

Community-Based Operations Research: Introduction, Theory and Applications

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Abstract

Community-based operations research is the name of a new sub-discipline within operations research and the management sciences. CBOR synthesizes previous practice and research traditions within OR/MS to address problems within the public sector that are often of a localized nature, that address the concerns of citizens affiliated through characteristics of race, ethnicity and class and other ties and that are solved using diverse qualitative and quantitative methods. Solutions to these problems are developed and implemented by formal and informal organizations, and embody a critical perspective towards traditional notions of decision-makers, stakeholders and analytic methods. The most proximate antecedents of CBOR are the well-studied fields of community operational research, problem structuring methods and soft systems methodologies. This chapter provides a framework for understanding CBOR through key themes such as the importance of place and space, community, disadvantaged populations and multiple methods. It introduces a theory of CBOR, surveys recent literature within CBOR and assesses the presence of CBOR in OR/MS literature, education and practice. After a summary of this book's twelve chapters, eleven of which are newly published, the introduction concludes by summarizing the important contributions of CBOR and identifies some promising avenues for future research.

1 Introduction

1.1 Motivation for this book

Operations research and the management sciences are disciplines that have their roots in quantitative analysis of real-world phenomena in order to support business tactics and strategy, military operations, and social policy interventions, among many other applications. A brief history of OR/MS is provided in Pollock and Maltz (1994). Many of the first examples of OR/MS that students encounter address services that have social impacts—think of the diet problem, estimates of waiting times at bus stops, and staffing models for public agencies. However, the

majority of examples of OR/MS applications that students typically solve, and the ones that tend to define the profession, are drawn from the private sector: production planning, logistics and distribution of goods, call center management, portfolio optimization, and many others (see for example the introductory examples in Winston and Venkataraman 2003).

This is a cause for concern, since goods and services provided by government and non-profit organizations are a large part of the US economy: in 2005, of the 1.4 million nonprofit organizations known to the Internal Revenue Service, those nonprofits which reported their financial status to the IRS accounted for \$1.6 trillion in revenue and \$3.4 trillion in assets (Blackwood, Wing and Pollock 2008). Many aspects of our daily lives are defined by the quality of goods and services provided by not-for-profit means. Examples of these include education, public safety, human and social services, community and economic development and environmental conservation and preservation. Increasingly, nonprofit organizations face severe challenges to delivering these goods and services, resulting from fiscal burdens transferred from state and local governments to nonprofits and foundations, a lack of knowledge about the mission and services of nonprofit organizations, and the increasing absence of nonprofits from the political process and public discourse (Delaney 2011a,b).

Many of these public goods and services have a local character: we may care more about the quality of our local school than ones across the city; we want emergency medical services to respond quickly to calls from our neighborhood first and foremost; we complain about waste or degraded environment that we experience nearby rather than in areas we don't often visit. A recent United Nations conference on local government and development goals emphasized the importance of decentralization of government resources and responsibility for local public services (United Nations Capital Development Fund 2010); these trends are especially salient in the United States, with its strong tradition of federalism, performance management and local autonomy. Social movements in the United States, and around the world, have increasingly focused on local organizing rather than national protests (Voss and Williams 2009).

Moreover, we may care more about the impact of policies on groups of people who share our values, upbringing or racial or ethnic background, or who live in or near to our neighborhoods, as opposed to those who differ from us in various important ways¹. Thus, there is a need for OR/MS applications that respond to public needs of a local nature and that reflect and are influenced by communities that define our daily lives.

¹ The field of social network analysis is based on relationships between individuals and groups that share common beliefs, characteristics or goals (Wasserman and Faust 1994). The importance of social virtues and duties and participative decision-making distinguishes the 'communitarian' view of communities from the 'liberal' view (Midgley and Ochoa-Arias 2004b).

