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Community-Based Operations Research

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Abstract *Community-based operations research* is defined as the collection of analytical methods applied to problem domains in which interests of underrepresented, underserved, or vulnerable populations in localized jurisdictions, formal or informal, receive special emphasis, and for which solutions to problems of core concern for daily living must be identified and implemented so as to jointly optimize economic efficiency, social equity, and administrative burdens. As such, it represents a specific domain within public-sector OR. Community-based operations research (OR) problems tend to be "messy" and highly dependent on political and social considerations. Nevertheless, solution of these problems is essential to the continued health and well-being of individuals, families, communities, and entire regions. This tutorial emphasizes current research in a variety of application areas. We identify a tension between problems that reflect unique characteristics of local communities and those that represent more general characteristics that bridge diverse communities. We propose principles for bridging the gap between quantitative model- and method-based approaches typically associated with private-sector problems, and qualitative policy and process-oriented approaches typically associated with public-sector problems. We examine two research applications in detail: food security and affordable housing. In so doing we emphasize the commonality of problem attributes and the diversity of modeling and solution methods.

Keywords public sector; policy modeling; urban affairs; multiple-objective optimization; equity; non-profit operations research

1. What is Community-Based OR?

1.1. Introduction

Many public-sector problems in the United States of interest to researchers and practitioners have origins and solutions with a strong local or community flavor and reflect concern with individual life outcomes. Such problems include poverty, food security, urban education, criminal justice, and human services. Indicators of the severity of these problems are numerous. The U.S. poverty rate, about 12.6% in 2005, has not decreased significantly over the past three years despite growth in multiple economic indicators. Moreover, the poverty rate for African Americans and Hispanics remains about three times that of non-Hispanic whites (U.S. Census Bureau [86]). Performance of public and private elementary and secondary school students on a national measure of academic achievement has shown only modest improvements between 1999 and 2004, with non-Hispanic white students two to three times more likely to score at the highest levels (National Center for Educational Statistics [71]). Unemployment rates for African American males without college education have increased dramatically over the past 15 years, with rates two to three times that of whites; incarceration rates for African Americans in their late 20s are about six times that of whites

(Western [95], Bureau of Justice Statistics [17]). The number of U.S. households with at least moderate housing burdens (at least 30% of income) rose from 31 to 34 million between 2001 and 2004, whereas average commute times increased at greater rates for lower-income families than for higher-income families (Joint Center for Housing Studies [47]).

Research on social issues such as those described above has traditionally been descriptive in nature, and concentrated within the social sciences, urban planning, and related disciplines; they have tended to receive somewhat less attention from disciplines such as operations research/management science (OR/MS) whose models and methods tend to be more prescriptive. We assert that an adaptation of previously identified domains of OR/MS, which we denote as *community-based operations research*, is well positioned to provide models and analytic methods that can provide guidance to individuals, government, and nongovernmental organizations that seek to address these problems. In this tutorial, we describe the characteristics of problems that fall within the scope of community-based OR, develop a taxonomy of problem areas, provide a review of related OR/MS research literature, and explore two case studies of community-based OR applications. Finally, we identify some next steps for research and practice in this area.

The scope of this tutorial is largely limited to the U.S., as American political and social values, and demographic and economic characteristics may differ from other developed countries in certain ways relevant to community-based OR. We focus on the last 30 or so years of research and applications, the scope of time within which "public-sector operations research" has become a well-defined domain. We define OR/MS broadly to include prescriptive decision models as well as descriptive models that are directly applicable to decision modeling. Evidence to support the presence of community-based OR comes primarily from refereed journal articles, published books, and conference proceedings, although working papers are cited if they provide primary evidence of recent research activity in a given domain.

1.2. Defining Community-Based OR

Fundamentally, community-based OR addresses public-sector problems, that is, problems in which the primary outcome measure to be optimized is not a direct representation—or proxy for—shareholder benefit and in which the outputs are subject to public scrutiny (see, e.g., Pollock and Maltz [75], p. 6). Community-based OR is a subfield of public-sector OR (see e.g., Pollock et al. [76], Larson and Odoni [60]), which emphasizes most strongly the needs and concerns of disadvantaged human stakeholders in well-defined neighborhoods. Within these neighborhoods, localized characteristics vary over space and exert a strong influence over relevant analytic models and policy or operational prescriptions. There are three important implications of this definition that distinguish community-based OR from other areas of public-sector OR.

First, our focus on human stakeholders implies a fundamental interest in human versus physical resources, as might be represented by decision models for natural resources management, energy policy, and—to a lesser extent—infrastructure design. Second, our focus on disadvantaged, underserved, or vulnerable populations recognizes that these groups may have distinct social or political preferences, are less able to use political influence to adapt public policies to their own needs, and may suffer stigma that may impede access to resources, expertise and tools associated with state-of-the art decision models or policy interventions. Third, our focus on "place" implies that models should account for community-level characteristics, like socio-economic status, that are salient to decision models and which vary over space in systematic ways. For example, suppose a public-library-branch location model does not distinguish between demands originating from neighborhoods that differ according to socio-economic status. Then a poor and nonpoor neighborhood with equal levels of demand may be treated equally by the model, even if relative travel costs are higher and marginal benefits from access to recreational and educational resources greater for residents of poor neighborhoods as compared to nonpoor neighborhoods.

Community-based OR has its roots in a classic article by Ackoff [2] describing community-engaged problem solving in a distressed, mostly African American community in Philadelphia. This amalgam of analysis, action, and advocacy received the greatest attention in the United Kingdom during the 1980s and 1990s as *community operational research* (Jackson [37], Parry and Mingers [73], Taket and White [83]), although some attention has been given to this sort of OR practice and theory in the U.S. (e.g., Bajgier et al. [5]). An important goal of this tutorial is to respond to Parry and Mingers' statement that "very little has been published on Community OR, and as a result it is unclear how much as been achieved" ([73], p. 580). These authors demonstrated that much of the work in community OR appeared to consist of student projects and community outreach that might be classified now as "capacity-building," rather than applications based on analytic models intended to provide specific policy and operational guidance to decision makers in a way that extends existing theory and methods. Most of the applications of community-based OR described in this tutorial have occurred since Parry and Mingers' [73] article, and address the methodological concerns noted above.

