Engineering-Based Methods for Affordable Housing and Sustainable Community Development

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Overview and Acknowledgments

- Goals:
  - Demonstrate the value decision modeling adds to important problems in urban affairs
  - Draw links between supply chain analysis and human services provision
- I'd Like to thank…
  - National Science Foundation Faculty Early Career Development (CAREER) Program SES-0134890
  - Vincent Chiou, Changmi Jung, Jeannie Kim, Jiyoung Kim, Terence Cordero, Meredith Fisher, Julius Snell, Philip Akol

Overview

- Policy and research motivation
- Engineering-based methods: housing construction
- Urban and regional planning: affordable housing and community development
- Decision science methods: policy design and decision support
- Discussion and research extensions
- Conclusion

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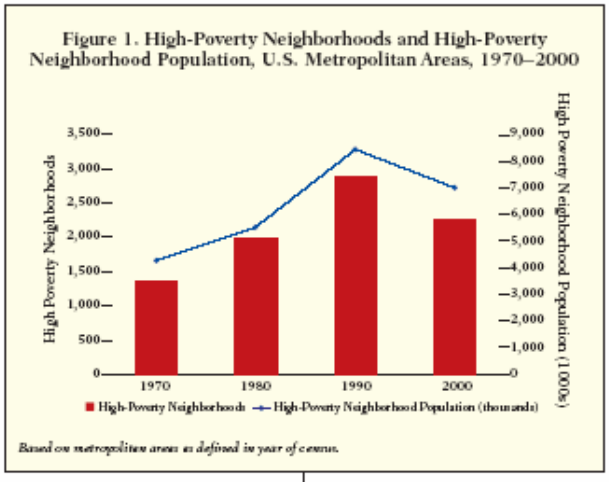
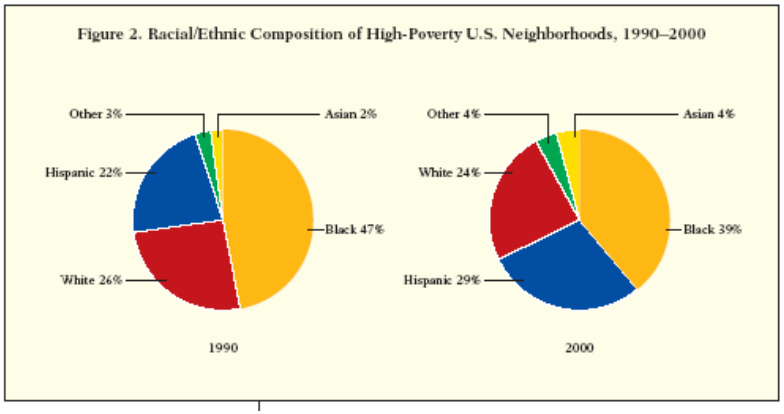
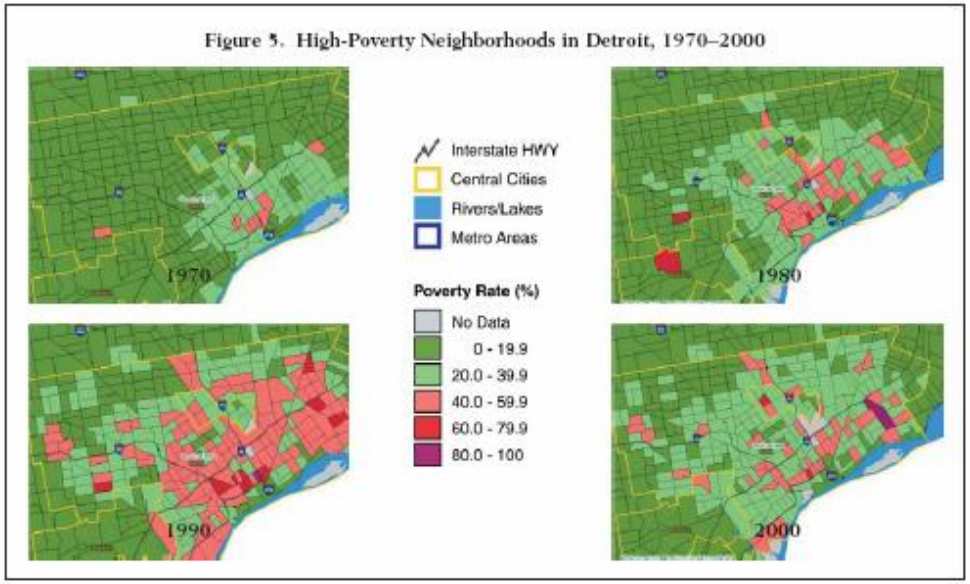
Housing and Community Development is an Important Public Policy Issue

- Real estate is one of the largest sectors of the U.S. economy (23% of U.S. GDP) and a primary source of individual wealth ($700 billion in equity)
- Many benefits of homeownership and rental housing in stable, opportunity-rich communities
- However, current housing trends are unfavorable:
  - Homeownership gap between whites and minorities
  - Downward trends in owner-occupied and rental markets
  - Affordable and “workforce housing” in short supply
  - Urban sprawl
- Multiple causes:
  - Racial and ethnic residential segregation
  - Housing discrimination
  - Restrictive local policies

Concentrated Urban Poverty, While Declining, Remains a Barrier to Opportunity







- Decreases in poverty been relatively minor
- Likely spatial redistribution of poverty

(Jargowsky 2003)

Dimensions of Housing and Community Development

- Stakeholders
  - Employers
  - Housing developers
  - Citizens
  - Government agencies
- Policy objectives
  - Minimize social costs
  - Maximize deconcentration and reduction of poverty
- Actions
  - Create new housing alternatives
  - Protect current alternatives
  - Change attitudes and preferences
- Place-based strategies
  - Housing development
  - Economic development
  - Public safety
  - Policy advocacy
- Person-based strategies
  - Mobility
  - Human services
  - Legal

Affordability and Sustainability are Central to Housing and Community Development

- Affordable housing enables families to devote income to meet many non-housing needs:
  - Education
  - Child care
  - Employment
  - Recreation
- Sustainable communities ensure the long-term health of regions:
  - Minimize adverse environmental impacts
  - Maximize access to social resources
  - Enable all sectors to pay full prices for, and enjoy full benefits of, development decisions

What Do These Terms Mean?

- Affordable housing:
  - Shelter whose expenses do not exceed 30 – 50% of a family's budget
  - Policy emphasis on lower-income families (80% AMI and below)
  - Can be owner- *and* renter-occupied; includes government-subsidized housing ("public housing", "Section 8") as special cases
- Community development:
  - Combination of investments in homes, businesses, infrastructure and human services that addresses:
    - Reduction of poverty
    - Increased access to social and economic opportunity
    - Improved quality of built environment
  - Multiple lenses (geography, race, class)
  - Multiple names ("revitalization", "growth management")

Challenges and Opportunities in Policy Design and Implementation

- People may support the notion of affordable housing and sustainable community development, but…
  - People do not see affordable housing as a high priority
  - Preference for traditional detached single-family homes
  - Regarded mostly as a local problem
- Evidence on policy impacts is encouraging
  - Promising outcomes for housing mobility programs
  - Housing revitalization programs improve quality of assisted housing stock
  - “Smart growth” emphasizes compact development and affordability for all
- Federal leadership is limited
  - Post-Katrina planning?
  - Flat or declining funding on existing programs
  - Emphasis on reducing regulatory barriers to housing production

What is the Role of Decision Models?