However, a focus on publicly-provided goods and services, especially those of a local nature, confronts the fundamental social concern of inequalities. For example, the Organisation for Economic Co-operation and Development (OECD) reports that the US has the highest inequality and poverty rate across OECD countries with the exception of Mexico and Turkey; likewise, social mobility is lower, redistribution of income by the government plays a smaller role, and the distribution of earnings is greater, than other OECD countries (OECD 2008). Therefore, if we wish to ensure that society ensures that all members have an adequate quality of life, or a certain common level of access to opportunity, the problem of designing policies or prescriptions regarding provision of public goods and services of a local nature must account for populations that have differing levels of prosperity or political and social influence.

We refer to OR/MS applications that address provision of goods and services, or prescribe social policy actions, for which stakeholders are defined, in a spatial or social sense, as localized, or who are considered disadvantaged or underserved, or for which issues of equity or social influence are important considerations, as examples of *community-based operations research*. This definition differs somewhat from that provided in Johnson and Smilowitz (2007) in that it recognizes that ‘community’ need not be tied exclusively or predominately to local neighborhoods. This sub-field is an important area of inquiry because it provides those in the community of OR/MS as well as those in other fields the opportunity to develop theory and applications for research and practice that have the potential to improve the lives of individuals and communities in tangible ways. Moreover, such theory and applications can reflect multiple disciplinary perspectives and can adapt multiple methods in ways that are tailored for the problems at hand, and not necessarily to follow a given research tradition. Finally, community-based OR can generate applications that reduce disparities in social inputs and outcomes across different groups using methods that are rooted in theory and evidence, and whose applications can be widely disseminated using appropriate modeling and information technology.

Methods in community-based operations research may vary widely, from traditional instances of prescriptive math models, to a combination of qualitative and quantitative methods that may have much in common with related disciplines such as community planning, public health and criminology. In addition, the design of specific recommendations for action may be less important than a deepened understanding about the social problem at hand, or the values and concerns of the stakeholders that may provide a basis for future efforts at prescriptive modeling.

This book, which contains eleven previously unpublished chapters, attempts to define the range of scholarly inquiry in this field, and to lay the groundwork for further research, teaching and practice. One should immediately acknowledge the large literature in related fields of OR/MS, principally that of community operational research (Midgley and Ochoa-Arias 2004a). Later in this chapter we explore the similarities and differences between UK-style community OR and this novel

rubric that reflects the social, political and economic characteristics of the US that has provided much of the theoretical and practice base of OR/MS. This book draws its inspiration from a recent paper (Johnson and Smilowitz 2007), reprinted in this volume, that was an initial effort to define CBOR; later in this chapter we update many key findings from that paper.

There are a number of themes in recent academic research, discussed in more detail below, that provide direct motivation for this book. The first is the importance of *space, place and community* in policy design and service delivery, a traditional motivation for OR/MS generally. Recent work emphasizing this dimension includes Grubestic and Murray (2010), Johnson, Turcotte and Sullivan (2010), Mills (2009) and The Health Foundation (2010). A second motivating theme is a focus on *disadvantaged, underrepresented or underserved populations* (which usually have a spatial and/or localized component as well), for example Cole (1994), Rawal et al. (2008) and Schweigman (2008). Also important are *international and transnational applications* that go beyond the use of traditional models in non-US contexts, such as Caulkins et al. (2008), Jehu-Appiah et al. (2008) and Schweigman (2008). In common with community OR, CBOR benefits from *multi-method, cross-disciplinary and comparative approaches and appropriate technology* rooted in OR/MS (which are often especially suitable for locally-focused problems). Examples of these include Bartolucci and Gallo (2010), Franco and Montibeller (2010), Hermans and Thissen (2009), Namen, Bornstein and Rosenhead (2009) and Wenstop and Koppang (2008). Finally, the recent trend in quantitative and prescriptive modeling called '*analytics*' (Liberatore and Luo 2010) has much to contribute to CBOR as it supports a notion of generalized insight into problems of operations, uses a wide variety of quantitative methods and is intended to support changes in policy and practice.