Certain public-sector problems are not amenable to community-based OR. As mentioned previously, many social problems, such as criminal offending, low-quality housing, or inadequate access to retail food outlets exhibit symptoms that vary across neighborhoods. These problems may also have important regional or national characteristics that are aggregates of individual outcomes, for example high incarceration rates, residential segregation, or adverse health outcomes related to food insecurity. In turn, these high-level characteristics may be associated with regional or national-level policy failures, such as ineffective national drug enforcement policy, inadequate funding for affordable housing, or insufficient incentives for grocery stores to locate in underserved communities. An important area of public-sector OR, referred to by Kaplan [52] as *policy modeling*, uses stylized models inspired by problems of a local nature that may generate important insights regarding regional or national-level policy design. Policy modeling has yielded novel and influential insights in drug policy (see e.g., Rydell et al. [79]), crime policy (see e.g., Blumstein et al. [12]), and public health (see e.g., Kaplan and Merson [55]). Community-based OR, although quite distinct from policy modeling, can complement policy modeling by generating solutions associated with direct and rapid improvements in individual and neighborhood-level outcomes.

We may summarize the defining characteristics of community-based OR problems as follows. They tend to have *multiple stakeholders and multiple decision makers* (Gass [26], Bardach [8]). We enumerate typical stakeholder and/or decision-maker groups as follows. Donors are government, nonprofit, or for-profit organizations whose direct or in-kind contributions support service provision. Clients are individuals, families, or organizations who benefit directly from service provision. Nonclient residents are individuals, families, or organizations who benefit indirectly or not at all from service provision but who may nevertheless pay for it through taxes. Service providers are government or non-profit organizations who design, implement, and manage service provision strategies. Local government enforces laws, administrative rules, and codes that define the legality of various initiatives. As we have emphasized, key stakeholders and decision makers are *localized* and often economically or socially *disadvantaged*. Therefore, trade-offs between efficiency, effectiveness, and equity are essential. In contrast to other private- and public-sector OR models, limiting focus to a single decision maker, stakeholder, or objective function type may obscure important aspects of the problem at hand.

As for United Kingdom-style community OR, successful community-based OR models and applications require substantial *stakeholder participation* in problem definition, solution, and implementation (Bajgier et al. [5], Taket and White [83]). This is incompatible with the conventional "consultant" view of OR modeling in which a dispassionate expert becomes immersed in a problem domain, formulates and solves an appropriate analytical model, and presents a range of recommendations to decision makers.

Accountability, a traditional focus of public administration generally (Heinrich [35]; see also Gates [27]) is especially important for community-based OR for determining the social impact of model solutions. Many important community-based services, targeted as they are on disadvantaged populations, generate relatively low levels of user fees and rely disproportionately on support from nongovernmental organizations. In turn, these donors may want service providers to demonstrate that they have achieved significant client and system outcomes—but these are difficult to measure and communicate, as compared to process outputs. The implications of this criterion are twofold: There is an increased need for researchers to design effectiveness measures that can be easily implemented in community OR models, and there is an increased need for practitioners to work closely with funders to justify the support received.

Finally, there is a general tension between *uniqueness* and *generalizeability* that affects how community-based OR models and applications are viewed by disciplines that might take an interest in them. The greater the programmatic and spatial specificity of a given application and the focus given to community engagement, the greater is the resemblance of community-based OR to domains at the intersection of community planning, community organizing, and social work. As Kaplan [52] observes, this view of community-based OR may have led Ackoff [3] to become disenchanted with the prospects of "traditional" OR as a vehicle for making significant changes in society. The greater the generality of the model and the application, the greater is the resemblance of community-based OR to decision modeling applications whose contribution is primarily technical and methodological, or those, like policy modeling, that take a regional or national focus, decreasing the likelihood of direct, relatively rapid benefits to community stakeholders. Our belief is that, all else equal, the long-term impact of community-based OR is likely to be greatest if emphasis is placed on models that provide specific, theory-based guidance to local decision makers that can be easily replicated in different application contexts.

1.3. Sample Application: Public-School System Design

An example of an application that captures many of the characteristics of community-based OR described above is that of an urban public-school district facing declining enrollment, increasingly rigorous educational quality targets and revenue shortfalls that must simultaneously decide on a set of schools to close and to combine, academic programs to relocate, and students to reassign (see e.g., Mar Molinero [64], and Johnson [41]). Table 1 demonstrates the various dimensions along which community-based OR can help decision makers and stakeholders collaborate to generate specific recommendations for policy and operational guidance.

Results indicate that this problem is rich, in terms of opportunities for community engagement, mathematical modeling complexity, data requirements, and multi-stakeholder decision support. A traditional OR approach to this application might emphasize sophisticated, high-quality solution algorithms for a somewhat stylized representation of the underlying problem, perhaps using simulated data, and a focus on efficiency and possibly effectiveness measures. A community-based OR approach might instead result in a model that captures the local environment more fully, and incorporate equity and effectiveness explicitly, thus implying greater difficulty in optimal solution procedures. However, this approach might also result in heuristic solution algorithms and strategies for model formulation and policy implementation that emphasize qualitative methods more typical of UK-style community OR.

1.4. A Taxonomy of Community-Based OR Applications

There is no concise, standard classification of public-sector service areas known to us (a comprehensive list of service areas is available on the U.S. Blue Pages, http://www.usbluepages.gov). For the purposes of this tutorial, we classify community-based OR application areas

Table 1. Example community-based OR application: Urban public-school closings.

Attribute	Description
Localized focus	A school-closing policy may differentially affect low-performing schools, and disadvantaged neighborhoods, as compared to schools and neighborhoods overall. Therefore, generic modeling constructs may not capture the most challenging aspects of urban public-education policy.
Multiple conflicting objectives	Efficiency: direct dollar savings in fixed and variable costs Effectiveness: changes in student educational performance Equity: changes in average school travel times across neighborhoods; changes in levels of racial, ethnic or class segregation across and within schools.
Multiple stakeholders	Donors: local school district, federal government, local foundations. Clients: families whose children attend public schools. Nonclient residents: households without school-age children, or whose children attend nonpublic schools. Service provider: local board of education.
Role of disadvantage	Racial and ethnic minorities, who tend to be economically disadvantaged and segregated, may constitute a majority of students enrolled in public schools, although not necessarily a majority of the voting population, or cadre of professional analysts, funders, or political leaders.
Accountability	Cost savings are a direct consequence of school closings; improved educational outcomes are not. Educational outcomes may even worsen over the short term as the system re-equilibrates. School-closing decisions could be based, in part, on conventional measures such as standardized test scores—or, alternatively, on more sophisticated measures that identify the "value added" by schools. But specifying the latter might be controversial and expensive.
Lack of resources	Local boards of education may have no analysts with experience in OR/MS models and methods, and few hardware or software resources to solve the challenging models that arise in developing school-closing strategies.
Uniqueness versus generalizeability	Too much focus on local attributes shifts emphasis to politics, community organizing, and educational administration rather than a more generic model that can incorporate issues relevant to many different cities.

