et al., 2013) and typically as a supplement to—rather than substitute for—mobility-based evaluation.

Incorporation of accessibility metrics as performance measures for systemwide regional development scenarios is a step forward for accessibility-based planning, yet the impact of this approach is limited. Regional planning agencies typically do not make actual land-use decisions, so integrated transportation/land-use planning at the regional level primarily operates as a persuasive or visioning exercise, rather than as an operational guide to transportation investments or land-use regulation. The use of accessibility metrics in transportation and land-use scenarios can illustrate the consequences of broad development directions and—one hopes—help encourage the alignment of local government planning decisions with a regional vision. But regional-level outcomes, as a practical matter, are the result of the aggregation of thousands of individual decisions on specific transportation investments and

land-use regulations—decisions that remain to this day largely guided by mobility-based evaluation procedures, such as highway level of service. With that in mind, this article aims to develop a new practical indicator to facilitate accessibility-based planning practice for land-use decisions at the level of the individual project.

1.2   Attributes of Project-Level Evaluation

The metric is oriented toward transportation and land-use planners in local practice; for this reason, simplicity and accessibility of data sources and methodological requirements is central. These practitioners do not generally have ready access to regional travel-demand models yet are regularly called upon to analyze the transportation impacts of contemplated land-use changes. Their primary tool currently is traffic-impact analysis (Institute of Transportation Engineers 2010), which takes land-development projects as an input and forecasts traffic delay and the resultant level of service for nearby affected intersections. These findings are often incorporated into decisions on project permitting or modification, or traffic mitigation requirements imposed on the developer. Notwithstanding the ubiquity of the traffic-impact analysis tool, it suffers from an inherent flaw: since it is strictly based in (auto)mobility, it is incapable of incorporating the accessibility benefits that may flow from the proposed development's proximity to other origins or destinations. The effect is to penalize proposals in close-in areas currently suffering from congestion, to encourage greenfield development at the metropolitan periphery. While each individual development may be consistent with adequate performance at nearby intersections, the resultant land use pattern likely results in a low-accessibility metropolitan form (Levine et al. 2012).

The proposed metric would be applicable where local planners currently rely on traffic-impact analysis. In fact, it begins with current approaches to traffic-impact analysis and demonstrates how these existing analytic tools can be modified for the accessibility analysis of land-development projects.

Requirements for a Shift to Project-Level Accessibility Evaluation

The shift from regional-scenario to project-level evaluation is not a shift in geographic scale. In fact, accessibility impacts are gauged at the regional scale for both types of analysis. Instead, it is a shift in the nature of the accessibility question being asked. Regional scenarios pertaining to transportation/land-use systems are states, whether an actual current state or a contemplated future state. Regional-scenario accessibility analysis amounts to a snapshot, automatically capturing relevant transportation and land-use aspects alike. By contrast, project-level land-use evaluation is an analysis of a marginal change in a state, typically asking what would happen if a specific land-development project—which is small relative to the entire regional transportation-and land use system—were developed. Even when analysis focuses on multi-project bundles it remains project-based in that it is characterized by the two attributes described below (basis of comparison, and projection of impacts on the complementary system). By contrast, when a comprehensive set of contemplated transportation investments is analyzed jointly with their anticipated land-use impacts (or vice-versa) the analysis shift from project- to regional-scenario-based.

Project-level accessibility evaluation differs in two important respects from regional-scenario analysis of accessibility—aspects that render standard regional-scenario-level tools inadequate to the task of project-level evaluation:

1. Basis of Comparison: Project-level analysis of accessibility demands attention to the basis of comparison. Regional-scenario analyses are quite readily compared over time (metro A at time 1 versus time 2) (Levinson and Marion, 2010; Merlin, 2015) or space (metro A compared to metro B) (Grengs et al. 2010). Other bases of comparison flow naturally from regional-scenario analysis, including comparison of accessibility among parts of a region or among sociodemographic groups. By contrast, the basis of comparison for project-level analyses is not immediately apparent. For example, a new residential development in a central location may lower accessibility for its neighbors by increasing congestion without adding destinations. Incoming residents presumably enjoy compensating accessibility increases—but compared to what? Neither their previous residential locations, nor their hypothetical locations in the absence of the proposed development are known to the analyst; for this reason, the "compared-to-what?" question demands explicit attention in project-level analysis.

2. Projection of Impacts on Complementary System: Regional-scenario analyses, whether snapshots of a current situation or calculations based on future contemplated regional scenarios, inherently incorporate both transportation and land-use aspects. By contrast, projects generally come packaged in the form of *either* transportation investment or land development. Without attention to the impact of transportation on land use or vice versa (referred to here as complementary systems), the implicit assessment is on of "no impact." There are in fact multiple examples of this is the literature as well as in transportation planning practice, where for example a transportation project is analyzed as if it would have no land use impact (National Cooperative Highway Research Program 1997, p. 41; Hensher et al. 2014; Gulhan et al. 2014). To be sure, the land-use impacts of a transportation investment take time to materialize and are difficult to model reliably. Nevertheless, anticipating land-use impacts of transportation investment is essential to a meaningful analysis of accessibility because under the implicit assumption of "no land-use impact," all mobility improvements become accessibility improvements. Only when the possibility of induced spread of origins and destinations is introduced do accessibility and mobility become truly separate measures.

   This paper is geared at the accessibility-based analysis of land-use projects. A subsequent paper will demonstrate project-level analysis of transportation projects. (Applying the indicator presented here to transportation projects is somewhat more involved because of the complexity of forecasting transportation's impact on land development).

1.3   Additional Desirable Characteristics for Project-Level Accessibility Evaluation

In addition to these two inherent differences between regional-scenario and project-level accessibility analyses, seven attributes are either necessary or desirable for project-level analysis;

these fall under the categories of geographic interpretability, usability, and consistency with formal definitions of accessibility and derived demand. In sum, the inherent differences and the desirable attributes are referred to below as the nine attributes of project-level evaluation.

1. Geographic interpretability

    a. Regional Impact of Individual Project: Since most land-use projects are approved on a project-by-project basis, accessibility indicators must be able to evaluate project-level decisions, yet they must not be restricted in their geographic scope to the project's immediate area. That is, they should be able to assess the marginal impact of a proposed land-use project on regional accessibility; restricting the geographic scope of accessibility analyses to the local area can produce misleading results (Appendix 1).

    b. Comparison Based in Regional Context: Every evaluated project needs a basis for comparison to facilitate the interpretation of its accessibility performance. Since the goal is to evaluate projects within their metropolitan context, the basis of comparison should be relative to the potential of the region, rather than absolute. For example, a land-development project in a small region would be reachable by many fewer people than a similar project in a large region and would thus offer a smaller marginal accessibility contribution. It would not be reasonable to expect similar accessibility contributions from the two; instead, the relevant question for the planner is "how does this project perform in accessibility terms relative to other alternatives in our region."

2. Usability

    c. Easy Interpretability: Individual projects are not likely to shift regional accessibility metrics by much; they suffer from the "drop in the ocean" phenomenon when it comes to regional accessibility measurement. Analytical results must be interpretable notwithstanding the frequently infinitesimal impact of an individual project on overall regional accessibility.

    d. Technical Ease of Use: The audience for the indicators developed here is transportation or land-use planners in local practice. These people are presumed to have access neither to regional travel-demand models nor sophisticated multivariate statistical tools.

