Engaging and Informing Citizens with Household Indicators

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Abstract

Urban simulation systems can be a powerful tool for helping to understand the complex, long-term consequences of urban planning decisions. Simulation results are summarized and reported using indicators: aggregate measures such as population density or total minutes of vehicle delay. To citizens without expertise in urban planning, such indicators may be abstract and unfamiliar; they are difficult to compare to experiences of the city today. Household Indicators address this gap by presenting a personalized, household-level view on simulation results through a web-based interface. This paper discusses the design of a Household Indicators tool, employing the Value Sensitive Design theory and methodology.

1. Introduction

Regional officials, urban planners, and citizens grapple with issues such as traffic jams, resource consumption, and urban sprawl. Decisions about new freeways, transit service expansions, or land use regulations are often controversial and expensive, with long-term consequences. The goal of the UrbanSim project is to provide tools that help stakeholders evaluate different packages of policies and investments by modeling the resulting patterns of urban growth and redevelopment, of transportation usage, and of environmental impacts, over periods of 20-30 years [2]. A further goal is to design interfaces and interaction techniques for such urban simulation systems that facilitate public understanding and citizen engagement.

In urban planning, indicators [11] are often used to monitor changes in a region with respect to certain attributes of concern. Indicators such as population density and annual hours of vehicle delay are familiar to urban planners engaged in monitoring and modeling urban development, and are typically visualized as charts, maps, or tables. The Indicator Browser makes it easier for urban planners and others to view indicators of UrbanSim results for the range of simulated years and scenarios being investigated [15], while Technical Documentation provides ready-to-hand technical information about the indicators and how UrbanSim computes them [1].

However, an aggregate measure such as annual hours of vehicle delay may be unfamiliar to citizens without expertise in urban planning. A more concrete measure, such as the expected travel time between the user's home and workplace, may be both more comprehensible and more compelling by allowing direct comparison with the user's experiences in the ordinary world.

Household Indicators [3] are a new approach for enabling citizen interaction with UrbanSim results. Using personal information provided by the user, this web application attempts to address the question, "How will this decision affect *me*?" Rather than presenting a view of the entire region under different policy alternatives, Household Indicators provide a lens through which to view the simulation results from the perspective of a single household and its interactions with its immediate environment—the neighborhoods where members of the household live, work, learn, shop, and play, as well as their travels between those places. Potential Household Indicators include population and employment density of different places, housing opportunities for different households, and travel times between different places.

This paper discusses the design of a Household Indicators tool, employing the Value Sensitive Design theory and methodology. The next two sections provide background on UrbanSim and the application of Value Sensitive Design to UrbanSim indicators. Section 4 lays out the design problem, while sections 5 and 6 present and discuss the Household Indicators design process. Section 7 briefly discusses the software architecture of the prototype implementation. The paper concludes in section 8.

2. UrbanSim

UrbanSim's interacting component models represent major actors and processes in the urban system [2]. The system takes a highly disaggregated approach, modeling individual households, jobs, and real-estate development and location choices. The region is divided into relatively small grid cells, typically 150 x 150 meters. Most UrbanSim models are discrete-choice models, in which the probability that a given agent will make a particular choice is a function of a set of variables that measure the relative attractiveness of that choice. For example, in the Residential Location Choice model, the probability that a particular household will choose to locate to a residential unit within a particular area depends on household attributes, such as income and number of children, as well as attributes of the potential dwelling, such as cost and location. An external travel model simulates trips between the locations of various households and jobs. The resulting patterns of transportation use and congestion then give rise to accessibility measure for different locations, which in turn influence the desirability of those locations for housing or jobs.

The most recent version of the system, UrbanSim 4, is built on the Open Platform for Urban Simulation (OPUS), a new object-oriented architecture and platform. OPUS and UrbanSim 4 are implemented in Python, making use of highly optimized array and matrix manipulation packages written in C++ to handle inner loop computations.

As of the time of this work, UrbanSim was being transitioned into operational use in the central Puget Sound region (Seattle and surrounding areas), Honolulu, and Salt Lake City; it had already been used operationally in Houston. There have been research and pilot applications in Amsterdam, Detroit, Eugene, Paris, Phoenix, Tel Aviv, Zurich, and other cities. The system is open source, under the GNU Public License, and continues to evolve with the development of new and improved models and indicators.

3. Value Sensitive Design of Indicators

The domain of urban planning is value-laden and rife with long-standing disagreements, including the choice of indicators to consider and how they are presented and described. To approach these issues in a principled fashion, design of interactions with UrbanSim indicators has employed the Value Sensitive Design theory and methodology [9].