Note. Problem description: Johnson [41].

in four broad categories: human services, community development, public health and safety, and nonprofit management. *Human services* consist of services to senior citizens, humanitarian (e.g., post-disaster) logistics, public libraries and literacy, public education, and family supportive services. Family supportive services include e.g., foster care, income-based benefits such as food stamps and public assistance, and need-based benefits such as mental health/mental retardation, drug/alcohol treatment, and homeless services.

Community development consists of housing, community/urban planning, and transportation. In turn, housing can be classified as low- and moderate-income housing, often provided through government subsidies, and affordable, mixed-income, and workforce housing, often provided through zoning ordinances or private initiative as well as direct government support. Community and urban planning can address conventional economic development of distressed or isolated communities as well as pre-disaster planning and post-disaster reconstruction.

Public health and safety addresses health care, criminal justice, emergency services, hazardous/undesirable facility location, and the correlation of chronic diseases and individual deprivation or social externalities, such as food insecurity or proximity to environmental

hazards. Finally, *nonprofit management* addresses general issues in management of community-based or community-oriented service providers. In §2 we will review selected research literature in these broad application areas.

Table 2 displays a variety of community-based OR application areas according to multiple attributes such as geographic/temporal scope, performance/outcome metrics, and modeling/computational complexity. If there are multiple examples of published OR applications in a particular category, we emphasize the application we believe has the strongest community orientation.

Note that community-based OR problems can be operational, tactical, or strategic in nature; that analytical methods from logistics and multicriteria decision-analysis/decision theory tend to dominate, and that there are multiple outcome measures of interest, some of which may require knowledge of economics to quantify (e.g., net social benefit), others of which may require close examination of stakeholder values (e.g., equity).

1.5. What is Community-Based OR's Profile Within the Profession?

We conclude this introductory section by assessing the visibility of community-based OR within the OR/MS community. Community-based OR appears to have a low profile within top-tier disciplinary OR/MS journals. A review of articles published between 2002 and 2007 whose topics appear consistent with our definition of community-based OR yields four papers in *Operations Research* out of 401,[1] or 1%, and no papers in *Management Science*, *Transportation Science*, or *Information Systems Review*.

Community-based OR also appears to have a low profile within academic degree programs that intersect OR/MS. A scan of curricula of top schools, according to the 2007 rankings of *U.S. News and World Report* [90, 91], indicates that within the top 25 undergraduate industrial engineering/operations research programs, none appears to offer courses that address community-based OR; within the top 10 graduate industrial engineering/operations research programs, only one offers one or more courses whose content includes community-based OR. Within the top 25 undergraduate business programs, only one appears to offer one or more courses that address community-based OR; a similar result holds for the top 25 graduate programs in business. Finally, within the top 25 graduate programs in public affairs, only three offer courses with significant OR/MS content, and of these only one school's OR/MS course offerings appear to address community-based OR.

We acknowledge that much important work in OR/MS that intersects community-based OR is done outside of business schools, departments of industrial engineering and remains unpublished, or is published in non-OR/MS flagship journals. For example, pro bono OR consulting and applications, as advocated by Woolsey [97] and McCardle [66], often address problems of interest to public-sector organizations. However, we believe that a greater emphasis on community-based OR in education, research, and practice may increase the professional returns to those who work in this area. We make specific suggestions in this regard in the final section.

2. Literature Review

In the years since the Parry and Mingers (1991) survey of community OR, a number of papers have appeared that address their concerns. In the review that follows, we focus on studies in OR/MS and related fields that address analytic methods, public or nonprofit management, localized needs, equity concerns, or disadvantaged/underserved populations with a bias toward model-based prescriptions.

[1] Three of these papers appeared in a special 50th anniversary edition of *Operations Research* comprised of specially commissioned retrospectives.

Table 2. Community-based OR application areas.

	Attributes							
Application areas	Example application(s)	Entity	Geographic/ temporal scope	Performance/ outcome metrics	Relevant methods	Modeling/ computational complexity	Political/social controversy	Example application
Food security	Distribution of donated food from warehouse to local pantries	Government, NGO*	Regional; strategic/ tactical/ operational	Percentage food outlet needs met; resource utilization	Vehicle routing, inventory theory	High	Low	Lien et al. [61]
Senior services	Design and location of site-based senior services (meals-on-wheels, recreational facilities)	Government, NGO	Regional; strategic/ tactical/ operational	Total cost; percentage of demands met	Location-allocation, vehicle routing	Moderate to high	Moderate	Johnson et al. [46]
Humanitarian logistics	Location of staging areas for post-disaster delivery of supplies; routing and scheduling of supply shipments	Government, NGO	Nation, region; strategic/tactical/ operational	Total cost, lives saved	Location-allocation, vehicle routing, inventory theory	High	Moderate	Campbell et al. [18]
Affordable/ subsidized housing	Location of "project-based" housing; potential allocations of households using "tenant-based" subsidies; decision support for individual household relocation	Government, NGO, public-private partnerships	Region, neighborhood, individual; strategic/tactical/ operational	Net social benefit; percentage of demand met; equity	Location-allocation; cost-benefit analysis; multi-criteria decision models	Moderate	High	Johnson [39]
Public education	Opening/closing/resizing/ reconfiguring buildings and services; demand forecasting; performance evaluation; student transportation	Government	Region; strategic/ tactical/ operational	Net social benefit; percentage of demand met; equity	Location-allocation; forecasting; data envelopment analysis; districting; vehicle routing	High	High	Mar Molinero [64]