        There are a few examples of research that evaluates alternative proposals and puts forth tools to evaluate both transportation and land use changes on accessibility in an integrated fashion. In this way the work's goals are the closest match for the current project. However, previous research in this vein uniformly requires high technical capacity (Geurs et al. 2012; Geurs et al. 2010). This article seeks to build accessibility-based decision support indicators that can be put into practice in most local planning offices with reasonable amounts of technical capacity.

e. Capacity to Evaluate Land-Use Proposals: While both transportation and land use shape accessibility, the research literature is decidedly more focused on the impacts of transportation projects rather than land-development projects (e.g., Fan et al. 2010, Gjestland et al. 2012, Gulhan et al. 2014, Gutierrez 2001, Halden 2011, Hensher et al. 2014). Since mobility-based analysis is applied to both the transportation and land-use contexts, a project-based accessibility metric needs to be applicable in both realms.

3. Consistency with Accessibility and Derived Demand

f. Relevance to all Transportation Modes and Development Approaches: The concept of accessibility has often been associated with non-automotive modes, or equated by definition with walkable urbanist approaches to development (Cervero 1996, Curtis and Scheurer 2010, Tumlin 2012). By contrast, accessibility evaluation methods described here are equally relevant to all transportation modes and types or locations of development.

g. Basis in the Benefits of Transportation: This article uses evaluation metrics which, because they are accessibility based, are grounded the benefits of transportation. Evaluation rubrics that focus on vehicle-kilometers traveled (with an eye to their reduction) incorporate the cost side of transportation alone (e.g., California Governor's Office of Planning and Research 2014). By contrast, the approach presented here identifies the accessibility benefits provided by a transportation or land-use project, and therefore considers the positive contribution of development to the built environment, not only its detrimental effects.

1.4 Recent Work in Prospective Accessibility Assessment

Methods of accessibility analysis are largely geared at measuring current regional accessibility (see Handy and Niemeyer 1997 for a review). The largest body of work to date on prospective (i.e., future) accessibility analysis is in the realm of regional scenario planning (Ammiano et al. 2004; Chicago Metropolitan Agency for Planning, 2010; Puget Sound Regional Council, 2001). In this work a number of future land-use and transportation scenarios are laid out at the regional scale. As with traditional regional scenario planning, land use futures are created by a "what if" approach; that is, the various land-use scenarios compared are generated by policy-driven exploration rather than by forecast. Most of these regional scenario analyses of accessibility have employed cumulative-opportunity accessibility measures, and evaluations are typically based upon region-wide comparisons with defined travel time thresholds (for example, access to employment within 30 minutes). Such analyses are often represented as maps designed to inform the planning process (Bertolini et al. 2005; Curtis 2011).

A similar body of work on regional-scale prospective accessibility analysis examines the impacts of large transportation infrastructure improvements on accessibility (Fan et al. 2010; Geurs et al., 2012; Gjestland et al. 2012; Gulhan et al. 2014). Typically, such analyses do not assume any induced land-use change, only improvements or changes to travel times. Transportation improvements will by definition

enhance accessibility if land-use patterns are assumed to be held constant (Geurs et al., 2012; Hensher et al. 2014).

It is relatively rare for such prospective analyses of the accessibility impacts of transportation projects to include expected impacts on land use as well. One exception is Geurs et al. (2012), which employs a land-use model to forecast variation in employment location as a result of the proposed transportation projects. This research uses the logsum metric to capture the accessibility concept. Since the logsum is a direct measure of the maximum expected utility from a choice set of destinations, it makes for a sensible accessibility metric. However, the logsum approach requires a high level of technical skill and is too sophisticated in technique and software for the average local planning agency to use it on a regular basis.

Policy in the United Kingdom has required accessibility analyses from local transport authorities and for significant public projects since 2005 (Department for Transport, 2005; Kilby and Smith, 2012). Local transport authorities as well as other sectors have been asked to plan for increased accessibility to essential services, including health care, schools, and shopping services. The focus of this policy focus is on removing barriers to accessibility broadly construed, including not just travel time, but also access to information, affordability barriers, time-of-day barriers, and so forth. In some cases analyses have been conducted on how the location of specific facilities would impact accessibility for specific underserved populations. One criticism of this approach is that any new facility almost by definition enhances accessibility because it creates a new destination (Halden 2011).

A notable effort at reforming transportation evaluation was triggered by legislative action: California Senate Bill 743, which in 2013 mandated a shift in transportation analysis within the California Environmental Quality Act (CEQA) from highway level of service (LOS) to indicators of greenhouse gas emissions, creation of multimodal networks, and promotion of a mix of land uses (Governor's Office of Planning and Research 2014). Within this framework vehicle-kilometers traveled (VKT) was proposed as a primary performance measure, with transportation or land-use projects that reduced VKT receiving higher evaluations. California's move is an important shift from the US norm of mobility-based evaluation of transportation and land use. Yet it faced the logical hurdle of viewing transportation only as a harm to be reduced. California's choice was a function of the legislative mandate and the environmental-mitigation framework within which it operated: the operative California Environmental Quality Act's purpose is "preventing environmental damage" (California Public Resources Code) rather than seeking net societal benefits. By contrast, accessibility metrics capture the core purpose or benefits related to transportation.

2.1   Methods

2.2   How the Proposed Method Addresses Necessary Characteristics

The nine attributes listed above are addressed through an accessibility *elasticity* metric that is calculated after incorporating the results of a traffic-impact analysis into the regional travel time matrix. Accessibility elasticity is defined as the percent change in accessibility divided by the percent change in

regional size (measured in either population or employment); see Equation iii below for a formal definition. It is calculated with respect to population for residential development, and with respect to jobs for non-residential developments such as retail or commercial.

Using accessibility elasticity in conjunction with traffic-impact analysis addresses the challenges of project-level accessibility analysis. The first challenge is dealing with the problem of establishing a meaningful baseline for comparison. Hypothetically, any new development can be compared with that same development in other locations, but this would involve performing additional analyses and establishing reasonable counterfactual locations. Using accessibility elasticity implicitly establishes the existing built environment as the basis of comparison. An accessibility elasticity of 1.0 indicates that the marginal person or job at the contemplated location contributes to the region's accessibility equally to the person or job that is at the average level of accessibility in the region. Elasticities of over 1.0 indicate that incoming people or jobs are contributing more than the average; elasticities of under 1.0 reduce average regional accessibility by introducing residents or jobs at locations at lower accessibility than the average. In this way, the analysis is automatically scaled to the accessibility of the region (criterion #4).

The baseline of comparison—the accessibility contribution of the average person or job in accessibility terms—is by design relative to the regional context. The implicit relevant question for local planning is "how much does this project contribute to accessibility relative to others that might be pursued in my region?" Because it is scaled to the region in which it is calculated, this metric can be relevant across a range of metropolitan conditions; it avoids creating accessibility comparisons between small and large metropolitan regions, preferring instead a comparison against a baseline determined by local potential. This procedure simultaneously addresses criterion #3 (the need to base calculations on regional accessibility) and criterion #9 (based in the benefits of transportation) since percent change in accessibility at the regional level is in the numerator of the elasticity metric. With percent change in population or employment in the denominator, the metric is automatically scaled to the size of the project, and even projects that are small relative to their region may be meaningfully analyzed and their metrics readily interpreted (criterion #5).