Value Sensitive Design is an approach to the design of information systems that seeks to account for human values in a principled and comprehensive way throughout the design process. Key features of the methodology are its interactional perspective, tripartite methodology, and emphasis on indirect as well as direct stakeholders. First, Value Sensitive Design is an interactional theory: people and social systems affect technological development, and technologies shape (but do not rigidly determine) individual behavior and social systems. Second, Value Sensitive Design employs a tripartite methdology, consisting of conceptual, empirical, and technical investigations. Third, Value Sensitive Design emphasizes attention to both direct and indirect stakeholders. Direct stakeholders are those who interact directly with the system or its outputs: for UrbanSim in its current form, urban planners and modelers. Indirect stakeholders are those who do not themselves interact with the system but are affected by how the system is used. UrbanSim's indirect stakeholders include government officials, voters, and ultimately everyone who lives, works, or travels in the region. Thus, one goal in developing UrbanSim has been to provide strongly impacted indirect stakeholders—notably citizens of the region—with opportunities to become direct stakeholders.

Previous design work on UrbanSim indicators has begun to address this goal. The primary goal in developing Technical Documentation was to provide technical information about UrbanSim indicators to urban planners and modelers, the current direct stakeholders, in support of transparency and legitimation; stakeholders without such expertise were a secondary audience [1]. The Indicator Browser is similarly intended to provide urban planners and modelers with ready access to UrbanSim results. Urban planners and modelers who participated in the evaluation of the system said they would also recommend the Indicator Browser to activist groups and the general public [15]. Finally, the Indicator Perspectives Framework [1] provides a platform for organizations such as advocacy groups and business associations to present their views on which indicators should be used to evaluate UrbanSim scenarios, how they should be interpreted, and why. The primary audience is citizens and officials who will engage in deliberation about urban planning decisions. The work presented here continues that effort by providing a new interface, Household Indicators, intended to engage citizens in exploration and evaluation of UrbanSim results.

UrbanSim's context of use, urban planning, involves a multiplicity of stakeholders who bring to the table not only differing expertise but also a range of deeply held, sometimes conflicting values. Early in conceptual investigations [1], [9], the researchers (Batya Friedman, Alan Borning, the author, and others) made a clear, principled distinction between explicitly supported values—those which the researchers intend to embed in the designs—and stakeholder values—those that are important to some but not necessarily all stakeholders. Next, the researchers committed to several key moral values to support explicitly: fairness (and more specifically, freedom from bias [10]), representativeness, accountability, and support for a democratic society. In turn, as part of supporting a democratic society, the researchers decided that the system should not a priori favor or rule out any given set of stakeholder values, but instead should allow different stakeholders to articulate the values that are most important to them, and evaluate the alternatives in light of those values.

Finally, usability issues are also of concern. In particular, Borning, Friedman, Davis, and Lin [1] identified the goal of making information "ready-to-hand", that is, easy to access in the course of interacting with UrbanSim, both as an end in itself and also in support of transparency. Prior work on the GovStat project [13], an effort to help people find and understand statistical information provided by the United States federal government, faced similar problems with presenting metadata and explaining unfamiliar abstractions.

The remainder of this section discusses four particular values: freedom from bias, legitimation, transparency, and democratic engagement.

3.1. Freedom from Bias

Friedman and Nissenbaum refer to "bias" in computer systems as

> computer systems that systematically and unfairly discriminate against certain individuals in favor of others. A system discriminates unfairly if it denies an opportunity or a good or if it assigns an undesirable output to an individual or group of individuals based on grounds that are unreasonable or inappropriate [10].

To warrant the term *biased*, then, discrimination must be both systematic and without fair justification.

They identify three sources of bias: pre-existing bias, technical bias, and emergent bias [10]. *Pre-existing bias* occurs when design is influenced by the existing biases of society or of an individual against particular individuals or groups, for example, as in a real estate listing service supporting the practice of red-lining. *Technical bias* arises from technical constraints or considerations. There is no intent to discriminate unfairly, but in practice, some groups have less desirable outcomes than others. Friedman and Nissenbaum identify "inadequate formalizations of human concepts" [10] as one type of technical bias, which is of particular concern for UrbanSim as a simulation system. *Emergent bias* may result when new contexts of use differ significantly from the original design context, for instance applying UrbanSim to a city in the developing world such as Mumbai.

Freedom from bias is a moral good in itself, and the researchers first identified freedom from bias as an explicitly supported value for this reason [9]. However, freedom from bias is also instrumental to equal opportunity to participate in democratic society; stakeholders whose concerns are represented in the system may have a privileged place in deliberation relative to those whose concerns are not represented. Furthermore, the use of a biased information system could undermine the legitimacy of the decision making process it informs. Even the perception of bias could raise doubts about the accuracy of the information provided and the intent of the system designers.