continued

TABLE 2. Continued

	Attributes							
Application areas	Example application(s)	Entity	Geographic/ temporal scope	Performance/ outcome metrics	Relevant methods	Modeling/ computational complexity	Political/social controversy	Example application
Criminal justice	Location of community corrections centers; facilitating prisoner re-entry into communities	Government, NGO	Region, neighborhood; tactical	Net social benefit; equity	Location-allocation; forecasting	Moderate	High	Johnson [40]
Urban and regional development	Post-disaster reconstruction; design of community redevelopment initiatives; site selection and parcel acquisition	Government, NGO, public-private partnerships	Region, neighborhood; strategic/tactical	Net social benefit; equity; sustainability; spatial desirability	Location-allocation; districting; project selection; multi-criteria decision models; decision analysis	High	High	Patz et al. [74]
Public health	Location/service design of health centers; blood distribution; design of public health initiatives	Government, NGO	Region, neighborhood, individual; strategic/tactical/ operational	Net social benefit, equity, lives saved	Location-allocation; vehicle routing; inventory theory; stochastic processes; decision theory	High	High	Kaplan [52]
Public libraries/ literacy	Location/service design	Government	Region, neighborhood; strategic/tactical/ operational	Social cost, physical access	Location-allocation, scheduling	Moderate	Low	Mandell [63]
Undesirable facility location	Waste dumps, power plants, human services	Government, NGO	Region, neighborhood; strategic/tactical	Net social benefit, equity	Location-allocation, multi-criteria decision models	Moderate	High	Murray et al. [70]
Emergency services	Location of fire, police and EMS stations; dispatching, routing and staffing	Government	Regional, neighborhood; strategic/tactical/ operational	Total cost, lives saved, crime averted, equity	Location-allocation, queueing theory, decision theory, vehicle routing	High	High	Bodily [13]

*NGO = Nongovernmental organizations, e.g., community development organizations, social service agencies, churches.

2.1. Analytic Methods

2.1.1. Quantitative Methods. We know of no conventional quantitative modeling methods from OR/MS that cannot be applied to community-based OR problems. We draw attention to Erlenkotter's [23] examination of an extension of the uncapacitated fixed-charge facility location models to account for price-sensitive demands. He shows that a conventional private-sector objective of profit maximization is equivalent to marginal-cost pricing, whereas a public-sector objective of total social benefit maximization yields revenues that do not cover total costs. A "quasi-public" variant of this problem ensures nonnegative profits. This analysis reinforces our emphasis on community-based OR models that attempt to jointly optimize measures of equity and social welfare. The latter objective, moreover, is generally not equivalent to profit maximization.

2.1.2. Qualitative Methods. Qualitative methods provide a valuable complement to traditional approaches. UK-style community OR draws heavily from methods such as "soft systems methodology" (see e.g., Checkland [19]) that focus on systems analysis and qualitative methods for learning *about* the problem. Community-based OR, in addition, accommodates methods such as "value-focused thinking" (Keeney [56]) that assists modelers in formulating decision problems that are closely aligned with stakeholder values and amenable to analytical methods that yield specific prescriptions.

2.2. Human Services

2.2.1. Senior Services. Bartholdi et al. [9] develop a heuristic vehicle-routing strategy for home-delivered meals (HDM, i.e., meals on wheels) that can be easily implemented by the resource-constrained organization using earlier work on space-filling curves. Wong and Meyer [96] use geographic information systems (GIS) to locate HDM kitchens and design delivery routes to minimize total travel distance. Gorr et al. [28] develop an interactive, optimization-based spatial decision support system (SDSS) for HDM kitchen location, catchment area design, and vehicle routing for the needs of nonprofit managers seeking incremental or dramatic changes to service strategies. Johnson et al. [46] design and implement hierarchical facility location models to locate facilities that provide daytime congregate services to senior citizens that minimize distance-based costs and maximize utility using current local data on senior centers and demands for services.

2.2.2. Humanitarian Logistics. Haghani and Oh [34] consider operational transportation problems for a fixed distribution network and develop a model of the distribution process. Jia et al. [38] introduce network design models for large-scale emergency medical service in response to terrorist attacks. Balcik and Beamon [7] study distribution network design for relief chains managed by nongovernmental organizations. Campbell et al. [18] explore various objective functions for the local distribution of supplies after a disaster. To ensure equity and efficiency, two objectives are considered: minimizing the maximum arrival of supplies and minimizing the average arrival of supplies. Beamon and Kotleba [10] design a stochastic inventory control model that determines optimal order quantities and reorder points for a long-term emergency relief response.

2.2.3. Public Libraries and Literacy. Mandell [63] presents multiple models of equity and effectiveness, and applies them to the problem of book acquisition for public libraries. Francis et al. [25] develop models to assist a large suburban library system to manage its vehicle fleet and optimize operations under budget constraints. The objective function balances travel time incurred by the delivery agency and the service benefit to the libraries served. A similar, smaller interlibrary loan system in Ohio, studied in Min [68], differs from the current example in that all libraries are visited daily.

2.2.4. Public Education. Thanassoulis and Dunstan [85] show how data envelopment analysis (DEA) can be used to guide secondary schools to improved performance through role-model identification and target setting in a way that recognizes the multioutcome nature of the education process and reflects the relative desirability of improving individual outcomes. The approach presented in the paper draws from a DEA-based assessment of the schools of a local education authority carried out by the authors. Mar Molinero [64] develops recommendations for school closures in a region with declining school-age population using techniques to measure the similarity of school catchment areas that are input to a multidimensional scaling analysis that identifies socio-economic characteristics of these areas. Recommendations to close high-cost, low-performing schools that serve most-disadvantaged regions are contrasted with political opposition from local communities that seek to preserve local educational opportunities. Bowerman [14] formulates a multiobjective model for urban school-bus routing that addresses efficiency and equity jointly, and develops a two-phase approach combining student clustering and route generation. Taylor et al. [84] describe forecasting models for school attendance and optimization models for public-school locations and attendance boundaries, which reflect detailed knowledge of school administrators, elected representatives, and planners. These models address the need for racial balance across schools to minimize the need for busing, and have increased the confidence of community stakeholders in the school planning process, as measured by decreased political opposition to siting plans and increased passage rate of funding referenda.

2.3. Community Development

2.3.1. Housing. Kaplan [49], Kaplan and Amir [53], and Kaplan and Berman [54] formulate and solve math programs related to production-scheduling problems to design policies for relocating families in public-housing communities undergoing renovations to minimize total development time while ensuring that as few families as possible are displaced from public housing into private markets. Kaplan [50] uses queuing theory to evaluate the impacts of race-based versus nonrace-based tenant-assignment policies in public housing on levels of racial segregation and waiting times for available units. Forgionne [24] describes a decision-support system for assessing the army's needs for on-base new construction or off-base leased housing, determined in part by estimates of the level of off-base affordable housing available to its personnel.