- Civil, industrial, environmental and mechanical engineering generate improved methods for implementing housing initiatives:
  - Housing construction
  - Physical infrastructure
  - Transportation management
- Urban and regional planning develop guidelines for physical development given current technologies:
  - Supply and demand for buildings and services
  - Management of development process
  - Consensus among stakeholders
- Decision sciences link engineering and planning:
  - Generate actionable strategies that optimize multiple objectives
  - Take as given best practices in engineering and/or planning
  - Generalize the notion of “facility location” and “service provision”

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Engineering-Based Methods: Framework for Sustainability

- Focus on environmental impacts:
  - Impact on greenhouse gas emissions
  - Quality of air, water, and soil
  - Noise, stench
  - Impact on stock of nonrenewable materials
- Flows determine the environmental impact of system:
  - Energy, Material, Water flows
- Impacts on behavior:
  - “Rebound” effect
  - Eco-unfriendly development in reaction to contradictory incentives
- Recommendations:
  - Better coordination between sectors
  - International approach

(Priemus 2005)

Engineering-Based Methods: Energy Consumption

- Increased use of energy-conserving materials and systems (Steven Winter Associates, Inc. 2001):
  - Windows, insulation and appliances
  - Alternative energy sources
  - Improved construction methods
  - More efficient heating and air conditioning systems
  - 26% – 46% energy savings over Model Energy Code
- Improved building designs (Balcomb, Hancock and Barker 1999)
  - Computer simulation methods compare actual and projected savings
  - Architectural choices: site selection, building orientation, compact floor plans
  - 75% reduction in energy usage over model house and MEC

Engineering-Based Methods: Construction Processes

- Concurrent engineering improves use of customer requirements for industrialized housing (Armacost *et al*. 1994)
  - Housing is increasingly “assembled” from pre-made components
  - Quality Function Deployment matches customer needs to supplier resources
  - Analytic Hierarchy Process is used to develop customer priorities
- Knowledge management increases coordination between owners, designers and developers (Ibrahim and Nissen 2003)
  - Key phases: Feasibility, Entitlements, Building Permit, Construction, Property Management
  - Expertise in documents and memory hard to collect, analyze
  - Implement Knowledge Group Set using agent-based simulation

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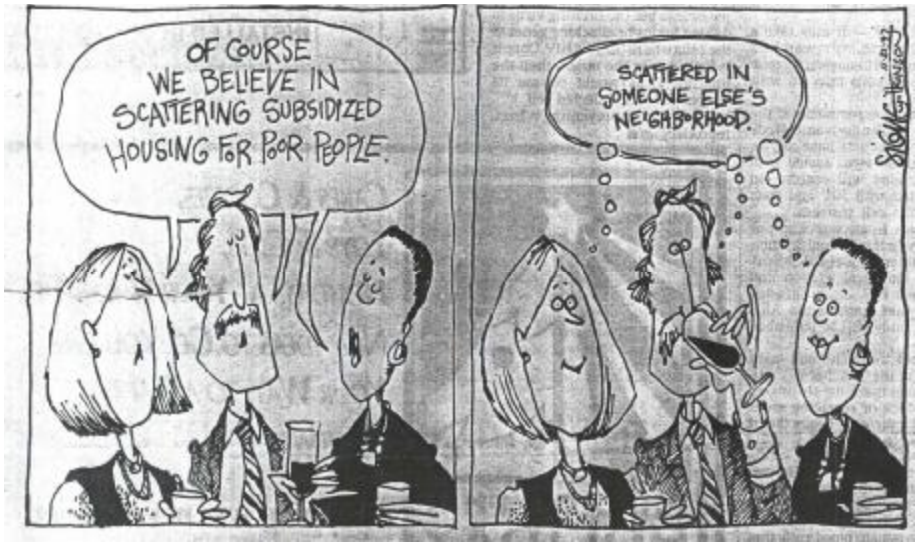
Planning Methods: Housing Policy

- Direct government subsidies:
  - Project-based subsidies
    - Public housing
    - Developer-focused assistance programs
    - Special-needs housing
  - Tenant-based subsidies
    - Rental subsidies
    - Homeowner assistance programs
- Indirect government subsidies:
  - Tax credits
  - Community development block grants
  - Housing trust funds
- Policy tools:
  - Planning and zoning tools
  - Innovative design

(The Washington Area Housing Partnership 2005)

Planning Methods: Regional Opportunity Structure

- Segregation plays a fundamental role in U.S. metropolitan areas
  - By race/ethnicity
  - By class
  - By housing type
- Opportunity arises through multiple life choices
  - Housing
  - Education
  - Employment
- Improving access to opportunity is difficult and controversial…



(de Souza Briggs 2005)

Planning Methods: Current Trends

- Evolution of Assisted Housing Policy (von Hoffman 1996, Quercia and Galster 1997)
  - Movement from centrally-planned public housing communities to partnerships and individual choice
  - Multiple conflicting objectives: integration, fiscal stability, opportunity, subsidies
- Smart Growth (Pendall et al. 2005)
  - Traditional suburban development: large lots, new infrastructure, auto-based travel result in urban sprawl
  - Growth management: more local planning, limits on local impacts
  - Smart growth: address growth throughout the metropolitan area, urban design, and existing neighborhoods and resources
- Spatial decision support (Ayeni 1997)
  - Represent urban infrastructure using GIS, databases
  - Incorporate analytical models to study, understand, predict and plan urban development
  - Document planning and development processes

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Decision Science Methods for Affordable Housing Policy and Planning

- Decision science models address:
  - Space
  - Opportunity
  - Design
  - Choice
- Decision science models provide a range of guidance:
  - Trade-offs between stylized policy alternatives (*strategic*)
  - Multi-objective analysis of specific strategies (*tactical*)
  - Guidance regarding short-term processes (*operational*)
- Challenges to use of decision models:
  - Application-area theory may be weak or underdeveloped
  - Multi-stakeholder, multi-objective, data-intensive applications hard to implement in practice

Strategic Models

- Long-term policy design problem: estimate impacts of stylized initiatives
- Examples:
  - Public housing redevelopment policy (Gleeson 1992)
    - Application of reliability model to compare benefits and costs of renovating public housing units to constructing new units
  - Dynamic models for housing mobility (Caulkins et al. 2005)
    - One-state optimal control model generates multiple trajectories of populations over time
  - Policy simulation models (Johnson and Caulkins 2006)
    - More realistic dynamic model without optimization allows steady-state analysis and transient analysis

Optimal Control Model: Components

- State variable $X(t)$:
  - Population of "middle-class" community at time t
- Control variable $u(t)$:
  - Flow per unit time of "low-income" families into middle-class community from housing mobility program
- Middle-class neighborhood population dynamics:
  - $\frac{dX}{dt} = a \cdot X(t) \cdot (1 - X(t))$
- Flight of middle-class families: $\beta \cdot u$
- Assimilation of low-income families: $\gamma \cdot X \cdot u$
- Benefit to low-income families: \$1 per participant
- Benefit to middle-class families: $\rho \cdot X$
- Societal costs: $c \cdot u^2$
- Discount rate: r