3.2. Legitimation: A Habermasian View

In earlier work by Borning, Friedman, Davis, and Lin [1], legitimation developed as a key value in support of a democratic society. Supporting UrbanSim's legitimation is crucial because disagreements about its legitimacy might lead some stakeholders to derail or disengage from the decision-making process, or cause the agency to abandon use of the system.

Drawing primarily on the work of Jürgen Habermas [12], Borning et al. identified four design goals in support of UrbanSim's legitimation potential. First, the information UrbanSim provides should be comprehensible to the range of stakeholders. Second, UrbanSim's models and results should be a reasonable representation of reality. Third, UrbanSim should be transparent with respect to its inner workings and design, so that stakeholders can see that the model and its results are truthfully represented in the deliberation. Fourth, UrbanSim is cast in the role of a source of relatively factual, technical information in a highly political process. To rightly fulfill this role, and in the interest of fairness to all stakeholders, UrbanSim should provide information that is as unbiased as possible. The information provided should be appropriate and relevant to the policy context. Although these are not new goals for operational models (e.g., see reference [14]), tying these goals to legitimation potential helps us understand their significance for models that must support democratic decision making. These goals were a primary focus in the design and evaluation of the Technical Documentation [1], and are also a focus of the work presented here.

3.3. Transparency

Transparency was also identified as a design goal in work on the Technical Documentation [1]. In public policy, transparency designates mechanisms for public disclosure; for example, Finel and Lord [6] use the metaphor of a "glass box" to convey the visibility of the internal characteristics of a government. Typically, transparency designates the opposite of a "black box" system, which hides all information beyond its inputs and outputs. Fleischmann and Wallace [7] advocate for transparency in simulations: Models should be thoroughly documented, their assumptions should be explicit and testable, and model components should be accessible to the user. Transparency in this larger sense supports several of the goals for legitimation: it helps stakeholders to comprehend simulation results, it allows them to assess whether the simulation's assumptions hold and its models are sufficiently realistic for the decision making context, and it allows stakeholders to verify the intent of the model developers to provide relatively unbiased information. Furthermore, Value Sensitive Design leads us to consider transparency for both direct and indirect stakeholders, who will have differing expertise with respect to urban planning, simulation, computer systems, and the region in which UrbanSim is applied.

3.4. Democratic Engagement

A goal in supporting more democratic urban planning is to foster citizen engagement in the decision making process [4]. According to Delli Carpini, characteristics of an engaged citizen include

> (1) adherence to democratic norms and values; (2) having a set of empirically grounded attitudes and beliefs about the nature of the political and social world; (3) holding stable, consistent, and informed opinions on major public issues of the day; and (4) engaging in behaviors designed to influence, directly or indirectly, the quality of public life for oneself and others. Underlying all of these elements is the assumption that citizens also have the skills and resources necessary to develop informed values, attitudes, and opinions, connect them together, and translate them into effective action. [5]

To foster engaged attitudes, consistent opinions, and enthusiastic participation, a planning system must provide information about the issues that form the substance of political life. UrbanSim helps fulfill that requirement by providing information about potential impacts of land-use and transportation alternatives—a major political issue.

But providing information is not enough. Citizens must want to use it. UrbanSim's designers seek to foster such democratic engagement, not only to help citizens make more informed decisions, but also to encourage an attitude that can lead to participation in public decision making. Information systems, such as online discussion forums or tools for citizens to propose new policy and investment packages, for example, could provide new opportunities for citizen participation in urban planning. Of course, systems such as UrbanSim supplement—not replace—informal discussions, town meetings, and voting.

4. Household Indicators: Design Problem

The overarching goal of Household Indicators is to support democratic engagement in regional land use and transportation decisions by providing citizens with information that addresses their values with respect to their own interactions with the city, at the scale of a single household. At the same time, it must uphold commitments to fairness, transparency, and legitimation.

I identified several concrete goals for selecting indicators, presenting information, and fostering democratic engagement through my design process. These goals stem from conceptual investigations presented in the previous section, but also respond to what I have learned about the particular context of Household Indicators through empirical and technical investigations.

I aim to select indicators that

- are relevant to citizens' values and interests, in support of the system's legitimacy;
- avoid bias in the form of providing useful information to some citizens, but not to others (e.g., providing information about housing costs to homeowners but not to renters);
- and are feasible to implement, taking into account UrbanSim's capabilities and limitations.

Further drawing on the goals for legitimation potential and the explicitly supported value of freedom from bias, I seek to present information in an manner that is

- comprehensible to as many citizens as possible;
- an accurate representation of simulation results;
- transparent with respect to the model's input data, results, assumptions, and limitations;
- and relatively factual.

Additional challenges arise from appropriating results from a model that was designed with regional planners as its primary audience; planners' goals and expertise in interacting with UrbanSim may be quite different from those of citizens. These challenges also present an opportunity to influence UrbanSim's future development to better account for non-planners' conceptions and interests.