The themes described above and the recent literature illustrating them, are certainly valued contributions to OR/MS. However, there is a need to address more fundamental questions regarding community-based operations research, and public-sector OR/MS generally that goes beyond most research currently available. First, is there a way to do OR that balances positivist and quantitative approaches that dominate US-style practice with a more critical and subjective approach to decision modeling, that accommodates a variety of qualitative and mixed-methods? Is rigorous OR compatible with motivating values of social change and social justice? Can we develop a theory of CBOR that can provide guidance simultaneously to researchers who seek principles guiding diverse applications and practitioners who seek specific guidance to solve difficult real-world problems? Finally, can CBOR, as we present it here, yield research outputs that will find exposure in the most prestigious research journals and academic programs and thus influence the understanding of CBOR within the discipline? This book presents diverse applications that provide a basis to address these questions regarding community-based operations research, and public-sector OR/MS in general.

1.2 The Historical Context of CBOR and Its Role within OR/MS

There has been a long-lived debate over the proper role of OR/MS in addressing important societal problems. Of most interest to this book are three trends in OR/MS that precipitated major disagreements regarding the proper role of OR in society. The first trend, described by Pollock and Maltz (1994), is represented by the public service-oriented OR initiatives such as the ‘Operations Research in Public Affairs’ program held at Massachusetts Institute of Technology in 1966, the Science and Technology Task Force of 1967 that initiated quantitative analysis of criminal justice problems and the prevalence of quantitative analysis used in the prosecution of the Vietnam War. The second trend is the institutionalization of OR/MS within private-sector companies and the transition of OR/MS from a transformational technology to one that increasingly focused on mathematical analysis and incremental gains in efficiency (Jackson 1994). The third trend, also described by Pollock and Maltz, is societal disenchantment with quantitative methods that promised so much, yet seemed, with the increasingly unsuccessful Vietnam War and social unrest in America’s cities as a backdrop, not to be delivering on their promise to improve society.

Russell Ackoff’s classic 1970 paper in *Operations Research* described a primarily qualitative study to improve a poor, minority neighborhood in Philadelphia that involved collaborations with local residents. This represented the start of Ackoff’s progressive frustration with an OR/MS discipline that appeared to him to place undue emphasis on applied mathematics as against human processes, and stylized quantitative models versus a systems-learning approach (see Ackoff 1979a,b). Yet other researchers in the OR/MS field, such as C. West Churchman and Peter Checkland, shared Ackoff’s beliefs in an alternative approach to OR/MS that would emphasize a broader understanding of “problems” and the social and political aspects of problem identification and solution, rather than a focus on theory-building and algorithm development for stylized mathematical representations of the real world. These decision problems would be viewed as part of a social system rather than a distinct entity that could be solved directly, as a consultant might (Churchman, 1970, Checkland 1981). Kirby (2007) describes thirty years of disagreements between what could be called US-style OR, an increasingly mathematical and problem-focused approach, and an alternative, critical approach championed by researchers in the UK that closely examined the roles of power, class and community in defining problems amenable to OR/MS models and methods, as well as the stakeholders who are affected by the problems and play a role in solving them.

Alternatives to traditional OR/MS are represented by community operational research (Midgley and Ochoa-Arias (2004a), soft-OR and soft systems methodologies (Checkland 1981, Churchman 1979) and problem structuring methods (Rosenhead and Mingers 2001). It is instructive to note that the US and UK experiences with a critical approach to OR diverged radically during the 1970s. This is

due in large part to economic dislocations associated with the economic recession that affected UK residents in a larger and more fundamental way than Americans, as well as the larger role that socialist and Marxist political movements played in the UK as opposed to the US (Kirby 2007). While a relatively small but stable proportion of UK academics use community OR for research, hard-OR continues to dominate in applied research in the UK (Kirby 2007).

We now briefly review other well-known variants of traditional OR/MS that are related to CBOR and which do not embody the critical perspective of the UK-based methods. Public-sector operations research, as indicated above, has played a role in OR/MS from the very beginning of the discipline. The standard reference in this area (Pollock, Rothkopf and Barnett 1994) tends to center on government and large nonprofit organizations as decision makers and use traditional prescriptive and quantitative decision models. Larson and Odoni's classic text on urban operations research (2007) focuses on urban operations and logistics issues without a critical examination of the social processes that make urban problems different from those of others, nor does the text address the role of social policy in urban operations modeling. Policy modeling (e.g. Kaplan 2008, Grass et al. 2010) uses stylized models from OR/MS, optimal control and other areas to estimate impacts of policy changes that incorporate time, uncertainty and systems dynamics. Analytics (Liberatore and Luo 2010) allows a more flexible notion of analytic and prescriptive methods for quantitative operations and planning problems, though typically motivated by and applied to private-sector issues.