Johnson and Hurter [45] generate alternative potential allocations of households using rental vouchers to Census tracts across a county to jointly optimize measures of net social benefit and equity, subject to constraints on programmatic and political feasibility. Estimates of dollar-valued impacts of subsidized housing are derived from models adapted from housing economics that use observations of actual households. Johnson [43] solves a multiobjective model for location of project-based affordable renter- and owner-occupied housing to optimize social efficiency and equity measures. Objective functions and structural parameter values are derived from discussions with nonprofit housing providers. Johnson [44] estimates structural parameters for math programming-based models for affordable housing design using microeconomic models of the firm and of the consumer, and statistical methods such as forecasting and factor analysis. Observations of housing units, households, and housing projects are provided by community-based nonprofit housing developers.

Johnson [39] presents a Web-accessible prototype of a SDSS for individual housing mobility counseling using multiple decision models and reflecting the needs of housing clients, counselors, and landlords. Johnson [42] provides a research framework for a professional-quality housing counseling SDSS and provides evidence derived from field research that typical subsidized housing program participants can make productive use of quantitative decision models. Both of these papers are discussed in greater detail in §3.

2.3.2. Community/Urban Planning. Norman and Norman [72] evaluate case studies of public art installations in Japan and the UK to support the concept of centralized, model-based decision making in the provision of public amenities. Patz et al. [74] develop decision models to design land-use strategies in a European context, allowing especially for existing historic buildings and districts. Jung et al. [48] develop a planning model for post-disaster reconstruction planning in urban areas inspired by Hurricane Katrina, which struck the U.S. Gulf Coast in 2005. In this model, small neighborhoods are aggregated into districts that share the same land-use designation (e.g., human use or passive use) in order to jointly optimize measures of environmental protection, social impacts, and spatial integrity.

2.3.3. Transportation. Vlahos et al. [93] develop a framework for computer-aided transportation planning that accommodates multiple, possibly antagonistic, stakeholders for the purposes of presentation, analysis, and judgment. A case study of this methodology emphasizes how community-based participants can collaborate with government and elected officials in developing a controversial transportation strategy. Murray and Davis [69] use community-level data on socio-economic status, public transport access, and public transport need to determine differential impacts on communities of alternative public transit investments.

2.4. Public Health and Safety

2.4.1. Public Health. Kaplan [51] estimates changes in HIV-infection rates associated with an experimental needle-exchange program using maximum likelihood change-point models and continuous-time Markov processes. Both models are estimated using observations of the HIV status of used needles provided by injection drug users. Aaby et al. [1] present models to improve pre-contagion planning for clinics that dispense medications and vaccines using discrete-event simulations, queuing models, and capacity planning models. Griffin et al. [32, 33] have developed a decision model based on the maximum covering facility location problem to identify centroids of U.S. counties at which community health centers (CHC) may be sited in order to maximize the weighted demand for CHC services, subject to constraints on funds available for fixed and variable costs and facility capacities. Their model qualifies as "community-based" in two ways: first, the care with which they have analyzed available health-care data to impute localized measures of health services demand, especially for medically underserved populations, and second, evidence provided that recommendations are fairly insensitive to smaller spatial units of analysis such as Census tracts. They find significant improvements in a variety of performance measures, including total encounters, cost per encounter, and number of uninsured persons served.

Models to address food insecurity include Chou and Zheng [20] and Lien et al. [61]. Chou and Zheng study a bread delivery problem where unsold bread from bakeries is delivered by volunteers to needy families. In their problem, demands are fixed and supply is random. They show how incorporating flexibility, meaning allowing volunteers to deliver to multiple families, can reduce the amount of wasted bread. Lien, Iravani, and Smilowitz develop mathematical models and solution methods for perishable food distribution from donors to agencies that address vehicle-routing problems (assigning donors and agencies to routes and sequencing stops within each route) and inventory-allocation problems (determining the amount to distribute to each agency). In contrast to cost-minimizing objectives, which can lead to inequitable solutions, a novel service-based maximin fill-rate objective incorporates fairness and agency sustainability, albeit at the cost of more complex modeling and solution techniques. This latter paper is discussed in greater detail in §3.

2.4.2. Criminal Justice. Brown and Liu [16] develop crime forecasts to support tactical operations, in particular the presence and intensity of local "hot spots" using a multivariate prediction model that relates the features in an area to the predicted occurrence of

crimes through the preference structure of criminals. Xu and Chen [98] use link analysis techniques based on shortest-path algorithms to identify networks of offenders in areas such as narcotics violation, terrorism, and kidnapping and find differing levels of effectiveness depending on the shortest-path search strategy. Johnson [40] develops decision models to select sites for community correction centers using multiobjective math programming and multicriteria decision analysis. These models reflect field research with stakeholders and propose siting strategies that account for neighborhood-level amenities that may be associated with successful re-entry to civilian life as well as concerns regarding potential re-offending. Blumstein [11] offers a comprehensive review of OR/MS applications to law enforcement and criminology, focused on policy modeling but reflecting close examination of community-level dynamics that motivate more stylized analytical approaches.

2.4.3. Emergency Services. The literature on fire and emergency medical services provision is extensive and long-lived; Swersey [82] provides a comprehensive review. Models for location of emergency services facilities (e.g., Walker [94], Marianov and ReVelle [65], Hogan and ReVelle [36]) and end-user applications (RAND Fire Project [77]) are innovative in applying set covering models, maximum covering models, and backup coverage models, they typically do not address community-level or equity issues explicitly. However, Schilling et al. [81] formulated a multiple-objective maximum-covering-based model for fire-station location that balances population coverage, property value coverage, and area coverage, i.e., the equity/efficiency/effectiveness objectives defined as key to community-based OR applications. The police-sector-design problem, in which a study area is partitioned into regions with equal service characteristics, has been dominated by queuing models such as the Larson's [58], [59] hypercube model. Bodily [13] applied multiattribute utility theory to the hypercube model to incorporate preferences of citizens interested in service equity, police officers interested in workload equalization, and administrators interested in system efficiency.

2.4.4. Hazardous/Undesirable Facilities. The process by which undesirable, obnoxious or hazardous facilities are located, and prescriptive models for doing so, contain elements of commonality with community-based OR. Kleindorfer and Kunreuther [57] provide a comprehensive overview of this domain and describe a detailed process for facility siting that incorporates community concerns. Gregory et al. [31] present policies by which community stakeholders can be fairly compensated for accepting location of undesirable facilities.