Similar challenges will be faced by any designer who aims to develop interfaces that present such tailored views of simulation results intended to inform public decision making. For instance, models used to project the impacts of changes to the tax structure could also be used to provide citizens with personalized information about how they could be impacted by those changes. While I do not claim to fully address these goals in the current design of Household Indicators, I have made progress in understanding and addressing each of them.

5. Design Process

This section provides an overview of the four design iterations conducted thus far, while the next section discusses themes that recurred throughout the design process.

5.1. Phase 1: Initial Explorations

Initial investigations of Household Indicators spanned the conceptual, technical, and empirical. In conceptual investigations, I considered benefits and harms. Potential benefits to users included greater access to information and increased transparency of the simulation models; potential harms included misunderstandings of or inappropriate confidence in the data, as well as loss of privacy. Potential harms to a democratic society include compounding of the digital divide and gaps between engaged and disengaged citizens—the concern that this helps only those who are already involved and have access to information. In technical investigations, I identified potential Household Indicators that UrbanSim could readily produce.

To explore these concerns, I conducted informational interviews with citizens. Nine Seattle citizens (4 women, 5 men) ranging in age from 31 to 49 (M = 36) were recruited through posters in the Greenwood neighborhood and email to the Greenwood-discussion mailing list. I engaged the participants in semi-structured interviews lasting approximately 1.5 hours. Questions addressed particular values and indicators that might be of interest, potential harms and benefits of Household Indicators, the role of self-interest, and democratic engagement. Most participants were positive about Household Indicators, and a few were quite enthusiastic. They saw a range of potential benefits with respect to democratic engagement, access to information, and, surprisingly, *personal* decisions such as where to buy a house. Some participants were concerned about transparency of the information provided, and that information could mislead or be used inappropriately.

5.2. Phase 2: Paper Prototypes

Phase 2 comprised explorations of project scope and alternative interaction designs, culminating in a formative evaluation of paper prototypes with Seattle citizens. I focused on a small number of indicators that were of interest to interviewees and feasible to implement given UrbanSim's existing capabilities: indicators of population and employment density, land use mix, residential unit value, and commute times.

After exploring map- and chart-based visualizations, I decided the initial prototype would provide tables comparing results with base year data and across different scenarios. While trends are more easily seen in charts and graphs, tables show small datasets clearly and facilitate comparison [16], an essential task for understanding differences between alternatives. This decision also acknowledged the limitations of UrbanSim's existing visualization support: Generating maps and charts is a slow process, too slow to be done interactively. The Indicator Browser helps to address this, but it does so by allowing users to view previously computed visualizations and queue requests for new visualizations [15]. By contrast, tables are simple to produce in HTML once the necessary data is obtained.

Two distinct interaction designs emerged: a profile-centric approach and an indicator-centric approach. In the profile-centric approach, the user creates one or more household profiles and then views simulation results through the lens of these profiles; in the indicator-centric approach, initial regional views of indicators are personalized as the user enters data.

To compare these two approaches, I developed a series of paper prototypes. I tested these first with UrbanSim staff and then in a formative user study with six Seattle citizens (3 women, 3 men) ranging in age from 32 to 53 (M = 43.5), recruited as for the interviews in Phase 1. I asked each participant to think aloud while performing the same task with both prototypes, counterbalancing the order of the prototypes across participants. Each session lasted about one hour. I found the indicator-centric approach to be well suited to the task of exploring hypothetical future personal circumstances (e.g., moving to a different neighborhood, or a change in household income). The profile-centric approach supports these tasks less well, but better supports viewing many indicators with respect to the same personal information (e.g., many different indicators about where one lives or works). Returning to the initial question, "How will this decision affect me?" and the aim to afford comparison rather than exploration, I decided to pursue the profile-centric approach and leave the complementary indicator-centric approach to later work.

5.3. Phase 3: Interactive Mock-Up

In the next phase, I developed higher-fidelity HTML mockups of the interface. These mockups include a realistic layout of text, data, and widgets, including Google maps (http://www.google.com/apis/maps/) for specifying locations; however, the displayed information is fixed rather than responding to the user's input and does not incorporate data from UrbanSim runs. To produce these mockups, I engaged in a series of rapid design iterations, punctuated by critique sessions with colleagues. The majority of the work in this phase addressed visual layout and the sequencing of steps in creating the household profile.

5.4. Phase 4: Prototype Implementation

In Phase 4, my goals were to develop a working prototype of Household Indicators and conduct a formative evaluation focusing on value issues.