The indicator presented here is not intended for comparison of projects between different regions; rather it is designed to compare among potential projects or project bundles (with their associated locations) within a single region. Its application to interregional comparison would lead to misleading results for two reasons. First, the denominator (percent change in regional population or employment) is designed to scale the analysis to the scope of the contemplated change relative to its region. Second, the numerator (percent change in accessibility) would be interpreted very differently between regions; a one-percent increase in accessibility in a low-accessibility region might be more highly valued than a similar percentage increase in a high-accessibility counterpart. That is, accessibility increases would likely be subject to declining marginal utility. By contrast, within a single region the analysis would focus on changes in a single baseline accessibility and would avoid this problem.

The second criterion—projection of the impacts of land-use change on the transportation system—is met through incorporation of the results of previously estimated traffic-impact analyses. These analyses forecast additional seconds of delay at intersections surrounding a proposed development; the

procedure described below adds these delays to the travel time of the zonal pairs for which they are relevant. An updated regional zone-to-zone travel-time matrix is used to estimate regional accessibility with the proposed project in place. In this way the impact of the proposed land development are projected on the transportation system before accessibility impacts are projected.   This linkage from land-development proposals through traffic-impact analysis to accessibility also addresses criterion #7 (capacity to evaluate land-use proposals). And since traffic-impact analyses are largely focused on the movement of private cars, this technique avoids equating accessibility analysis with walkable urbanism (criterion #8).

The need to incorporate impacts on the complementary system is implemented here by evaluating land-development proposals while incorporating their traffic-impact analyses. These analyses forecast additional delays, denominated in seconds, to intersections near the proposed developments. These delays, together with the land-development proposals, are used to calculate accessibility impacts. The analysis is implementable with readily accessible tools, including commonly available GIS software (ArcGIS Network Analyst) (criterion #6). It does not require access to the regional travel-demand model, though it uses output exportable from the model, including travel-analysis zone boundaries and the zone-to-zone travel-time matrix.

It is important to note that neither standard traffic-impact analysis nor the accessibility method proposed here generate a new equilibrium solution for zone-to-zone traffic flows. For example, consider a new retail project in an already busy area. Standard methods of traffic-impact analysis will add the traffic generated by the project to the baseline of traffic already present, but do not generally consider the possibility that the project itself may alter travelers' destination choices. For example, the project may reduce some through travel by diverting trips that would ordinarily have continued on to a more remote retail location. Such revision to interzonal flow estimates is the task of regional travel-demand models, yet these are generally too coarse for the purposes of estimating additional seconds of delay at intersections (and for various movements through the intersections). The current project follows the logic of traffic-impact analysis, relying on fine-grained traffic-impact analyses, notwithstanding the fact that they skip over potential shifts to regional flows. The proposed method goes beyond standard traffic-impact analsyis, however, by incorporating the proximity impact of contemplated development on regional accessibility.

2.3   Overview of Analysis Steps

The auto-based accessibility evaluation of land-use development proposals is implemented as follows:

1. Calculate the total regional accessibility prior to the development.
2. Conduct a traffic-impact analysis for the development.
3. Update prospective interzonal travel times based on the information from the traffic-impact assessment.
4. Update prospective population and employment by zone based on information on the location and size of the development.

5. Calculate the total regional accessibility after the development, taking into account both travel pattern changes and land use changes.
6. Calculate the accessibility elasticity, using the before and after project information.

The data needed for this analysis are:

1. Population and employment totals by zone, such as travel-analysis zone (TAZ).
2. Auto travel times between pairs of zones for all zones.
3. Intersection-specific travel delays from a traffic-impact analysis.
4. Zone boundaries and a network data set with link-specific travel times for routing in GIS.

Table 1 explains the ways in which the proposed method addresses each of the nine attributes referred to above.

Criterion	Proposed method's approach to addressing
Inherent characteristics	
Basis of comparison	Elasticity metric compares residential or commercial development against a baseline of the average resident or average job—in accessibility terms—throughout the region
Projection of impacts on complementary system	Method uses traffic-impact analysis, which forecasts impact of proposed development on traffic delays induced in surrounding intersections
Geographic interpretability	
Regional impact of individual project	The numerator of the elasticity term is percent change in regional accessibility associated with the project
Comparison based in regional context	By comparing with the average resident or job in the region, the metric automatically scales to regional accessibility characteristics and potential
Usability	
Easy interpretability	Projects' tiny accessibility impacts at the regional level are scaled by percent change in population or jobs (the denominator of the elasticity term). This avoids the need to interpret very small numbers, and facilitates comparison among larger and smaller projects.
Technical ease of use	The tool does not require access to a regional travel-demand model. The single most computationally intense step is to update the prospective intrazonal travel times based on the information from the traffic-impact assessment. The analysis here was completed using ArcGIS Network Analyst, a widely (though not universally) available too. For this and subsequent steps the project has developed a prototype web tool to automate these tasks and obviate the need for ArcGIS Network Analyst; when complete, this tools will be make available without charge. The tool will also obviate the need to collect data items numbers 1, 3, and 4 above; these will be gleaned automatically from publicly available sources.
Capacity to evaluate land-use proposals	The method takes development projects as input, using population as an indicator for residential projects, and jobs as an indicator for commercial or industrial.
Consistency with transportation theory	
Relevance to all	The method may be estimated for any mode for which travel-time data are

transportation modes and development approaches	available, and accessibility is defined without regard to development style.
Basis in the benefits of transportation	The method is based on accessibility improvement (rather than mobility or VKT reduction)

Table 1: Proposed Method's Approach to Addressing the Criteria for Project-Based Accessibility Evaluation

2.4   Ann Arbor Data on Development Projects

The procedure is illustrated here with data from three proposed developments in Ann Arbor, Michigan (Figure 1), including two housing developments and one commercial development (Table 2). The study area or region for the analysis is Washtenaw County, which includes substantial suburban and rural populations outside of the City of Ann Arbor (the County had a population of 354,240 with 84% of the population living in urban areas in 2013 (US Census Bureau, 2013)). Since data and analyses come from different sources, not all dates are identical; data sources range from 2010 to 2015.

Table 2: Overview of Case Study Developments

Development Name	Nixon Condominiums	413 E. Huron	Arbor Hills
Development Type	Residential	Residential	Commercial
A. Location	North Ann Arbor	Downtown Ann Arbor	Southeast Ann Arbor
B. Size	473 residential units	216 residential units and 4,900 commercial square feet	90,700 square feet
C. Estimated Population	738	337	0
D. Estimated Employment	0	0	178