The debate over the role that qualitative, critical and community-oriented inquiry ought to play in OR/MS continues into the present. A letter to the editor of *OR/MS Today* (2009), in response to an editorial statement appearing in *Operations Research*, asserted that:

“...the issue is the way in which a recognized field of O.R. — sometimes referred to as "Soft O.R." or "problem structuring methods" (PSM) — is systematically ignored within the U.S. This field is now well-established and demonstrably successful within academic and practitioner communities elsewhere [1]. However, in many quarters of the U.S. operations research community, papers involving Soft O.R. are rarely, if ever, published in major journals...

“These methods have become widely accepted outside of the United States, and there is much evidence that they have been very successful in helping clients deal with complex, practical problems. However, they are virtually ignored within the United States, both in educational programs and in the major journals....

“We are concerned that this is gradually causing a split across the worldwide O.R. community, particularly between the U.S. and Europe...

“We call on the American O.R. community to accept that Soft O.R. and PSMs are worthy contributions to effective O.R. interventions, and

that they represent another valid, and valued, part of the O.R. discipline...” (Ackerman et al. 2009)

In response, the editor of *Operations Research* asserted:

“The proliferation of journals in our field demands the clarification of the scope and mission of each journal. In my 2006 Editorial statement, I focused on a scope that is broad enough to cover both methodology and applications...”

“Our objective is to serve the community by publishing high quality papers that are based on rigorous mathematical models and demonstrate potential impact on practice...”

“Having worked on many practical problems, I have no doubt that mathematical models have limitations and that in many cases these methods need to be complemented, or replaced, by other techniques. Of course, there are many available methods to choose from and the techniques from "Soft O.R." may well be some of those. Indeed, there are various tools appropriate for dealing with "messy" problems, e.g., expert systems, business rules, management systems and other techniques of modern management. But when they are not based on rigorous mathematical models, *Operations Research* is not the appropriate outlet for such papers.” (Simchi-Levi 2009)

In response to this scholarly exchange regarding the role of qualitative methods within OR/MS, Mingers (2009) published an article in *OR/MS Today* introducing ‘soft OR’ and related methods as well as relevant case studies to the US audience. A longer-form treatment of this topic has recently appeared (Mingers 2011a).

Sodhi and Tang (2010) develop a model of the OR/MS ‘ecosystem’ that is comprised of the core OR/MS community (researchers, educators and practitioners) and external entities that communicate with this community (end users, universities, funding agencies and professional societies). They argue that an excessive focus on mathematical theory and analytical tools, combined with an unclear profile for OR/MS, the uncertain status of OR/MS in business schools and uncertain employment prospects for those trained in OR/MS, among others, threatens the long-term viability of OR/MS as a discipline. The authors recommend that researchers move from examining stylized math models to engage the real world in significant practical problems, that academia reward researchers for doing so, and that educators increasingly train students to meet the needs of end users based in industry and government. These arguments are salient to community-based operations research, since CBOR problems and analytic methods, as we discuss below, are likely to be those that traditional U.S.-style OR disdains, as seen in the *OR/MS Today* response to the letter to the editor. It is likely that CBOR would benefit from a change in values, research topics and practice resources consistent with Sodhi and Tang’s recommendations.

The importance of this debate for current research and practice in OR/MS is not clear. As we will demonstrate later in this chapter, the profile of community-based operations research in US degree-granting programs related to OR/MS and in top-tier journals, most based in the US, is rather low and has not increased by much since Johnson and Smilowitz' 2007 review. However, the profile of CBOR in professional societies, especially the Institute for Operations Research and the Management Sciences (INFORMS) has increased somewhat since 2007. Thus, there is some evidence that there is modestly more interest in CBOR and related mixed-methods approaches within OR/MS in recent years than previously. The question remains: given the difficulty of addressing community-based problems in operations and strategy, is a rigorous mathematical basis for analysis the best or only way to do high-quality, cutting-edge research?