There are a variety of mathematical programming-based models for hazardous facility siting in which local community concerns and equity objectives are central. Ratick and White [78] formulate a model that balances measures of facility-location costs, political opposition as a function of the population within a risk radius of a facility, and equity, an increasing function of the number of communities perceived by any particular community as bearing equivalent risks associated with proximity to a facility. Erkut and Newman [22] extend the scale opposition factor within the model of Ratick and White by representing equity as a continuous (rather than discrete) function that increases in the distance between population centers, as well as decreasing in facility size. Murray et al. [70] choose locations for undesirable facilities to maximize the total population that is outside the "impact radius" of sited facilities, or, in a variant, maximize the total weighted population that is within the impact radius of at most one facility.

Merkhofer and Keeney [67] use decision theory to choose sites for a nuclear-waste repository while addressing community concerns, whereas Erkut and Moran [21] apply Analytic Hierarchy Process for location of municipal landfills, explicitly addressing a wide range of community-level factors that influence final rankings.

2.5. Nonprofit Management

Baker Werth [6] describes the development of a decision-support division within a county human-services agency to support strategic management and accountability services for local government. Vericourt and Lobo [92] model of a nonprofit's decision to partake in for-profit activities. For-profit activities often generate future revenue for nonprofit work at the expense of current resources. They show that under certain conditions the optimal investment decision in for-profit activities is of threshold type.

2.6. Lessons Learned

The past 15 years has seen a significant growth in research that is consistent with our definition of community-based OR. Increasingly, OR/MS researchers are aware of the need to incorporate socio-economic and political concerns directly into their planning models, rather than assert, as Gregg et al. [30] do in a stochastic programming model of facility location applied to library closings, that "political factors can be incorporated by means of user intervention" (p. 90). The models discussed in this section also reflect a desire to apply detailed understanding of stakeholder needs to quantitative models, which can yield actionable, policy-relevant prescriptions. These efforts stand in contrast to some research outputs associated with UK-style community OR and early U.S. efforts in this domain that focused more on community engagement and community efficacy. Finally, many of the models discussed in this section cross disciplinary boundaries, for example adapting models from other domains for purposes of decision making, or using research evidence outside of OR/MS to justify model-building efforts. However, more needs to be done to ensure that novel and innovative community-focused planning models are implemented in the field and their impacts on stakeholder groups evaluated rigorously. In this sense, the record of real-world impacts represented by models of the type presented in Larson and Odoni's *Urban Operations Research* [60] serve as a benchmark for community-based OR.

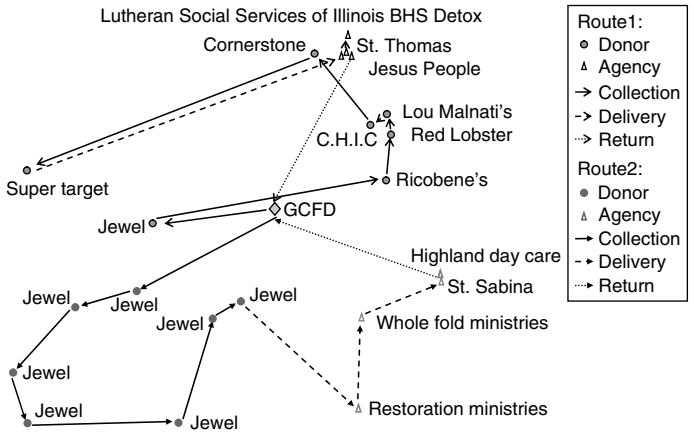
3. Applications

3.1. Food Security

In 2005, thirty-six million Americans suffered from hunger (U.S. Department of Agriculture [87]). Twenty-five million of these Americans rely on America's Second Harvest (ASH) and their network of pantries, shelters, and soup kitchens for food (ASH [4]). The largest suppliers to these agencies are regional and local food banks. Food banks are large-scale distribution centers that collect, store, and distribute food. Much of this food is donated by various sources of surplus food (e.g., supermarkets and grocery chains). According to the U.S. Department of Agriculture [88], about 96 billion pounds of food are wasted each year in the United States. The goal of ASH and the agencies in their network is to match surplus food with those in need. This matching is a large-scale distribution and inventory-management problem that occurs each day at thousands of nonprofit agencies across the country. Much research has been conducted on related supply-chain problems in commercial settings where the goal of such systems is either to maximize profit or minimize cost. Little work, however, has been conducted in nonprofit applications. In such settings, the objectives are often more difficult to quantify because issues such as equity and sustainability must be considered, yet efficient operations are still crucial.

The Greater Chicago Food Depository (GCFD) is an active ASH member. According to a recent study by the GCFD and ASH [29], 500,000 people in the Chicago region are served by the GCFD each year. One program run by the GCFD is the Food Rescue Program (FRP), which distributes perishable food from donors (e.g., supermarkets and restaurants) to agencies (e.g., shelters and soup kitchens). Over 80 donors and 100 agencies participate in the FRP, which moves over four million pounds of food annually.

FIGURE 1. Food rescue program sample routes.



The FRP operates five truck routes, each visiting between three and 17 donors and between two and 11 agencies daily. Two sample routes are shown in Figure 1. Routes begin at the depot, collect food from the donors, and distribute donations to the agencies. The frequency of visits to a location over the course of a month depends on the supply of the donor and the need of the agency. Routes are scheduled weeks in advance and remain fairly regular to facilitate driver familiarity with the routes they perform. Donation amounts and food demand are unknown until observed on the driver's arrival. The donation amounts depend on daily sales at the donor location; food demands depend on available storage and budget at the agencies. Drivers collect the full donation available at a donor. The allocation of food to agencies is left to the discretion of the driver who tries to satisfy an agency's demand while reserving supply for the remaining agencies on the route. Agencies are charged 4 cents per pound of food and view the FRP as a supplement to their main food acquisition operations.

Ongoing work (Lien et al. [61]) has focused on the design of inventory and routing policies for the FRP. The aim of this project is to develop mathematical models and solution methods for related vehicle-routing problems (assigning donors and agencies to routes and sequencing stops within each route) and inventory-allocation problems (determining the amount to distribute to each agency). In the private sector, related sequential inventory-allocation decisions are often made to either maximize revenue or minimize costs. Although cost-efficient operations remain desirable in the nonprofit sector, focusing purely on cost can lead to inequitable solutions. The GCFD seeks to provide all agencies with adequate resources in an equitable manner. The paper proposes an alternative service-based objective function (maximizing the minimum expected fill rate) that incorporates fairness and agency sustainability.

The use of an alternative objective function has important implications on the solution methods used to determine routing and inventory-allocation policies. The authors find that the useful mathematical properties of commercial distribution problems with profit-maximizing or cost-minimizing objectives (e.g., as in the multiperiod news-vendor problem) do not hold with the service-based objectives. As a result, new solution methods must be developed. The paper also proposes simple routing and inventory-allocation policies that perform well relative to more computer-intensive methods.