Optimal Control Model: Formulation

Choose values for control variable $u(t)$ to maximize

$$\int_0^{\infty} e^{-rt}\left(u(t) - cu(t)^2 + rX(t)\right)dt$$

Subject to system dynamics

$$\dot{X} = a \cdot X(t) \cdot \left(1 - X(t)\right) - b \cdot u(t) + g \cdot X(t) \cdot u(t)$$

and initial conditions

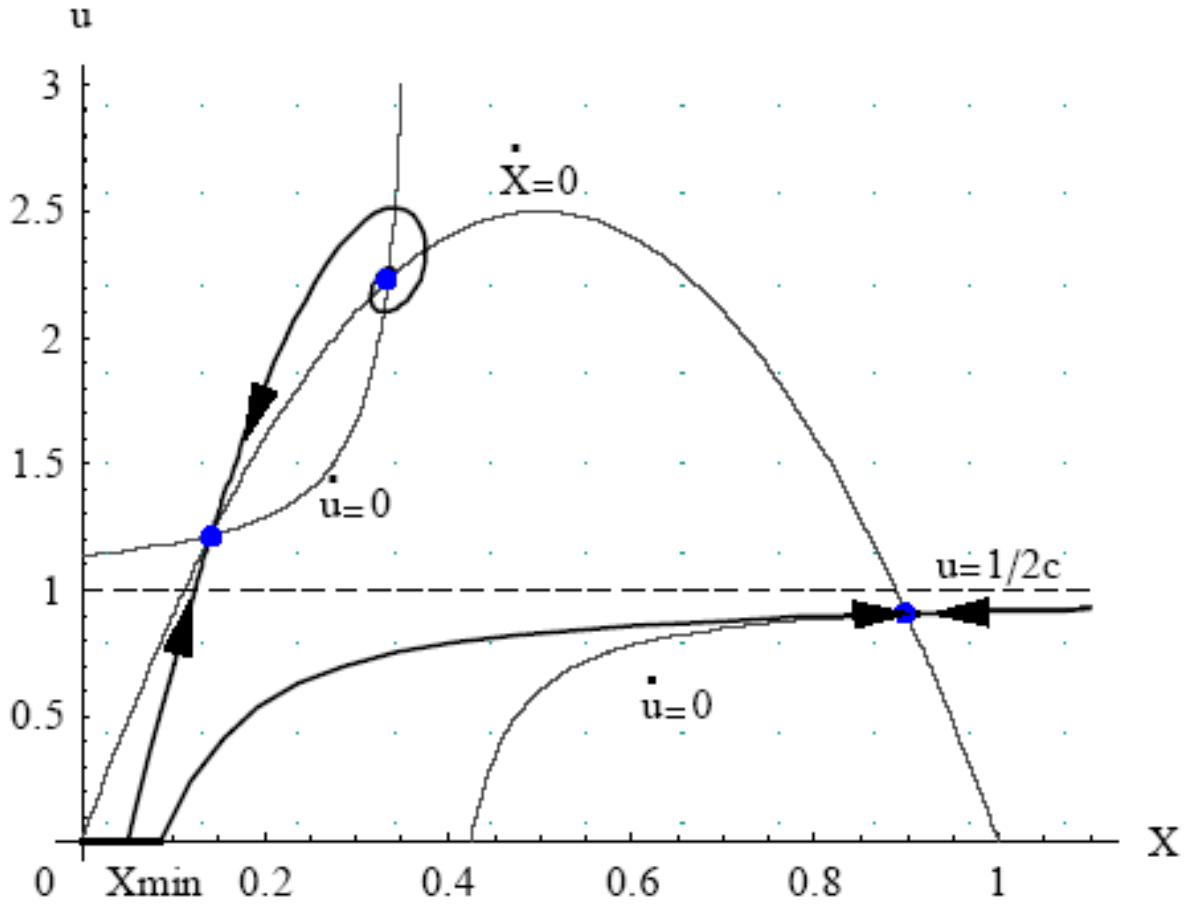
$$X(0) = X_{\text{start}}$$

Goals:

- Identify equilibrium points (X,u) associated with steady state
- Characterize state trajectories

Optimal Control Model: No Assimilation Solution

- $\alpha = 4$
- $\beta = 0.4$
- $r = 1$
- $\rho = 1$
- $c = 0.5$



Outcomes: Two stable equilibria
(high-u/low-X, low-u/high X); one unstable equilibrium

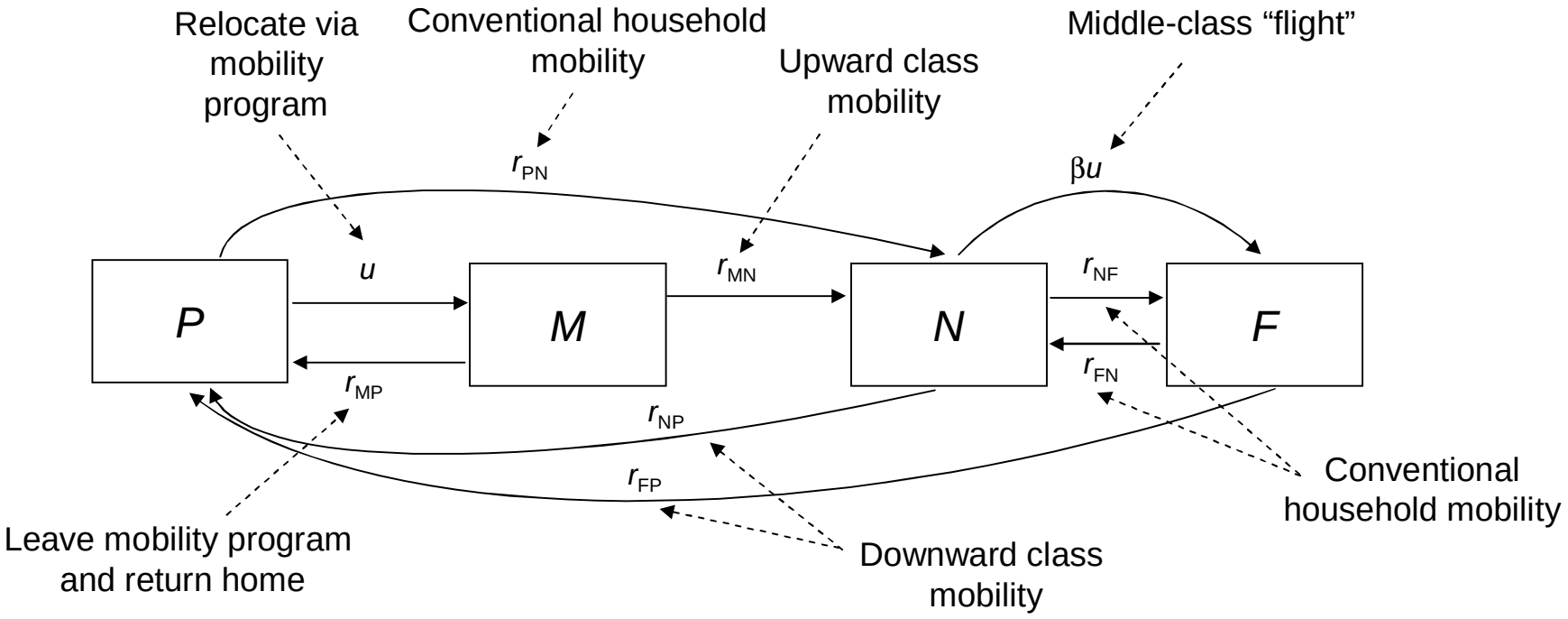
Policy Simulation Model: State Transitions