The prototype web application builds on the mockup from the previous phase by incorporating actual UrbanSim indicator data in response to information entered by the user. As shown in Figure 1, the prototype allows the user to specify a household name and location, other places important to the household, and the start, destination, travel mode, and time of day of various trips. The user can then compare possible personal impacts of four preliminary UrbanSim runs. The implemented indicators are Population within Walking Distance, Employment within Walking Distance, Land Use Mix within Walking Distance, and Average Home Value within Walking Distance, and Travel Times. The prototype also includes links to glossary terms, FAQs, and related regional indicators.

To evaluate the prototype with respect to relevance, comprehensibility, transparency, accuracy, and freedom from bias, I conducted four focus groups with a total of 13 participants (7 women, 6 men) ranging in age from 19 to 63 (M = 49). Participants were recruited in four Seattle neighborhoods using neighborhood email lists, posters, and word-of-mouth. After a brief demonstration, I elicited questions about the tool and asked the participants about potential biases, indicators of interest, and opportunities for the system to contribute to democratic engagement. Participants also volunteered concerns about accuracy of the data and appropriateness of the abstractions.

6. Discussion

In this section, I discuss recurring themes and directions for future work: potential biases, comprehensibility and transparency, selecting indicators, and supporting democratic engagement. To illustrate these themes, I begin by tracing the development of housing cost indicators through the four phases of design conducted thus far.

6.1. Designing a Housing Cost Indicator

In the initial explorations of Phase 1, I anticipated stakeholder interest in housing costs. Housing is the single largest expense for many households and greatly affects quality of life. All interviewees expressed at least some interest in either home prices or rents.

UrbanSim models residential property values, but the current housing abstraction is the *residential unit*, which encompasses both owner-occupied and rental housing and does not include characteristics such as number of bedrooms. Nonetheless, I believed that the information about property values would be useful and relevant, and that accounting for these limitations was a challenge of transparency—simply making the abstraction very clear.

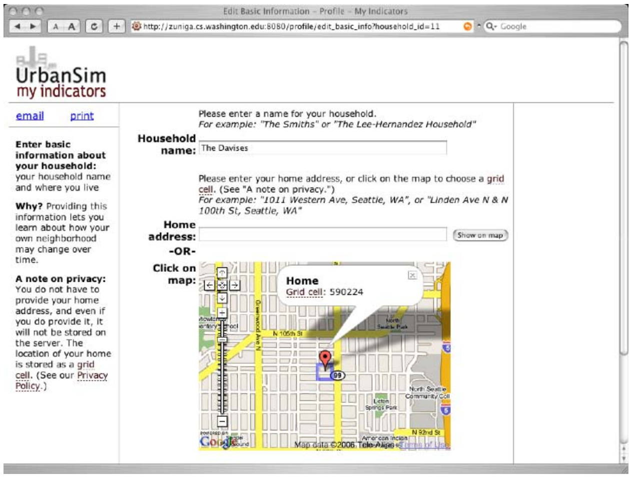
Based on interests expressed by Phase 1 interviewees, in Phase 2 I focused on the question "Where can I afford to live in the region?"—a question of great relevance to renters and other stakeholders who might move. I designed paper prototypes of an indicator that, given a household's income, would show how much housing in the region was "affordable" for that household and where it was located. I drew on a rule of thumb sometimes used in the real estate industry: that a household can afford a home with a price up to 2.5 or 3 times annual household income. This proved problematic: First, there is no reason to think the rule will be equally valid for renters. Second, it hides the raw data (property values) produced by UrbanSim, while making implicit assumptions about factors such as the mortgage interest rate and the down payment. While this indicator might be extremely relevant for some households, it introduces problems with transparency and a potential bias against renters.

Therefore, in the next phase of design I investigated indicators of monthly costs in the form of rent or mortgage payments. But the relationship between property values and monthly payments is complex. Computing monthly payments solely on the basis of property values would require many assumptions, posing the same problem as the rule of thumb used in Phase 2. So, I decided to postpone indicators of monthly costs until later—when UrbanSim's models are able to provide such indicators through models that are theoretically sound and empirically validated—and instead focus on showing the data that UrbanSim actually does produce now.

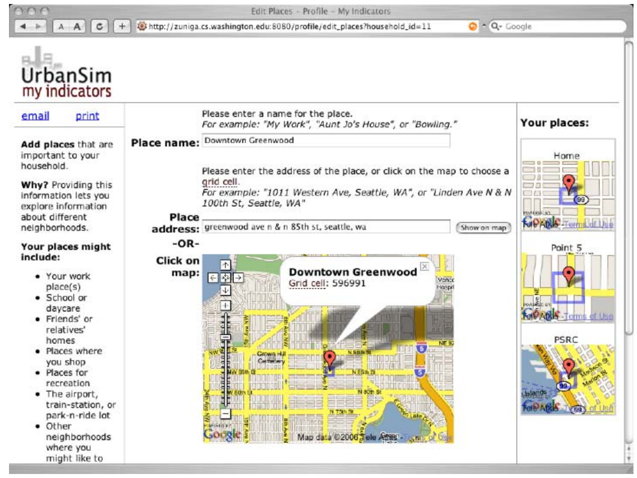
The HTML mockup I developed in Phase 3 instead aims to answer the question "How could residential property values change in my neighborhood?" The screenshot of the Average Home Value within Walking Distance indicator, shown in Figure 2, shows this data.