3.2. Affordable/Subsidized Housing

As of 2000, about 10% of the poor population in the U.S. lives in high-poverty neighborhoods (Census tracts with poverty rates of 40% or greater). An overall decrease in concentrated

poverty between 1990 and 2000 has been accompanied by stagnant or increasing levels of poverty concentration in the Northeastern and Western regions of the U.S., and increasing numbers of poor families living in communities far away from the centers of America's cities (Joint Center for Housing Studies of Harvard University [47]). Housing mobility, i.e., relocation of low-income families from distressed communities to more affluent, opportunity-rich communities, has been one goal of affordable and subsidized housing policy.

The Moving to Opportunity Program for Fair Housing (MTO), a national demonstration intended to evaluate outcomes of housing mobility-program participants, offers the possibility of significant improvements in living conditions and life outcomes for very low-income families who relocate using subsidies from the Housing Choice Voucher Program (HCVP). Over 6,000 families have participated in the experiment to date. Such areas for improvements in life outcomes include: risk of criminal victimization, housing quality, and mental health (U.S. Department of Housing and Urban Development [89]). MTO and HCVP is the inspiration for development of a prototype spatial decision-support system (SDSS) for housing-mobility counseling that might enable programs like MTO to be implemented on a large scale. This SDSS, called the Pittsburgh Housing eCounselor (http://www.housing-ecounselor.org) (Johnson [39]) is intended to assist housing counselors, clients, and landlords in connecting low-income families to good-quality housing in opportunity-rich neighborhoods.

This research confronts a number of gaps in current knowledge. First, there is little research on the actual decision-making process by which housing mobility program participants (or HCVP clients) search for housing. Second, the extent to which public housing authorities and other housing service agencies can assist creative decision making by clients who may face multiple life challenges is limited by a lack of technical knowledge on information technology (IT)-assisted decision making and the necessary IT infrastructure. Last, little is known about the ability of low-income families to frame and solve difficult problems using decision models and IT.

The Pittsburgh Housing eCounselor guides users through the process of identifying candidate housing units and neighborhoods, and ranking these candidate sites with two alternative multicriteria decision models (MCDM). The eCounselor uses Keeney's [56] value-focused thinking method to enable clients and counselors together to identify characteristics of housing units and neighborhoods that are important to the client and generate a subset of housing units and/or neighborhoods based on user-defined criteria. This process is represented by Figure 2, in which users start the search by identifying candidate neighborhoods or, alternatively, candidate housing units, through appropriate queries and rank candidate destinations using MCDM. Given these candidates for relocation, users choose acceptable housing units or, alternatively, neighborhoods, thus creating a set of acceptable housing units in acceptable neighborhoods suitable for site visits.

Neighborhood characteristics are represented with spatial data describing demographic, employment, and housing characteristics of Allegheny County, PA and displayed in a Web browser. Figure 3 shows an example of this spatial data display, for fair housing complaints in Allegheny County.

Housing unit characteristics are represented with tabular data describing actual housing units available for rent in the city of Pittsburgh and displayed in a Web browser similarly.

Neighborhoods or housing units can be ranked using one of two MCDMs: elimination by aspects (i.e., simple sort), in which users rank candidates in ascending order according to attribute values, or PROMETHEE (Brans and Vincke [15]), in which users specify the form of preference functions that measure the extent of a users' preference for one alternative over another with respect to the difference in performance of any pair of alternatives according to a single attribute. For example, a user could specify an increasing preference for one alternative over another as a linear function of the difference in crime rates of two neighborhoods.

FIGURE 2. Counseling support system destination search algorithm.

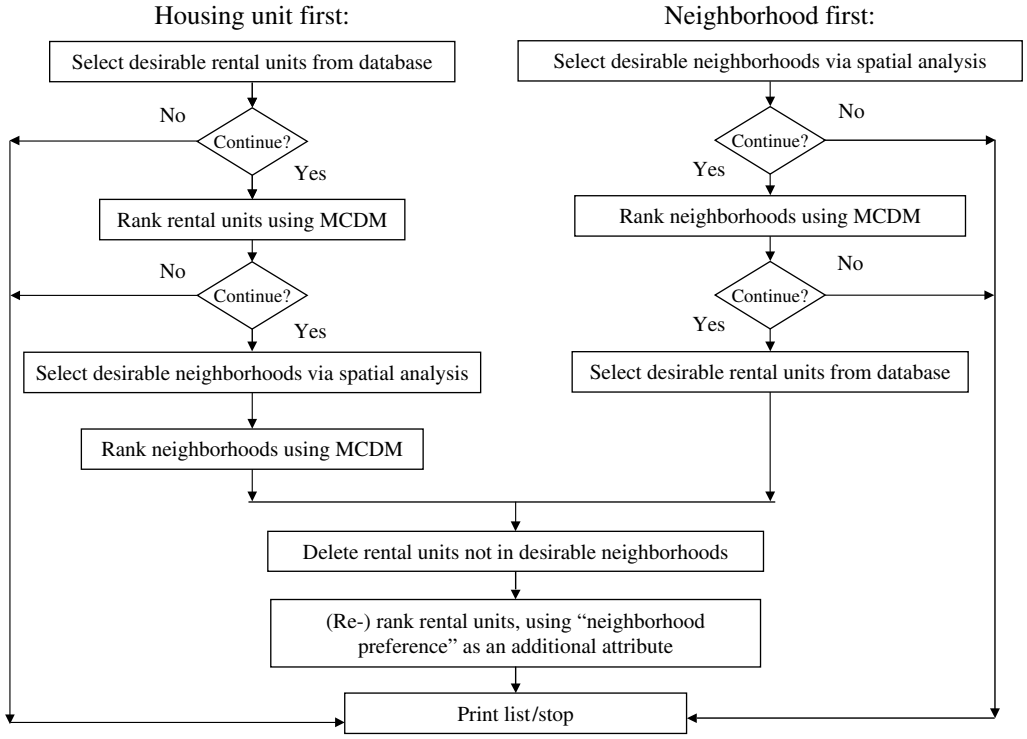
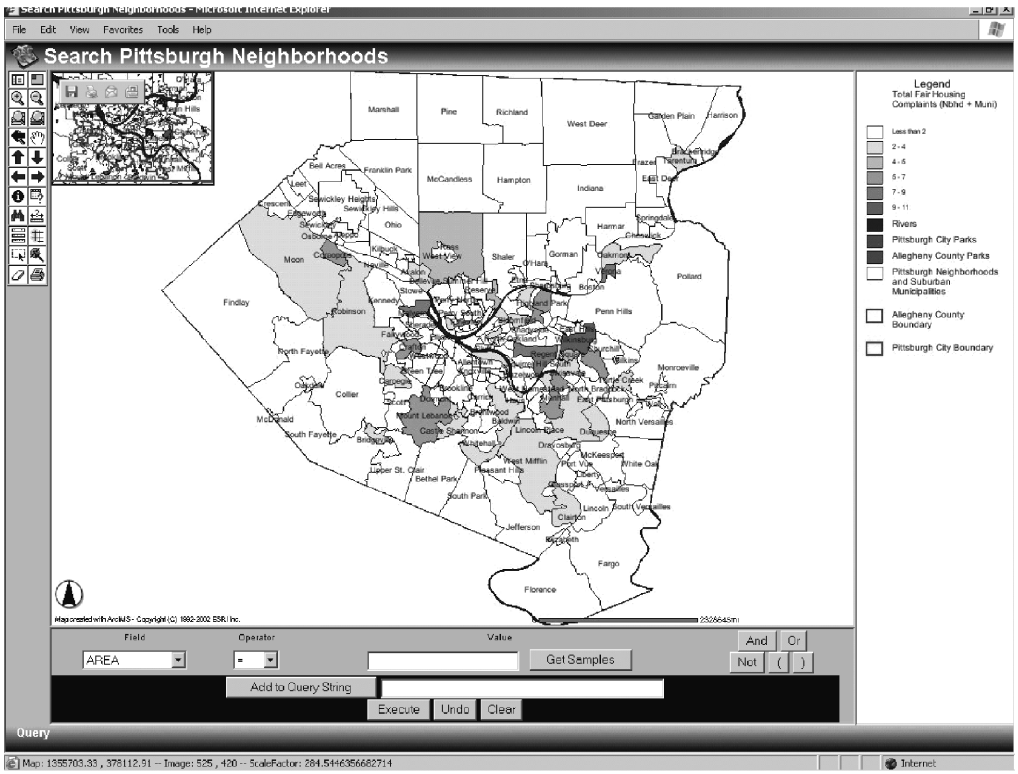