P: Residents of high-poverty inner central city neighborhood

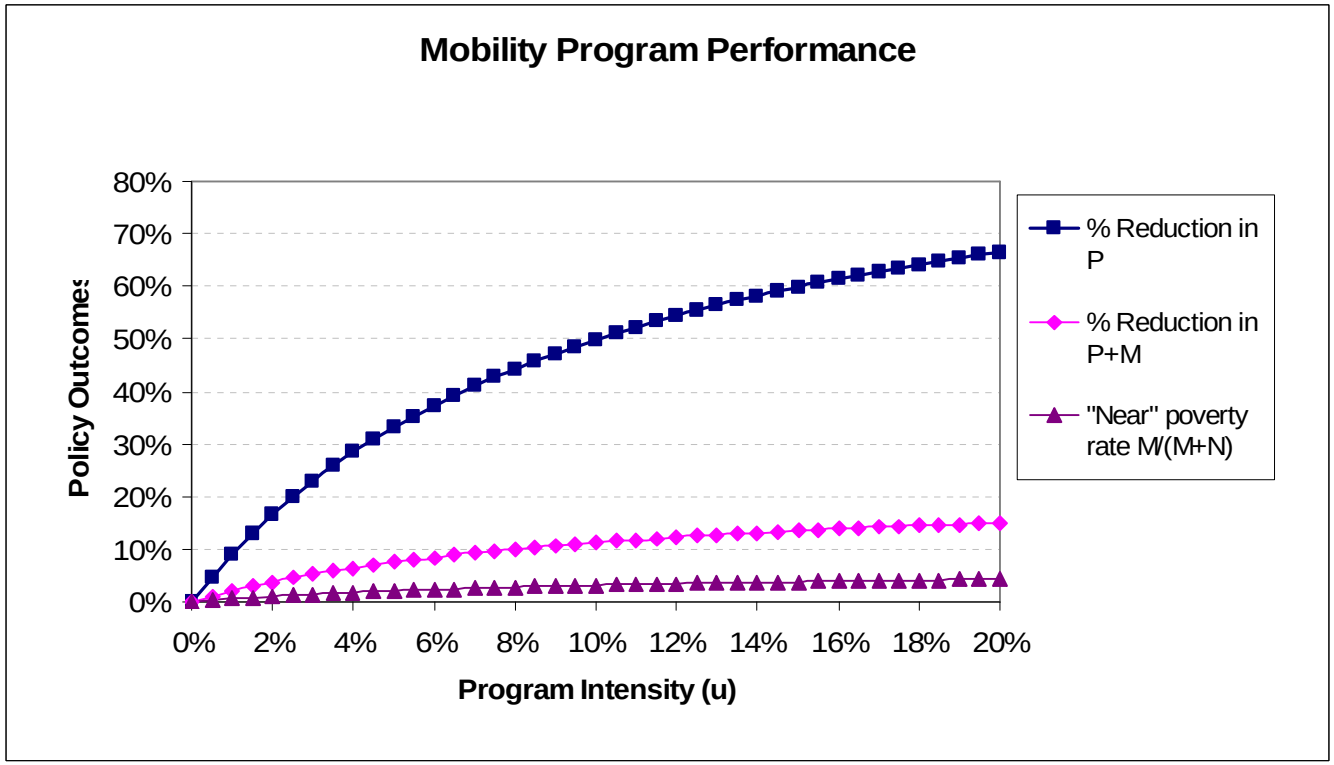
M: Poor residents in housing mobility program who have relocated to "near" middle-class neighborhood

N: Middle class residents of "near" neighborhood

F: Middle-class residents of "far" neighborhood



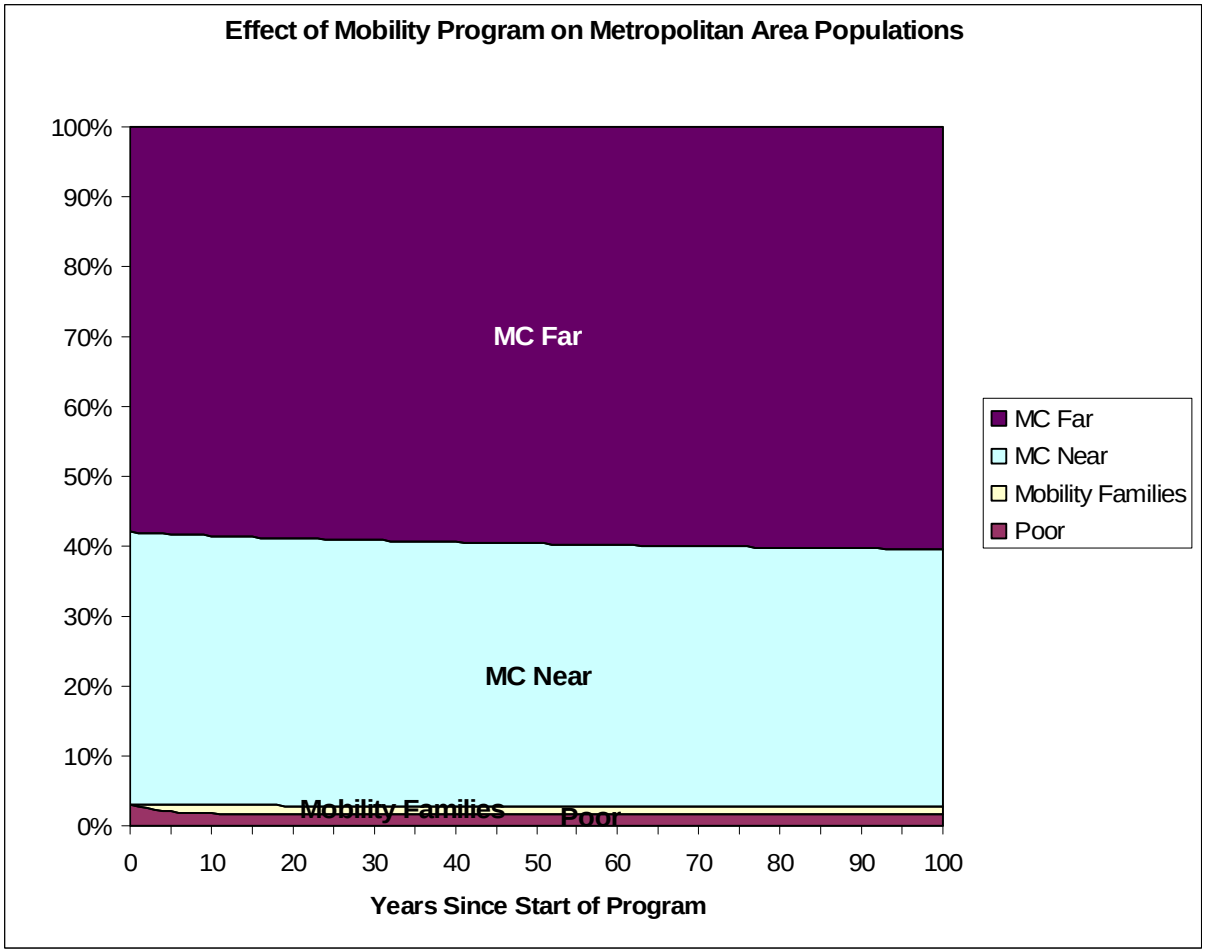
Steady-State Results



- Substantial decrease in concentrated urban poverty
- Moderate decrease in total poverty
- Moderate increase in poverty rate in destination communities
- “Flight” per mobility participant high, independent of program scale and indicative of significant sprawl-related social costs