This leaves the design at a not entirely satisfactory resting point. Because the residential unit abstraction combines housing units for rent and for sale, one can wonder whether participants truly understood the "average home value" indicator. The lack of a representation of monthly costs represents a potential bias against renters. And the prototype does not address the earlier question, "Where can I afford to live in the region?"

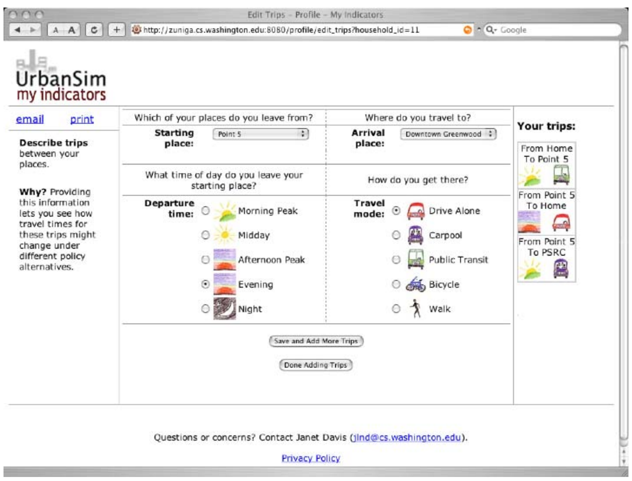
Yet, addressing these limitations and biases provides a clear direction for future development. This story illustrates how asking new questions, and providing new interactions with simulation results aimed at a different group of stakeholders, can lead to a reexamination of the abstractions underlying the simulation model.



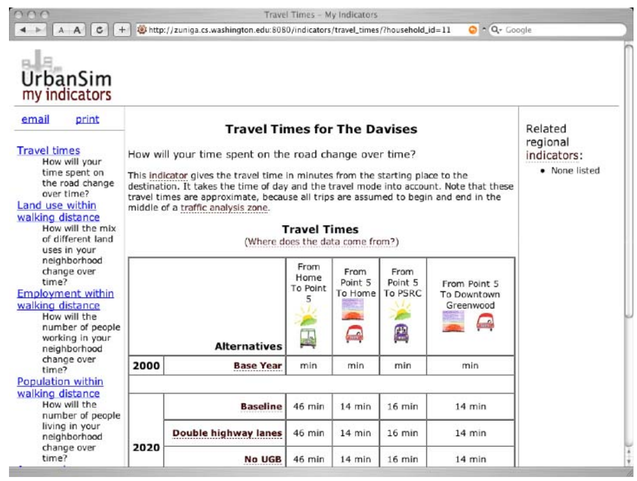
(a) In the first step, the user creates a new household profile including the household's name and the location of the household's home.



(b) In the next step, the user adds a number of places of personal importance—for instance, their workplace and their child's school.



(c) In the final step of creating the profile, the user describes trips, including the places where the trip begins and ends, the travel mode (drive alone, carpool, transit, bicycle, or walk), and the time of day.



(d) After the user is done entering trips, Household Indicators shows a table comparing travel times for these trips for the base year (2000) and the four alternatives in the year 2020.

Figure 1. The Household Indicators prototype.

6.2. Potential Biases

In the previous section, I discussed an emergent bias against renters, arising from appropriating an existing simulation model to ask new questions. Here, I discuss other potential biases and approaches to mitigating bias.

The prototype reflects a pre-existing bias in the United States that favors automobile travel over other modes. I found in Phase 4 focus groups that transit riders are concerned not only about travel times but the type of transit (city bus, train, etc.), waiting times, walking distances, number of transfers, and so on. While the existing Travel Times indicator provides a relatively complete representation of the experience of traveling by car, it is not so complete for mass transit. Moreover, in current practice at the Puget Sound Regional Council, mass transit is modeled only for morning peak and daytime, and not for afternoon peak, evening, or night. This reflects limited evening and night service (a pre-existing bias), but also an effort to reduce lengthly travel model runs (a technical bias). Other concerns reflect inadequate indicators for foot and bicycle travel, weekend travel, and travel costs.