(Residential unit totals and commercial square feet were converted into population totals and employment totals respectively using conventional planning resources such as the Census and Nelson (2004).
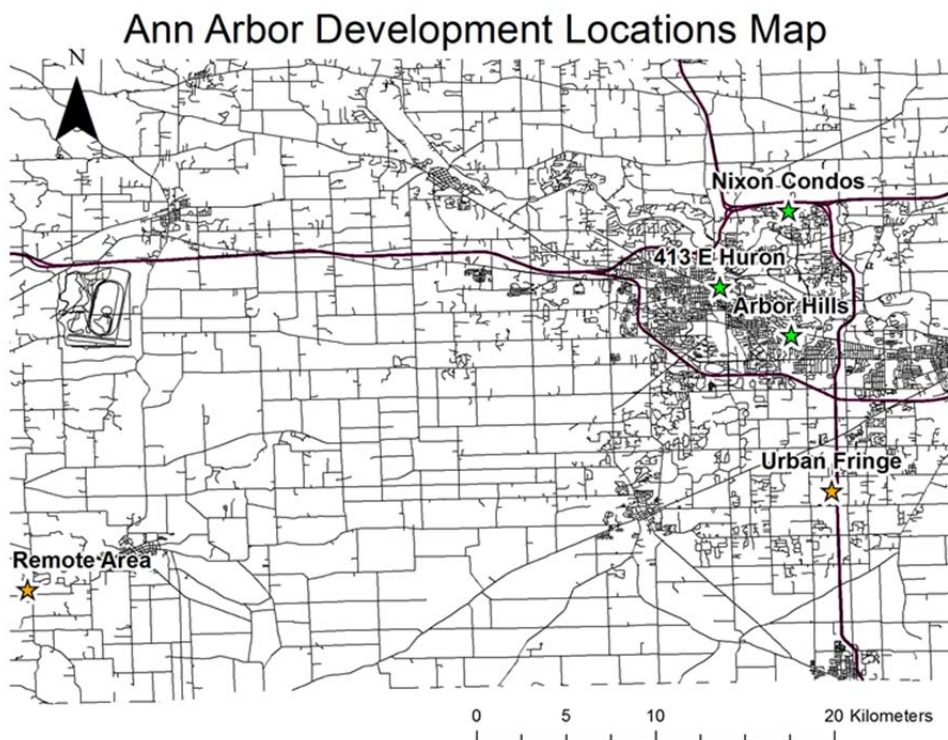
Figure 1: Development and Counterfactual Locations

Nixon Property Condominiums (Figure 2) is a proposed moderate-density residential development of 473 units located on the north end of the City Ann Arbor, contiguous to existing urban-density single family and multifamily residential developments. The peak hour for trips for Nixon Condos is projected to be in the morning (different from the other two projects): from 8:00-9:00 AM with a total of 265 trips during this period. The traffic impact analysis for this project was conducted in November of 2014. This development received initial approval by City of Ann Arbor in July 2015.

Figure 2: Site of Nixon Condominiums (Development will span both sides of Dhu Varren Road, pictured. Photo credit: Louis Merlin 2015)

413 East Huron Street (Figure 3) is a residential tower located in downtown Ann Arbor that was under construction during 2015. The tower will include 216 residential units and 4,900 commercial square feet on the ground floor. Peak trips projected for this development are estimated at 112 for the 4:45-5:45 PM hour. The traffic impact analysis for 413 East Huron was conducted in December of 2012.

Figure 3: Site of 413 E. Huron Street (Photo credit: Louis Merlin 2015)

Arbor Hills (Figure 4) is a high-end retail development located within the City of Ann Arbor (but not in downtown) along the major east-west corridor of Washtenaw Avenue. It includes 90,700 square feet of retail space with 692 estimated trips occurring during the PM peak hour. The traffic-impact analysis for Arbor Hills was conducted in May of 2011. As of May 2015, this development has been built and is fully occupied.

Figure 4: Arbor Hills Entrance and Shops (Photo credit: Louis Merlin 2015)

2.5   Detailed Description of Analysis Steps

Step 1: Calculate total accessibility for the region.

This project employs a gravity-based accessibility formula for measuring total regional accessibility to all employment, with the region defined as the county for this analysis (See Equation i). This measure is widely used in the research literature and is relatively straightforward to compute when interzonal travel time data are available. Cumulative accessibility measures are somewhat easier to compute and are readily interpretable. However, these measures generally count employment that is within a travel-time threshold that is defined in minutes. Travel time delays caused by an individual development are often measured in seconds and hence risk not being captured by a cumulative opportunity measure. The Southeast Michigan Council of Governments provided population and employment counts by travel-analysis zone (TAZ) and auto travel times between zones by time of day – AM peak, PM peak, and midday. Auto travel times are derived from the regional travel-demand model.

Gravity-based accessibility measures require that an impedance for travel time be selected or estimated. Impedances can be calibrated to travel behavior via the use of available destination choice data for a particular type of travel – work or nonwork travel. The calibration of the impedance is a relatively demanding analytical task that typically involves travel demand modeling software, and so we seek to define an analysis procedure that does not require such a calibration, so that local planners without ready access to such software can perform this analysis. Instead, past research suggests that there is a regular relationship between metropolitan population size and work travel impedance (Grengs et al.,

2010). Based upon this data, this project employed a range of impedances are that are typical for work travel for smaller metros: 0.10, 0.13, and 0.16, with 0.13 as the default.

Total regional accessibility is the sum of accessibility from each zone multiplied by the population in each zone. Total accessibility rather than per capita accessibility is used in this analysis because the effects of population growth are factored in at later stages through the elasticity calculation. The accessibility of each zone is a function of the number of destinations in other zones and the impedance of travel between zones (See Equation i). As such, total accessibility necessarily increases with any specific zonal increase in population or employment, if travel impedances are held constant and other zones population and employment counts are held constant.

The traffic-impact analysis typically identifies the peak impact periods for any proposed development. Regional travel times should be selected for this corresponding period.

The current analysis uses auto-based travel times for all zones in Washtenaw County derived from the Southeast Michigan Council of Governments travel demand model from the year 2010.

i. $total\ accessibility = \sum_i p_i a_i = \sum_i p_i \sum_j f(c_{ij}) m(d_j)$

Total accessibility is the sum of the accessibility in each zone I (a$_i$) and the population in each zone i. Accessibility for a given zone I is in turn a function of its travel costs to all other zones j (f(c$_{ij}$)) and the number of activities or destinations in each of those zones j (d$_j$).

Step 2: Conduct (or import) a traffic-impact analysis for the development.

Local jurisdictions in the United States commonly require a traffic-impact analysis for any sizable development. These analyses forecast additional delay expected to be caused by the development in isolation from other factors influencing traffic patterns, such as expected background increases in traffic volumes. In urban areas, traffic-impact analyses result in reports for additional seconds of delay for each type of movement through a set of affected intersections. Given the ubiquity of traffic-impact analysis for proposed development in the United States, it is likely that the accessibility analyst will not need to conduct an original study. For this reason this section reports on procedures for importing the results of traffic-impact analyses rather than methodologies for these studies themselves (Institute of Transportation Engineers 2010).

The procedure presented adds forecasted delays caused by the proposed development as additional time required for zone to zone travel times (aka "skims"). In order to do this, the delay for every movement through each intersection with the project is compared to the delay without the project. The difference between the delay with the project and without is the delay specifically associated with the project. Delays are then aggregated up to the intersection level by weighting each type of intersection movement with the projected number of trips making that movement, resulting in an average delay for the entire intersection

Table 3 below illustrates this procedure. The intersection under analysis is a signalized intersection at Plymouth Road and Nixon Road in Ann Arbor, one of the intersections impacted by the Nixon Road Condominium development.

Table 3: Calculations for Average Intersection Delay Using Data from a Traffic Impact Analysis, Plymouth and Nixon Roads, City of Ann Arbor, AM Peak Period

Road	Plymouth			Plymouth			Nixon			Nixon		
Travel Direction	Eastbound			Westbound			Northbound			Southbound		
Movement	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right
Forecast Volume for AM Peak	98	758	80	14	839	110	14	15	9	189	79	232
No Build Scenario (seconds)	17.2	16	16	12.2	19.4	19.4	33.9	42.7	42.7	48.3	46	46
Build Scenario (seconds)	14.6	17.7	17.7	4.4	12.2	12.2	33.2	32.9	32.9	47	46.3	46.3
Additional Delay (seconds)	0	1.7	1.7	0	0	0	0	0	0	0	0.3	0.3
Intersection-Weighted Average Delay for AM	0.6 seconds											

There are twelve potential movements through this intersection (the maximum possible for a four-way intersection) with straight, right, and left turn movements coming from each direction. For each of these movements, the delay with the project is subtracted from the delay without the project to obtain a movement-specific delay. This movement-level delay is bounded below by 0; no reductions in delay are permitted even if the model output forecasts them. Then each movement is weighted by future traffic volumes to obtain an intersection-level delay.