Transient Analysis

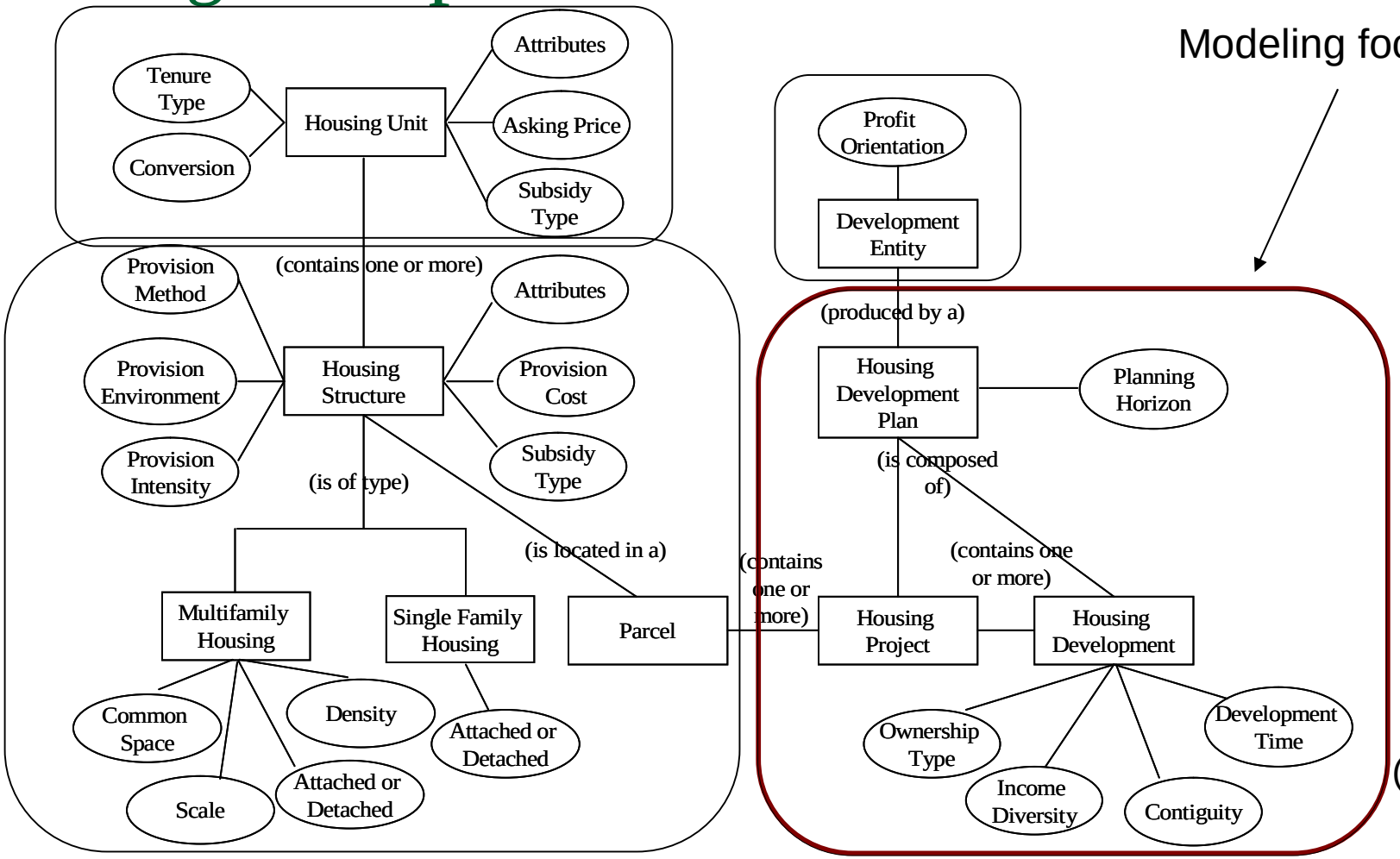
- Use discrete-time approximation to system dynamics
- Program intensity $u = 10\%$
- Convergence in < 20 years



Tactical Models

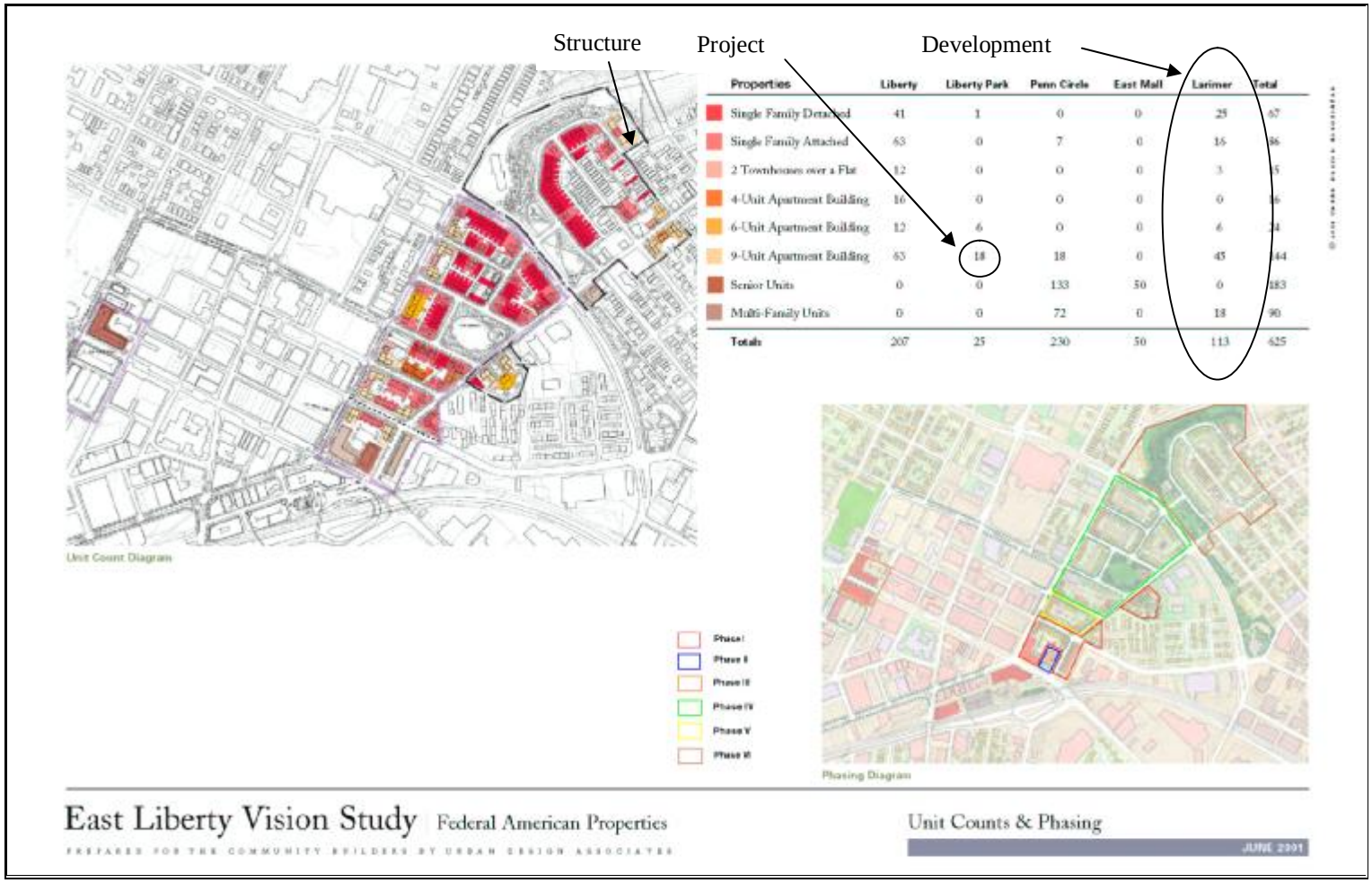
- Medium-term policy design problem: design development programs for specific study areas
- Examples:
  - Land development (Gabriel *et al*. 2006)
    - Choose parcels for development to jointly optimize objectives of government planner, environmentalist, conservationist, land developer
    - Consider land attributes relevant to “smart growth”: zoning classifications, contiguity, compactness
  - Armed forces housing (Forgionne and Frager 1988)
    - Forecast demand for Army on-base and off-base housing, and allocate resources to secure housing
  - Affordable/subsidized housing location (Johnson 2000, 2001, 2003, 2006
    - Allocate participants in mobility program across neighborhoods
    - Locate housing developments of different sizes and types across neighborhoods
    - Spatial decision support for mobility program policy design