To mitigate pre-existing biases, Friedman and Nissenbaum suggest identifying groups who suffer from societal biases and including them in empirical investigations [10]. The presence of renters and transit users in focus groups helped to identify biases; future evaluations should specifically include such stakeholders to help assess how well these biases have been addressed. To avoid technical biases, Friedman and Nissenbaum guide designers to

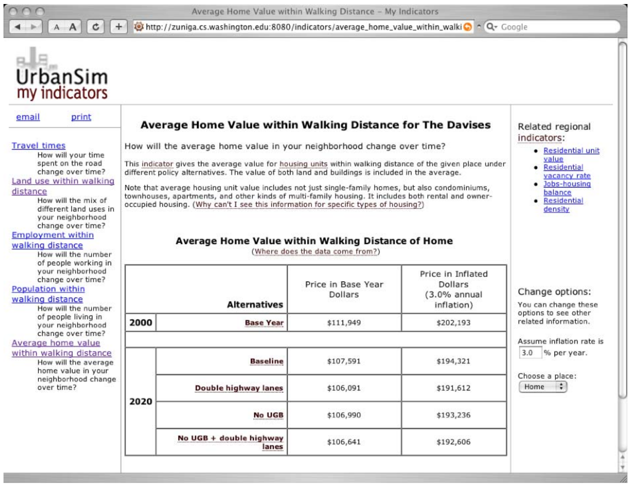


Figure 2. Prototype display of home value indicator.

envision the system in a context of use [10]. A lesson for simulation models is to be wary of abstractions such as the residential unit that erase morally significant distinctions between stakeholders, such as between homeowners and renters. At the same time, addressing such biases requires significant research effort to design new models that are theoretically and empirically sound.

6.3. Comprehensibility and Transparency

One of my hypotheses is that Household Indicators can be more comprehensible to stakeholders without urban planning expertise by grounding simulation results in experiences such as choosing a place to live or commuting to work. Yet, Household Indicators also pose challenges for comprehensibility and transparency.

Explanations and definitions need to be ready-to-hand in the context of using the system. The prototype shown in Figure 1 includes "ready-to-hand" FAQs placed close to where the question arises. Where it is necessary for transparency to use specialized terms such as "grid cell," comprehensibility is enhanced by using ready-to-hand FAQs and visual explanations. This approach is similar to the GovStat project's Statistical Interactive Glossary [13].

The story of housing costs given in Section 6.1 represents a struggle in part to show the data as clearly as possible. At the end of this process, focus group participants understood the data well enough to raise questions about its accuracy, such as, "Is this data from the year 2000?" and "What is being averaged here?" Participants also raised questions about what is and is not accounted for in the models, such as, "Is this limited to the four-county region?" and "Does this account for travel on surface streets or only on highways?" Thus, making simulation results more comprehensible pushes back on transparency. Household Indicators must respond to such skepticism by accounting for the operation and limitations of the models themselves in a way that is accessible to laypeople. Because not all such questions can be anticipated, the interface may need to provide a way for citizens to address further questions to urban planners and modelers in their region.

6.4. Selecting Indicators

Identifying and prioritizing potential Household Indicators requires balancing tensions between providing information relevant to stakeholders' interests and experiences, avoiding biases in what information is presented, and being true to the model's abstractions and limitations. The story of developing a housing costs indicator illustrates each of these concerns. Selecting indicators will remain a challenge in the future, as indicators should evolve in response to new decision contexts and the model's changing capabilities.

Implementing a new indicator may require a significant research and development effort, and resources are limited. At this stage in the development of Household Indicators, the desire to produce a working prototype using real UrbanSim output data has brought pragmatic concerns to the forefront. The five existing Household Indicators were relatively straightforward to implement given UrbanSim's existing capabilities. In future work, priority should be given to indicators that address morally significant biases discussed earlier, such as indicators of monthly costs for rentals and owner-occupied housing discussed earlier. Participants also expressed interest in indicators of neighborhood form, such as building height and open space, as well as indicators of access to shopping, services, and recreation.

6.5. Supporting Democratic Engagement

Finally, one of my goals in developing Household Indicators is to support democratic engagement. Even some of the "engaged citizens" recruited to participate in formative evaluations expressed cynicism about the land use and transportation planning process, and in particular that they could make a difference in the outcome. Yet, many participants in Phase 1 exploratory interviews expressed enthusiasm for the concept of Household Indicators, as did many of the Phase 4 focus group participants who saw the system in action. Some participants indicated that access to quantitative data would enhance citizens' credibility and power when raising their concerns to elected representatives and public officials.

I began this project with some concern that Household Indicators could promote self-interest at the expense of public interests. The engaged citizens I spoke with in Phase 1 interviews were well aware of the public interest, and of stakeholders beyond themselves and their loved ones. Some participants spoke derisively of acting out of pure self-interest while others said that it is all right or even necessary to consider one's own interests in forming political opinions. Using a tool that helps one to consider one's own interests does not guarantee a decision based on self-interest; public deliberation helps to promote decisions that are in the public interest. As Fraser argues [8], there is a place for discussion of private interests in the public sphere. The prevailing sense of the common good may not adequately include the interests of some individuals, who should, then, speak up for their own interests. Furthermore, individuals can clarify their own interests through deliberation with others.