Any zone-to-zone route that is expected to traverse this particular intersection is assigned this additional peak-hour delay. Therefore, intersection level delays are assigned to skims via a routing procedure explained in the next step.

Step 3: Update regional travel pattern data based on the information from the traffic impact assessment.

The next step involves translating intersection-level delays into updates to regional zone-to-zone travel times. This article presents a two-stage procedure for this translation, which does not presume that the planner employing these methods has access to a regional travel-demand model. Rather, needed inputs include a matrix of zone-to-zone travel times and a GIS layer of Transportation Analysis Zones (TAZ). These data are products of regional travel models that can be used independently of the models.

Each pair of TAZs is examined to see if the travel time between these two zones is affected. This is done via an exhaustive search using zone-to-zone routing software, such as ArcGIS Network Analyst. For every pair of TAZs, routes are mapped from one TAZ to the other, and then all the intersection delays are added up along the course each route.

For example, there are 374 TAZs in Washtenaw County with a total number of 139,876 possible routes between pairs of TAZS. Out of these, 8,955 were determined to route through one or more of the affected intersections and therefore have associated delays related to the Nixon Condominium development project.

Step 4: Change regional land use data based on information from the development

Given the proposed development's type—residential or non-residential--either population or employment can be added to the appropriate zone. Mapping the zones and the street network in ArcGIS software is sufficient to visually locate the proposed development within the appropriate zone.

Translation of housing units into a population change is accomplished on the basis of Census data on average household size for each particular type of housing unit within Washtenaw County. Washtenaw County had an average household size of 1.56 people per household for housing units with 5 or more attached units during the 2008-2013 data collection period (US Census Bureau, 2013).

To convert retail development size into employment totals, the Planners Estimating Guide (Nelson, 2004) suggest that approximately 510 square feet of space is required per retail job.

Step 5: Calculate the total accessibility after the development, taking into account both travel pattern changes and land use changes.

After taking into account the development's impact on land use patterns through changes to zonal population (or employment), and after taking into account the development's impact on transportation through changes to interzonal travel times, a new total regional accessibility can be calculated. The same gravity accessibility formula is used, but with new travel time, population, and employment information (See Equation ii).

In most cases the total accessibility will be higher, because additional population (or employment) has been added. However an increase in total accessibility does not necessarily imply an accessibility improvement. The accessibility gain must be compared with the size of the development to examine if it is a meaningful improvement. This is the purpose of the next step, calculating accessibility elasticity.

ii. $total\ accessibility\ after = \sum_i (p_i + \Delta p_i) \sum_j f(c_{ij} + \Delta c_{ij}) m(d_j + \Delta d_j)$

(Terms defined as in formula I, with Δ referring in the change in the value of the term between "without" and "with" the project under analysis).

Step 6: Calculate the accessibility elasticity, using the before and after information on total accessibility.

One can imagine any new development coming into the region as an opportunity to allocate resources or a budget for the purposes of improving the accessibility profile of the region. Assume that the amount of new development coming to a particular region is exogenously determined and the task is to locate it optimally. The allocation of population or employment among developments that in each instance maximize the accessibility elasticity simultaneously maximizes the total aggregate accessibility. This is proven in ***Appendix 3: Proof: Maximizing Accessibility Elasticity Maximizes Total*** Accessibility.

Accessibility elasticity is computed as the proportional change in accessibility divided by the proportional change in regional size. Regional size is typically measured by population or employment, but alternative measures are possible, such as square feet of development if available. The formula for accessibility elasticity is below in Equation iii. The accessibility elasticity score minus 1 yields the proportion by which the development outperforms or underperforms the existing accessibility profile of the region.

iii. $accessibility\ elasticity = \dfrac{(access^{after} - access^{before})/access^{before}}{(population^{after} - population^{before})/population^{before}}$

3.1   Results

3.2   Accessibility Evaluation for Three Ann Arbor Development Projects

Table 4 presents the prospective accessibility evaluation for each of the three developments. The first four rows explain contextual information: the type of development analyzed, the analysis area, the travel time period analyzed and the impedance coefficient used. Work impedances used here are estimated from region size using the method presented in Levine et al. (2010), while retail impedance is from Grengs (2015). [1] The next two rows present total regional accessibility before and after the

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[1] A range of impedance factors was tested; these have a meaningful effect on the outcome for accessibility elasticity. Smaller impedances allow a larger travel area to be relevant, typically improving the accessibility elasticity for outlying locations. Larger impedances shrink the area of relevance, typically improving the accessibility elasticity of central locations (See Appendix 2: Sensitivity to Impedance Parameter for an example of this). Therefore setting the impedance coefficient is itself an

project. Total regional accessibility will typically increase because new developments add to the total population or employment in a region (see Equation ii). This however does not necessarily represent an accessibility improvement. Only if the accessibility elasticity is greater than 1.0 does an accessibility improvement occur.

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important policy variable. Setting the impedance to a smaller value would allow the policy analyst to hold new development to a higher standard in terms of location. For an equitable comparison between developments, the impedance should be held at a constant level for a given region for a given travel type.

Table 4: Accessibility Evaluation for Three Proposed Ann Arbor Developments, Washtenaw County

Project Name	Nixon Condominiums			413 East Huron			Arbor Hills		
A. Development Type	Population (Residential)			Population (Residential)			Retail Employment (Commercial)		
B. Analysis Area	Washtenaw County			Washtenaw County			Washtenaw County		
C. Impedance Coefficient	0.13			0.13			0.28		
D. Time of Day	AM	PM	Midday	AM	PM	Midday	AM	PM	Midday
E. Accessibility Before	7.439E+09	6.818E+09	7.896E+09	7.439E+09	6.818E+09	7.896E+09	9.970E+07	8.056E+07	1.020E+08
F. Accessibility After	7.448E+09	6.830E+09	7.916E+09	7.452E+09	6.825E+09	7.910E+09	1.011E+08	8.146E+07	1.035E+08
G. Percent Change in Accessibility [(F/E)-1]*100	0.125%	0.186%	0.253%	0.182%	0.105%	0.179%	1.357%	1.119%	1.455%
H. Total Baseline Before	344,791 (population)			344,791 (population)			19,466 (retail jobs)		
I. Total Baseline After (H + Table 1, Line C)	345,529 (population)			345,128 (population)			19,644 (retail jobs)		
J. Percent Change in Baseline [(I/H)-1]*100	0.214%			0.098%			0.914%		
K. Accessibility Elasticity (G/J)	0.59	0.87	1.18	1.86	1.07	1.83	1.49	1.22	1.59

Sources for impedances: Work: Levine et al. (2010); Retail: Grengs (2015)

The percent change in total regional accessibility is compared with the percent change in the baseline growth factor. This baseline growth factor is a measure of regional size relevant for the analysis. For Nixon Condominiums and 413 East Huron population is the baseline growth factor, while for Arbor Hills retail jobs is the baseline growth factor.