Affordable Housing Can be Classified along Multiple Dimensions



(Johnson 2006)

Urban Affordable Housing Development Planning is Complex and Time-Consuming



(Johnson 2006)

Affordable Housing Location Model with Scale Effects

- Objectives:
  - Maximize net social impacts
  - Minimize distributional inequity
- Decision variables:
  - Siting (x_{ij})
  - Size (z_{ij})

  addressing "small", "medium" and "large" projects
- Parameters:
  - Social benefit with scale effects (b_{ij})
  - Fixed provision costs with scale effects (f_{ij})
  - Breakpoints for piecewise-linear approximations (l_j)

$$\text{Maximize} \sum_i \sum_j b_{ij} z_{ij} - \sum_i \sum_j f_{ij} x_{ij}$$

$$\text{Minimize Max}_{\substack{i \in I, \\ E_i > 0}} \left\{ \frac{\sum_{j=1}^{m} z_{ij}}{P} \Big/ \frac{E_i}{\sum_{i=1}^{n} E_i} \right\}$$

Subject to:

$$0 \le z_{ij} \le l_j - l_{j-1} \qquad \forall i, j$$

$$z_{ij} \le M \cdot x_{ij} \qquad \forall i, j$$

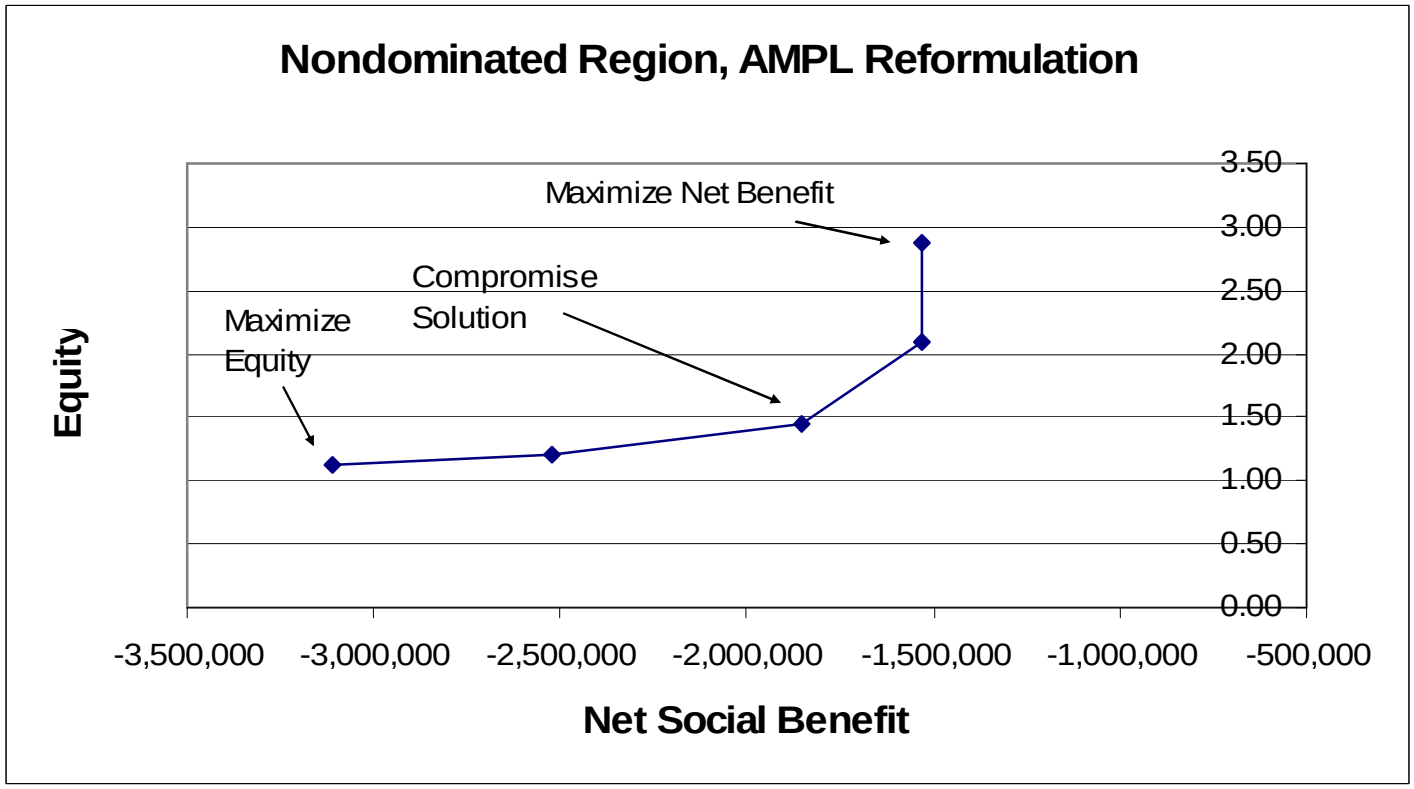
$$\sum_{j=1}^{m} z_{ij} \le E_i \qquad \forall i$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} \le P$$

$$x_{ij} \text{ binary} \qquad \forall i, j$$

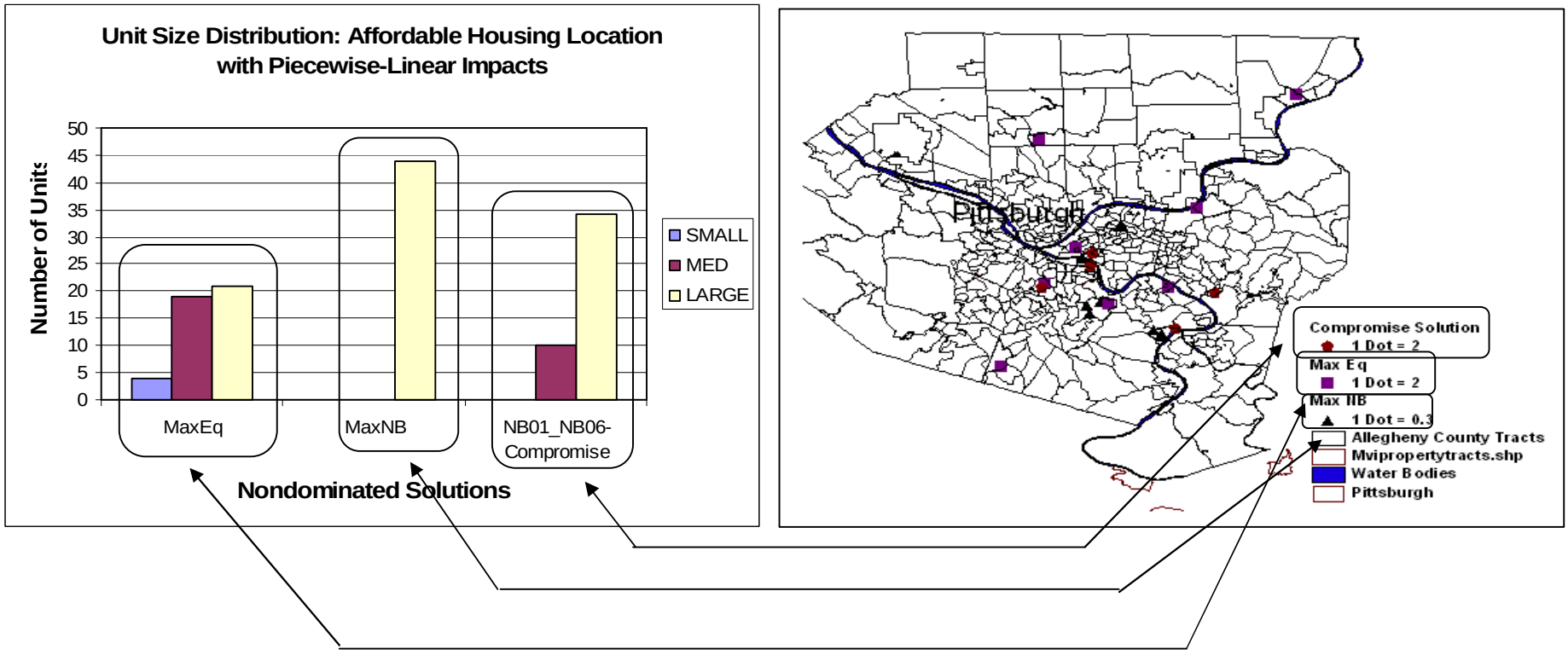
$$z_{ij} \text{ integral, non-negative} \qquad \forall i, j$$