FIGURE 3. Search Pittsburgh neighborhoods—fair housing complaints.



The SDSS project has motivated subsequent field research to better understand the ability of typical clients to make use of various MCDMs (Johnson [42]). A sample of eight housing-voucher clients of a local public-housing authority used a custom application to rank hypothetical neighborhoods using three MCDMs: simple additive weighting using rank sum weights (Malczewski [62], p. 199), Analytic Hierarchy Process (AHP; Saaty [80]), and PROMETHEE. We found that representative assisted-housing clients appear to appreciate the increased insight provided by more analytically demanding MCDMs such as PROMETHEE, and that neighborhood rankings were largely dissimilar across the three MCDMs. Thus, this research is supportive of the notion of model-based decision methods as a tool for improving housing counseling, and provides suggestive evidence that a range of MCDMs may allow clients to choose the application that is best suited to their skills and preferences.

3.3. Discussion

These case studies have demonstrated the potential of diverse methods in OR/MS to address important problems of a local nature whose solutions may provide direct benefits to traditionally underserved or underrepresented populations. Equity is addressed in the food distribution application through an objective function that accommodates the needs of as many food pantries as possible; the housing relocation SDSS incorporates equity by allowing clients themselves to define criteria and alternatives consistent with their own preferences, while enlarging their choice sets to the greatest extent possible. Although the two applications are inspired by region-specific policy problems, the solution methods may be applied to many other regions. Finally, both applications reflect a concern with the ability of local organizations to implement the models' recommendations: the food distribution model uses heuristic solution methods and the housing relocation SDSS has a user interface that guides clients' interactions with decision models.

4. Conclusion

In this chapter we have described a subfield of public-sector OR called community-based operations research that addresses topics of interest to researchers and practitioners for over 30 years and is known to different audiences in the U.S. and UK under a variety of names. Common in our definition of community-based OR is a localized focus, a high degree of ambiguity, complexity, and controversy, and an emphasis on stakeholder groups that are traditionally underrepresented or underserved by social and political systems of interest to the modeler. Also, we emphasize the need for modelers to combine a focus on inclusion of individual actors and community-based organizations in defining and solving the problem (the traditional focus of UK-style "community OR") with an emphasis on quantitative models that generate actionable and policy-relevant recommendations. We have provided case studies in food security and affordable/subsidized housing that are consistent with the various components of the definition above.

Based on our review of the research literature and resources within higher education, we believe there is an opportunity to increase the influence of community-based OR on education, scholarship, and practice. Most importantly, we advocate an increase in the number of courses in undergraduate and graduate programs in business administration, industrial engineering/operations research, and public affairs that address special characteristics of nonprofit and government organizations and the decision problems they face. These courses should not be limited to project or capstone courses that have nonprofit organizations as clients, but theory-based lecture courses as well. These courses should provide: greater emphasis on cross-disciplinary evidence to support OR/MS modeling, multidisciplinary solution approaches that emphasize less complex and/or qualitative solution methods, field research to generate realistic problem instances, and low-cost IT platforms for model and

service delivery. Such courses could leverage the considerable teaching resources associated with spreadsheet-based management science rather than specialized mathematical modeling applications.

Also, we recommend that professional societies increase the returns to community-based OR research and practice. This could be done by encouraging workshops and conference sessions devoted to community-based OR, greater awareness within the profession of public policy/equity implications of models and applications, more support for cross-disciplinary research that provides an evidentiary basis for community-based OR models, and increased emphasis on international public-sector applications of community-based OR.

There are many potential application areas for community-based OR. These include: location of businesses and services in low-income, especially urban and predominately minority communities, such as financial services for the unbanked; decision-support systems for system-level redesign for mass transit, public schools, and senior services; and community revitalization through reuse of vacant lots and abandoned buildings. Finally, given the ubiquity of the Internet, and recent decreases in the "digital divide" across race, ethnic, and income categories, there are opportunities for community-focused individual decision applications that use the Internet as a facilitator. Examples of these applications include identifying health and financial impacts of alternative food purchase strategies, especially for low-income families, behavior change for energy reduction, and matching needs and locations of low- and moderate-income families seeking family-support services with service providers.

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