Accessibility elasticity varies by time of day. In general, the AM peak accessibility to employment is the most important as most people commute during this period, but PM peak accessibility and midday accessibility are also important as many workers commute during these periods. The central development of 413 East Huron has a higher accessibility elasticity than the more peripheral Nixon Condominiums for all three times of day, and in every case its accessibility elasticity is over 1.0. That means for all times of day the 413 East Huron development improves employment accessibility on a per capita basis for the Washtenaw County region. The Nixon Condominiums development is above 1.0 for midday travel, but is significantly below for the AM peak (0.59) and PM peaks (0.87). This is primarily because the Nixon Condominium development is expected to result in significant delays at two heavily traveled intersections, Nixon and Dhu Varren and Nixon and Huron Parkway (Figure 5).
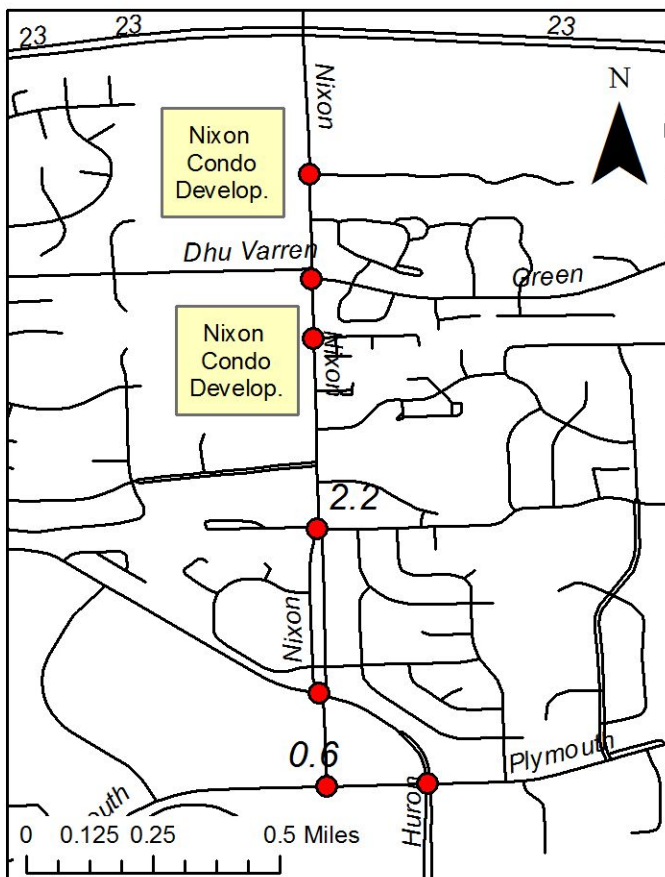

Figure 5: Seconds of Delay Forecasted for Intersections near Nixon Condominium Development

Arbor Hills is a retail development and therefore its analysis reflects its changes to the accessibility of shopping opportunities rather than changes to the accessibility of total employment. The Arbor Hills development offers an accessibility elasticity for retail significantly above 1.0 for all times of day. Since the peak shopping travel period is the PM peak or evening, this could be considered the most important accessibility elasticity for this particular development.

Numerical results may be interpreted as follows, using the Nixon Condominium development during the AM peak as an example. The addition of new residents at this location slightly increases the per capita accessibility of the region because more people live in close proximity to the region's destinations. At the same time, the addition of these new residents significantly decreases the per capita accessibility of existing residents because their presence on the roads imposes a slowing down of travel for a select set of origins and destinations. The total regional accessibility elasticity is the net effect of both of these influences. As an elasticity, the number reflects the marginal effect of each additional person. Therefore, with an accessibility elasticity of 0.59 in the AM peak, each additional person in the Nixon Condominium development adds 41% less accessibility than the average current resident of Washtenaw County.

There is no reason to assume that the 1.0 value should serve as a rigid threshold for approving new developments. Based on this small sample, it is clear that the 1.0 threshold is relatively difficult to reach for a new development, especially if it must be achieved across all times of day. The necessary level of accessibility elasticity for development approval is a policy question and land-use and transportation planners will develop a more nuanced understanding of favorable or unfavorable performance with respect to accessibility elasticity with experience. However by providing a stable and internally consistent measurement indicator for a development's impact on accessibility, this procedure offers an equitable and transparent basis for comparison.

Furthermore, the appropriate values for development approval will necessarily be tailored to adapt to local circumstances. What the proposed analysis indicator does provide is a clear metric for the degree to which a new development either contributes or detracts from regional accessibility, comparing to the existing built environment as a baseline.

3.3   Disaggregation of Impacts of Location and Traffic

Although the analysis integrates traffic and location impacts, these can be separated out to generate further insight into the relative influence of each, as shown in Table 5. For each of the three developments, the effect of location alone is greater than the percent change in the baseline factor. For example, for Nixon Condominiums the location-only impacts (i.e., holding travel speeds constant) result in a 0.228% increase, which results in an accessibility-elasticity ratio over 1.0. This means that each of the three developments would have an accessibility elasticity over 1.0 when considering location alone, i.e. if there had been no traffic impacts. This result highlights the importance of location, or proximity, in producing accessibility; these evaluations take into account both the influence of the location of the development as well as traffic impacts.

Table 5: Disaggregation of Accessibility by Location and Traffic Impacts, Washtenaw County

Project	Nixon Condominiums		413 East Huron		Arbor Hills	
Peak Period	AM	PM	AM	PM	AM	PM
Percent Change in Baseline	0.214% (population)		0.098% (population)		0.914% (retail jobs)	
Percent Change in Accessibility	0.125%	0.186%	0.182%	0.105%	1.357%	1.119%
Accessibility Elasticity	0.59	0.87	1.86	1.07	1.49	1.22
Accessibility, Location Impact Only	7.456E+09	6.835E+09	7.454E+09	6.828E+09	1.011E+08	8.162E+07
Percent Change in Accessibility, Location Impact Only	0.228%	0.254%	0.202%	0.158%	1.420%	1.319%
Elasticity of Location Impact Only	1.06	1.19	2.07	1.62	1.55	1.44
Accessibility, Traffic Impact Only	7.431E+09	6.813E+09	7.437E+09	6.814E+09	9.964E+07	8.042E+07
Percent Change in Accessibility, Traffic Impact Only	-0.098%	-0.066%	-0.020%	-0.052%	-0.058%	-0.176%
Elasticity of Traffic Impact Only	-0.46	-0.31	-0.21	-0.54	-0.06	-0.19
Sum of Elasticities by Location Impact and Traffic Impact	0.60	0.88	1.86	1.08	1.49	1.25
Ratio of Location Impact to Traffic Impact	2.3	3.8	10.1	3.0	24.5	7.5

Note: Accessibility in this table refers to the "total regional accessibility," the sum of accessibility from each zone multiplied by the population in each zone for the study area of Washtenaw County.

In fact, in each case the location of the development has a larger influence on accessibility than traffic delays, with location having at least twice as much impact, and in some cases much greater impact, than the effect of traffic delays (see the last row of Table 5). These ratios are much higher for the Arbor Hills retail development. The sum of the impact of the development location and the impact of the traffic is very close to, but not exactly, the total development's accessibility elasticity. This is because there are small interaction affects between shifts in travel times and the impact of a development's location.