Objective-Space Results, Minimax Equity Objective, Owner-Occupied Housing



- Negative net benefits result from limited data on program outcomes

Minimax Equity Objective Function Tradeoffs Influence Size and Spatial Distribution of Housing



Operational Problems

- Short-term policy design problem: provide direct services in specific study areas most efficiently
- Approaches:
  - Managing housing authority waiting lists (Kaplan and Berman 1988)
    - Application of queueing theory to give priorities for certain families currently in public housing to move to newly-rehabilitated public housing
  - Decision support for housing choice (Johnson 2005)
    - Spatial decision support system to enable housing voucher clients to improve quality of neighborhood and housing unit choices

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Discussion: Insights and Challenges

- What do decision models tell us about theory and practice in housing and community development?
  - Housing mobility programs are more likely to deconcentrate poverty than to alleviate poverty, with potentially significant social and environmental costs
  - Affordable housing location models are more likely to provide strategy directions than specific policy prescriptions
  - Mobility support systems require significant investments and expertise to improve quality of client choice
- What challenges must be met in putting decision models to work in real life?
  - Practitioners must move beyond “making the numbers work” to evaluating potential impacts and assessing tradeoffs
  - More favorable policy environment at all levels is essential to leveraging benefits of decision support models

Decision Modeling Extensions

- How can decision models address design and construction for buildings and communities jointly?
  - Architecture, urban and regional planning, OR
- How should urban neighborhoods be redeveloped in the wake of natural disasters?
  - Environmental management, urban and regional planning, OR
- How can affordable housing providers decide which parcels to acquire, and what development to pursue?
  - Housing policy, geography, OR
- What are the social benefits of decision models for housing and community development over the status quo?
  - Housing policy, OR

Decision Modeling Extensions, cont'd

- How can social networking and Internet technologies enable people to make and support choices that improve access to affordable housing and sustainable communities?
  - Human-computer interaction, spatial decision support systems
- How can simulations of housing mobility programs with intelligent actors clarify roles of individual choice, structural impediments to fair housing, public policy and social networks?
  - Agent-based simulation, social networks, housing policy

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Conclusion

- Housing and community development are central to the economic and social health of the country, but not commonly viewed as amenable to prescriptive methods
- Decision sciences contribute to design of housing and community development policies that extend current methods of provision-oriented engineering and urban/regional planning
- Housing policy must optimize social criteria, address technology aspects of housing provision and use best practices in planning to achieve affordability and sustainability
- Current research draws upon multiple technologies, academic disciplines and spatial/temporal scales to provide guidance to practitioners and policymakers

Questions?

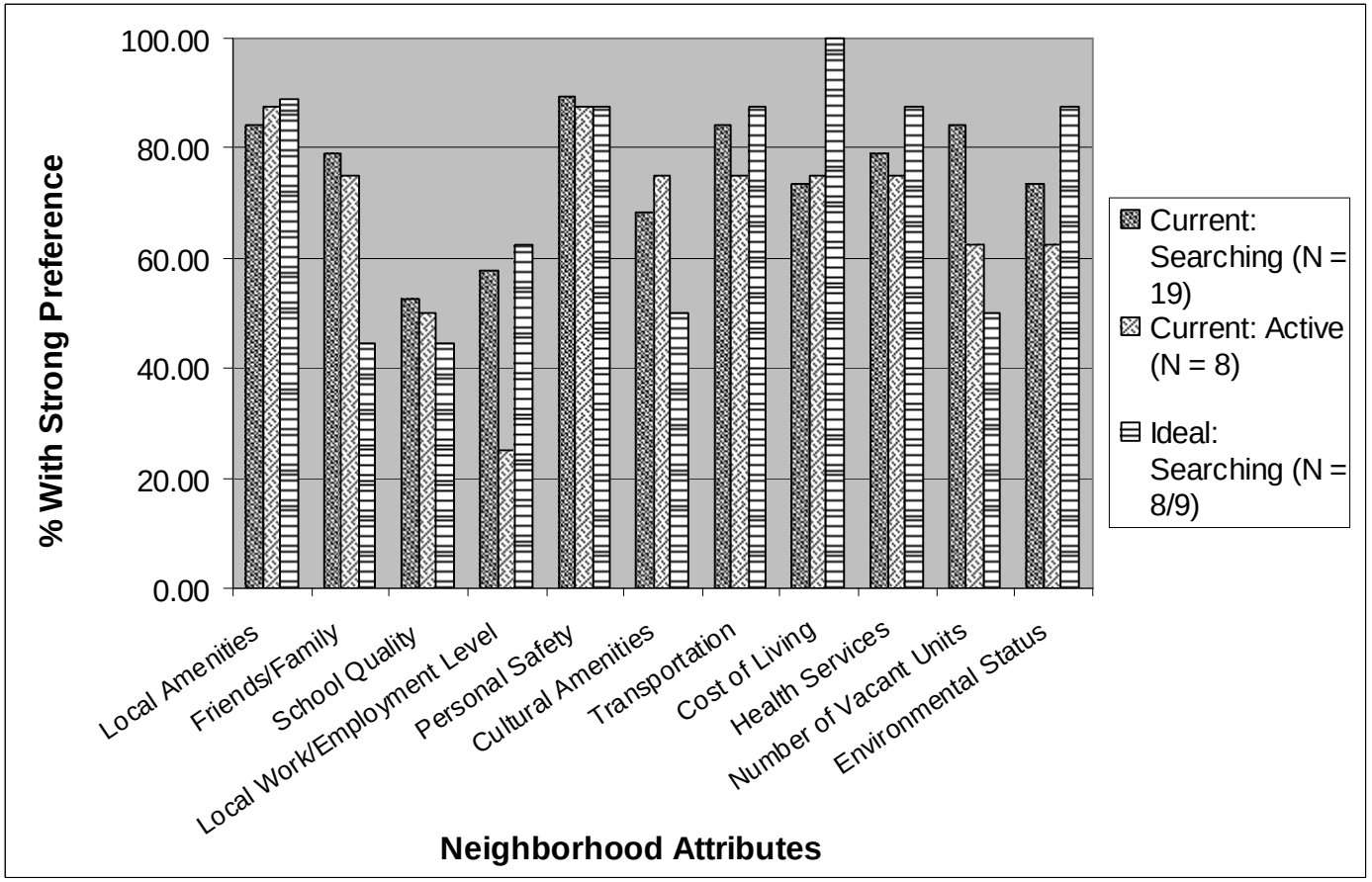
Thank you very much!