Nonetheless, it remains important to connect Household Indicators with regional perspectives on the alternatives and Indicator Perspectives developed by local organizations. Improving the integration of all the interfaces to UrbanSim results is a concern for future work. Furthermore, participants in empirical investigations have suggested that Household Indicators could link into existing structures for public deliberation and political engagement. Since each household profile includes the location of the household's home, the interface could readily provide contact information for the household's elected representatives and neighborhood council.

7. Software Architecture

The prototype is a stand-alone web application based on the TurboGears toolkit (http://turbogears.org). Turbogears is implemented in Python, making it easy to integrate UrbanSim4 components; it provides a supportive, flexible, and easy to learn environment for rapid development of web applications. The prototype implementation's modular architecture is supported by TurboGears' model/view/controller abstraction.

Models represent the underlying data. A key model is the household profile model, incorporating three classes, Household, Place, and Trip. These classes are implemented using the SQLObject library (http://www.sqlobject.org), which facilitates storing the objects in a relational database. Another key model is the MultiCacheAccessor, which enables access to output data contained in multiple UrbanSim run caches, allowing comparison across different years and scenarios.

Views comprise the web pages themselves; they are implemented using the Kid template language (http://www.kid-templating.org/), which lets the developer embed Python snippets in HTML pages. These snippets are executed on the web server. Client-side behaviors such as fetching new indicator data when the user selects a different place to view are implemented in JavaScript.

Controllers bridge the gap between models and views. As the user creates a household profile, the ProfileController validates the user's input, updates the household model based on that input, and configures the view to be presented next. Each indicator has a controller for configuring the view, while a single IndicatorDataController class interfaces with the MultiCacheAccessor class to fetch the appropriate indicator data. One controller geocodes addresses to latitude/longitude coordinates using a free service (http://geocoder.us), and another converts between latitude/longitude and UrbanSim grid cell coordinates using the PROJ.4 toolkit (http://proj.maptools.org). Finally, a FAQ controller controls views of information about Frequently Asked Questions.

The greatest challenge in implementing the prototype system was coping with the sheer volume of data—on the order of megabytes for a single attribute of a dataset such as all of the grid cells in the Puget Sound region. UrbanSim's typical data access pattern is to access each attribute for every entity in a dataset (e.g., access the number of residential units attribute for every grid cell in the region). UrbanSim's data structures are designed for this access pattern in that attribute data is loaded from disk and flushed from memory in large chunks. By contrast, Household Indicators need to access attribute data for only a small number of entities at a given time. The goal of comparing years and scenarios means that it must do so for several different datasets. A typical workstation's memory is not large enough to hold several attributes of several years and scenarios in memory at once, and loading all of the data for an attribute takes several seconds, making response time slow. To address this challenge, I used Numarray's Memmap feature to efficiently load into memory the desired attribute of only a single entity (e.g., the number of residential units for one specific grid cell). A production implementation may need to cache these single values in memory to reduce disk contention and improve scalability.

8. Conclusion

Household Indicators, a novel approach to interacting with the results of simulations such as UrbanSim, attempt to address the question, "How could this decision affect me?" I have developed a working prototype implementation of Household Indicators, conducted formative evaluations, and sketched several directions for future work.

Household Indicators pose significant challenges in selecting indicators, presenting information to laypeople, and appropriating existing models for a new context of use. Yet, Household Indicators have the potential to better engage citizens in the planning process and to enhance comprehensibility and transparency of UrbanSim results. Designers of other simulations intended to inform democratic decision-making—for example, projecting the impacts of new tax laws—should consider developing interfaces that help stakeholders to consider personal impacts.

More generally, Household Indicators serve as an example of designing an interface that facilitates the transition of strongly affected stakeholders from indirect to direct. When a strongly affected group does not have direct access to the information system, it makes sense to consider whether the values at hand could be better supported by broadening access.

Finally, the development of Household Indicators has thrown into sharp relief the gap between abstractions used in UrbanSim and the ordinary conceptions used by citizens who are not urban planning experts (e.g., between "residential units" and single-family houses, condos, apartments, and other types of housing). In order to address questions such as, "Where can I afford to live in the region?" model abstractions must be brought into greater alignment with such concepts.

In future work, a summative evaluation of the Household Indicators concept should address the goals of engaging citizens in urban planning by presenting personalized information that is comprehensible and relevant to understanding the personal impacts of urban planning decisions. Such an evaluation should ask, "Do Household Indicators contribute (beyond the existing regional indicators) to comprehensibility of UrbanSim results, to providing information relevant to decision making, and to supporting democratic engagement?"

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