The dominance of the location (proximity) effect over the traffic (mobility) effect demonstrates the magnitude of the error made by traditional metrics of mobility such as highway level of service. By neglecting proximity these metrics are neglecting what is in many cases the majority of the accessibility impact of a particular land-development project.

3.4   Sensitivity to Development Location

In order to explore the range of reasonable values for accessibility elasticity, three "what-if" scenarios were considered for the Nixon Condominium development. The first scenario examined the Nixon Condominiums in its current location, but without traffic impacts. The second scenario considered the same development in a counterfactual location on the urban fringe at the south of the region. This site was selected because new urban development is currently occurring in this area; therefore, this is at least a feasible location for a development of this kind. The third scenario considered the same development located in the most remote part of Washtenaw County, which is not a likely feasible location for this proposed development. However, this counterfactual location provides a meaningful test of the locational sensitivity of the accessibility elasticity metric. A map of the scenario locations is provided in Figure 1.

As Table 6 illustrates, the accessibility elasticity metric is highly sensitive to development location. The current location for the Nixon Condominium development performs much better than the location on the urban fringe (1.06 vs. 0.80). However it is possible that the urban fringe location might perform better overall if its traffic impacts are minimal. Both of these locations perform still much better than the hypothetical remote location, which comes in at a low 0.15. The remote location would almost certainly be the worst performing regardless of its traffic impacts. These results are as expected and confirm that the metric is sensitive enough to distinguish among the accessibility impacts of alternative development locations.

Table 6: Location Sensitivity Analysis for the Nixon Condominium Development

Alternative Locations	True Location	Urban Fringe	Remote Area
Accessibility Before ($\times 10^9$)	7.439	7.439	7.439
Accessibility After ($\times 10^9$)	7.456	7.451	7.441
Percent Change in Accessibility	0.228%	0.171%	0.033%
Percent Change in Baseline		0.214%	
Accessibility Elasticity	1.06	0.80	0.15

Notes: All of these analyses are for the same size condominium development in alternative locations. Accessibility elasticity analysis is conducted for the AM peak period for Washtenaw County study area. Zero traffic impacts are

assumed in each case in order to compare the real location of the development with counterfactual locations, which do not have associated traffic impact analyses.

4.1   Discussion

A standard tool for evaluating proposed land-use developments has long been traffic-impact analysis, which estimates the impact of a proposed development on roadway delays. This mobility-based analysis has the effect of penalizing development in locations where traffic is already near roadway capacities. Yet these are frequently the locations where a new development would contribute the most to regional accessibility. The accessibility-based analysis indicator proposed here gives credit for development in locations that offer high accessibility benefits, and enables decision makers to properly consider any negative mobility effects of proposed new developments in conjunction with their positive proximity effects.

This accessibility analysis metric is explicit about both the locational benefits and congestion costs of development. It does not inherently favor development at the center of a region over more peripheral suburban development, because travel times matter as well as location. Travel-speed impacts are not negligible and are fully accounted for within the proposed methodology. Mobility is an integral part of the accessibility concept and is integrated within this indicator.

Although the indicator was demonstrated here for the case of automobile travel, it can be extended to other modes as well. Transit travel times and transit-related impedances can be readily incorporated within this general approach. Accessibility benefits via bicycling and walking can be taken into account as well, although the entire regional travel matrix would not be needed in this case because most bicycling and walking can be presumed to be local in scale. A thorough accessibility evaluation for a proposed development project should take into account the accessibility impacts for all modes and consider the importance of each mode according to national, regional, and local planning priorities. Development approval should be contingent upon acceptable accessibility outcomes for multiple modes.

Ideally, project-based accessibility analysis would be adopted as a regular part of development approval for major development projects by most local governments. Because it incorporates both mobility and locational analysis, it renders stand-alone traffic-impact analysis superfluous. But traffic-impact analysis remains a necessary input to the project-level accessibility evaluation proposed here.

This proposed accessibility indicator integrates a great deal of data and necessarily suffers from certain analytical limitations. Firstly, the quality of the accessibility analysis is limited by the quality of the traffic-impact analysis. Secondly, the delay for each intersection is summarized as a single number reflecting the average delay of movements through that intersection, even though different types of movements will experience different amounts of delay. Thirdly, using ArcGIS Network Analyst to calculate which routes will experience delays neglects the fact that optimal routing changes with real time traffic conditions. In short there is room for further refinements around the calculation of travel

times and intersection delays. However the indicator presented here—accessibility elasticity—is able to meet the special challenges of project-level accessibility analysis.

5.1   Conclusion

Methodologies for gauging regional-scenario-level accessibility—such as current regional accessibility, or accessibility associated with a future regional-development scenario—are well established both in the research literature and in professional practice. But regional-scenario accessibility methodology is not directly applicable to individual transportation or land-use project decisions. Thus the planner seeking to evaluate the transportation implications of projects is left with inadequate alternatives to traffic-impact analysis (in the case of land-development projects) or highway level-of-service analyses for transportation.

To fill this gap, an indicator is presented here for prospectively evaluating the regional accessibility implications of proposed land-development projects. In comparison with the limited previous work on prospective accessibility-based analyses, the analysis presented here is distinctive because it incorporates the impacts of both land-use and transportation-system changes, it focuses on the impacts of proposed land development (as opposed to a proposed transportation improvement), and it is capable of quantifying the effect of small-scale projects.

In comparison with the current standard practice of traffic-impact analysis, the proposed analysis takes into account the positive benefits of location as well as the negative impacts of increased traffic of any given proposed land-use development. In comparison with proposals to evaluate developments based on changes in vehicle-kilometers traveled—such as California's reforms to transportation evaluation described above--the proposed metric accounts for the positive benefits of increased accessibility due to a proposed development rather than only examining the costs imposed by transportation externalities.

This approach can be adapted to allow for measuring the overall accessibility changes resulting from transportation projects as well. For transportation projects, land-use impacts must be forecast and the relative size of the transportation improvement in comparison with existing regional capacity must be benchmarked to determine a transportation projection's contribution to accessibility elasticity. Whether the initial change stems from a land-use development or a transportation project, the analysis methods proposed here examine holistic accessibility effects, accounting for changes to both land-use patterns and travel patterns.

Transportation and land-use planning have for decades been shaped by mobility-based modes of analysis, which erroneously treat movement as the purpose of transportation. This observation forms both a challenge and an opportunity for policy reform. The mobility framework is deeply entrenched and supported by institutions including professional associations, governmental planning mandates, municipal ordinances, and other legislation. This impedes reform as individual practitioners adopting accessibility-based evaluation are compelled to contend with institutional expectations and even mandates to maintain current modes of analysis. At the same time, the centrality of formal quantitative methods of evaluation in transportation and land-use planning offers an opportunity: the profession is

experienced in incorporating their outputs in decision making processes.   Revised metrics could readily be "plugged into" existing processes of planning, standard-setting, and evaluation with potentially far-reaching effects on built-environment outcomes. The challenge of reform is real, but the potential to better align transportation and land-use planning with its fundamental goals justifies the effort.

Glossary

Accessibility – A regional-level measure of the average individual's ability to reach opportunities located physically throughout a particular geography, by a particular mode.

Affected Intersection – An intersection with an associated delay caused by a proposed development as determined by a Traffic Impact Analysis.

Impedance – Resistance of individuals to incurring additional travel time and/or cost for reaching a particular destination.

Level of Service – Letter grade (A-F) qualitatively describing the operating conditions of a particular transportation facility in terms of its speed or delay characteristics.