Links to my publications and working papers are available at http://www.andrew.cmu.edu/user/johnson2/index.htm

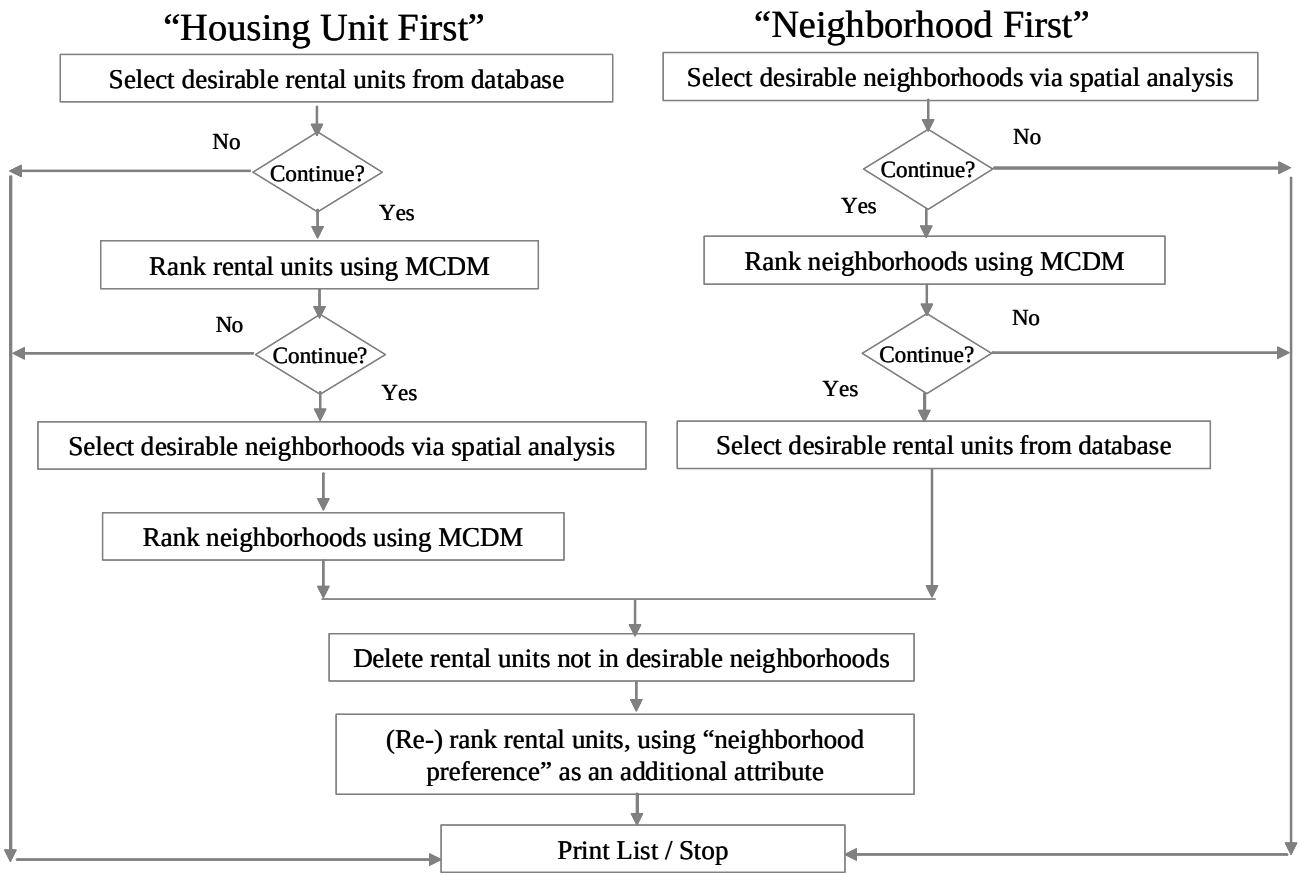
What is the Link to Supply Chain Management?

- Supply chain: network of facilities and transportation modes to transform inputs into finished goods and services
- Human services value chain: network of facilities, programs and services to improve individual life outcomes and neighborhood quality across a region
- Common tasks:
  - Measure, match supply and demand for goods and services
  - Facility location

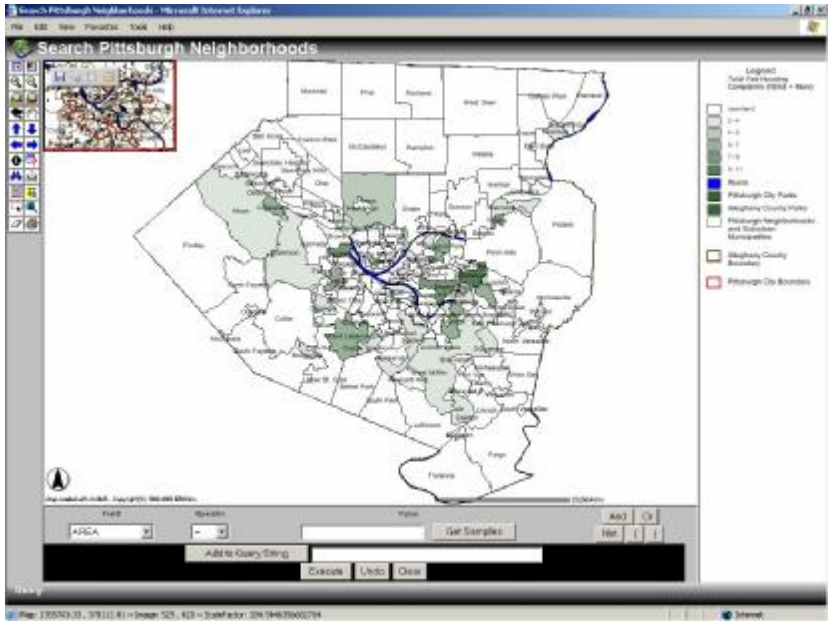
eCounselor: Client Preferences for Neighborhood Attributes

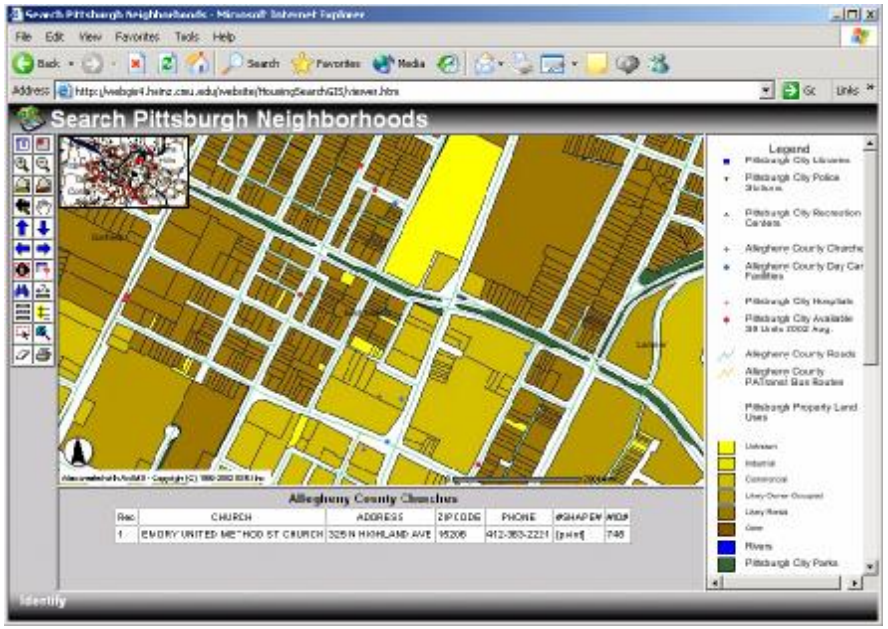


eCounselor: A Model of Housing Client Destination Choice



eCounselor: Client Component—Search Neighborhoods





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