Project-Level – Analysis targeted to determine the marginal impacts of a particular, site specific, discrete development project or transportation project.

Prospective – Analysis of future conditions, with some kind of forecasting element included within the scope of the analysis.

Regional – A designated area large enough so that a significant majority of travel of a given type occurs within the boundaries of that area.

TAZ – See Travel Analysis Zone.

Traffic Impact Analysis – A transportation analysis procedure for associating a certain amount of delay on a particular set of facilities with a particular development project. Delays are often reported through level of service categories.

Total Regional Accessibility – The sum product of the destination accessibility available from each zone and the resident population of each zone.

Travel Analysis Zone or TAZ – A geographic organization of space into a set of non-overlapping zones typically used for travel demand modeling and for the analysis of travel times and speeds.

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Acknowledgements

Appendix 1: Local Accessibility Losses Can Coincide with Regional Accessibility Gains

Table 7 illustrates how regional accessibility how regional accessibility gains can result even in the presence of local accessibility losses. In this hypothetical examine, there is a new residential development in high accessibility zone H which adds 506 people. As a result of the development, zonal accessibility is lower due to traffic impacts on H and the surrounding zones of E, F, and G. Other zones in the region are unaffected.

Table 7: Contrast of Regional and Local Accessibility Change

Zone	Zone Accessibility Before	Zone Population Before	Change in Accessibility	Change in Population	Zone Accessibility After	Zone Population After
Zones Unaffected by Traffic Impacts						
J	57	149	0	0	57	149
M	284	2560	0	0	284	2560
D	306	1498	0	0	306	1498
C	335	1947	0	0	335	1947
L	378	9	0	0	378	9
O	509	2024	0	0	509	2024
K	629	2797	0	0	629	2797
I	751	76	0	0	751	76
A	833	2038	0	0	833	2038
N	864	1071	0	0	864	1071
B	915	1199	0	0	915	1199
Zones Affected by Traffic Impacts						
G	582	1807	-22	0	560	1807
E	652	1491	-27	0	625	1491
F	916	2581	-16	0	900	2581
H	952	494	-17	506	935	1000
Population-Weighted Average	610.6				612.1	
Affected Zones Only	762.3				756.2	

If we examine the population-weighted accessibility change for this project only on the affected zones of E, F, G, and H, then accessibility declines from 762.3 to 756.2. However if we consider the entire region, accessibility increases from 610.6 to 612.1. This is because the affected zones are higher in accessibility than the rest of the region, so adding more population to these zones changes the population weighting to weight these high accessibility zones more heavily. As a result, regional accessibility rises even as local accessibility falls.

Appendix 2: Sensitivity to Impedance Parameter

Table 8 below shows the sensitivity of the accessibility elasticity outcome to the setting of the impedance parameter. Results for both residential developments are shown for the AM Peak. As the impedance parameter becomes larger, the accessibility elasticity becomes smaller for the Nixon Condominiums development and becomes larger for the 413 E. Huron development. This is because as the parameter becomes larger, locational advantage becomes more highly valued. The higher impedance coefficient effectively narrows the geographic scope of what counts as significant destinations (in this case employment locations). Because the 413 E. Huron development is highly central, it benefits in a relative sense from a narrower geographic scope. Because the Nixon Condominium development is in a more outlying area, its accessibility elasticity becomes worse as the impedance coefficient becomes higher. The range of impedance coefficients used in this table is representative of the range found for auto commuting trips in the United States with units in inverse minutes.

Table 8: Accessibility Elasticity Sensitivity to Impedance Parameter

	Accessibility Elasticity (AM Peak)	
Impedance Coefficient	Nixon Condos	413 E. Huron
0.07	0.79	1.45
0.10	0.69	1.66
0.13	0.59	1.86
0.16	0.49	2.06
0.19	0.41	2.24

Appendix 3: Proof: Maximizing Accessibility Elasticity Maximizes Total Accessibility

Accessibility Elasticity Proof

Let *M* be a metropolitan area with n districts *1, 2, …. i, … n.*

Define the weighted accessibility of a district d_i as:

$$a_i = \sum_{j=1}^{n} d_j f(c_{ij}) \geq 0$$

Where d_j is the count of destinations in district j, c_{ij} is the cost of traveling from district i to district j by some specified mode, and f is a decreasing friction function, where $f(cij) > f(c(kl))$ if and only if $cij < ckl$ and $f(cij) \geq 0$ for all i, j.

By assumption, the transportation infrastructure is fixed so the cost of traveling depends only upon the locations of the population and households. That is $c_{ij} = g(p_1, \ldots . p_n, d_1, \ldots d_n)$.

Let the population of metro area M at time 0 be divided among the districts, so that p_i^0 is the population of each district and:

$$p^0 = \sum_{i=1}^{n} p_i^0$$

Define the average accessibility of the metro area as:

$$A(M^t) = \sum_{i=1}^{n} a_i^t \frac{p_i^t}{p^t} = \sum_{i=1}^{n} a_i^0 \frac{p_i^0}{p^0} \; when \; t = 0$$

Let $\hat{A}$ be the set of all average accessibilities for the set of future potential metro areas M_r^1 given exogenous positive population change $\varDelta p > 0$:

$$\hat{A} = \left\{ A(M_r^1) = \sum_{i=1}^{n} a_i^1 \frac{p_i^1}{p^1} \mid p^1 - p^0 = \Delta p, d_i^1 = d_i^0 \; \forall i \right\}$$

Define **average accessibility change** as $A(M^1)\text{-}A(M^0)$.

Define **accessibility elasticity change** as:

$$\{[A(M^1) - A(M^0)]/A(M^0)\} \Big/ \left[\Delta p \Big/ p^0 \right]$$

Then there exists

1) $A^* \in \hat{A} \; st \; A^* = A(M_s^1) \; and \; A^* - A(M^0) = \max([A(M^1) - A(M^0)])$

And

2) $\{[A^* - A(M^0)]/A(M^0)\} \Big/ \left[\Delta p \Big/ p^0 \right] = \max\left(\{[A(M^1) - A(M^0)]/A(M^0)\} \Big/ \left[\Delta p \Big/ p^0 \right] \right)$

Proof. Let A^* be defined as:

$$A^* = max(\hat{A})$$

Then by definition

$$A^* \geq A(M_r^1) \ \forall r$$

Subtracting both sides by *A(M⁰)*:

3) $A^* - A(M^0) \geq A(M_r^1) - A(M^0) \ \forall r$

This proves part 1).

Now note that

4a) $A(M^0) = \sum_{i=1}^{n} a_i^0 \frac{p_i^0}{p^0} \geq 0 \ and \ 4b) \ \frac{\Delta p}{p^0} \geq 0$

Dividing 3) by 4a) and then by 4b):

$$\frac{A^* - A(M^0)}{A(M^0)} \geq \frac{A(M_r^1) - A(M^0)}{A(M^0)} \ \forall r$$

$$\left\{ \frac{[A^* - A(M^0)]}{A(M^0)} \right\} / \left[\frac{\Delta p}{p^0} \right] \geq \left\{ \frac{[A(M_r^1) - A(M^0)]}{A(M^0)} \right\} / \left[\frac{\Delta p}{p^0} \right] \ \forall r$$

Which demonstrates 2). Therefore the proof concludes, the same metropolitan area *Mₛ* with *A* = A(Mₛ¹)* which maximizes accessibility elasticity also maximizes average accessibility change.