1.3 Chapter Outline

Section two of this chapter provides a more detailed survey of community operational research, which is the most direct motivation for this book. Section three presents a theory of CBOR that extends the traditional notion of OR/MS inquiry. Section four summarizes published work related to CBOR that has appeared since 2007. Section five provides an updated assessment of CBOR's profile within OR/MS across research, education and practice. Section six contains a thematic summary of the twelve chapters within this volume. The last section concludes and identifies promising next steps for research within CBOR.

2 Community Operational Research: An Antecedent to CBOR

In this section we summarize the most important aspects of community operational research. The many streams within community OR have been summarized well by Midgley and Ochoa-Arias (2004a) in their edited volume. Midgley and Ochoa-Arias (2004b) and Parry and Mingers (2004) assert that the fundamental goals of community OR are to address the needs of low-income, mission-driven organizations, to build theory through engaged problem-solving, to redress societal imbalances by advocating for and solving problems of special interest to disadvantaged populations as against more-privileged classes, and to solve unusual problems for non-standard clients using multiple analytic methods, including qualitative methods not necessarily prescriptive in nature, with a systems view of the problem at hand. In summary, community OR seeks to make change within communities through diverse methodologies, processes, methods and techniques.

An important aspect of community OR is the importance placed on understanding the social context within which analysis is done. Jackson (2004) describes six problem contexts by which all problems which may yield prescriptions based on analytic methods can be classified. ‘Mechanical-Unitary’ denotes problems that have a single decision-maker and which can be easily quantified and optimized, in other words, the sorts of problems, like production planning, crew scheduling or queueing analysis, that are well-studied and understood from the traditional context of US-based OR/MS. “Systemic-Unitary” problems are those associated with complex, probabilistic systems that can still be quantified in a way agreeable to stakeholders, for example a multi-period supply chain management decision model incorporating uncertainty that reflects the concern of a single decision maker. “Mechanical-Pluralist” problems reflect fundamental disagreements between participants about the nature of the problem, but which could be reduced to the Mechanical-Unitary problem if a single stakeholder’s views dominate. An example of this problem is regional planning that addresses fundamental conflicts between land-use, transportation and environmental sustainability between residents, businesses, planners and politicians. “Systemic-Pluralist” problems have multiple stakeholders and address complex problems that cannot easily be reduced to those reflecting the needs of a single stakeholder. The long-running debates in the US on health care reflect this view. Finally, “Mechanical-Coercive” and “Systemic-Coercive” problems serve the needs of the powerful, and specific solutions can be enforced through the power of the state, or corporations exerting market power. Military and national security problems are examples of these.

Midgley and Ochoa-Arias (2004b) explore, through the lens of political philosophy, the fundamental notion of ‘community’ from which community OR problems originate and through which community OR findings are implemented. A ‘liberal’ concept of community is based on autonomous individuals who assert their own rights above community cohesion. Such a community, associated with a traditional notion of capitalism, can result in consumerism and the dominance of corporations in establishing values, yielding social fragmentation and inequity. In contrast, a ‘communitarian’ concept of community is based on social virtues and duties to individuals and the wider social group as opposed to individual rights, and leads to cooperative decision-making rooted in collective participation to generate shared values. The authors identify participation as central to enabling productive individual action in community OR, and specify three dimensions of participation: citizen power, versus non-participation and tokenism; inclusion, versus exclusion, of human and non-human stakeholders, and critical versus consumerist participation. Finally, the authors discuss four kinds of communitarianism that are consistent with a productive application of community OR: participative democratic communitarianism, historical communitarianism, religious communitarianism and green communitarianism.

Taket and White (2000) examine partnership and participation across agencies to enhance policy development and decision-making and to enable group processes to become more participatory and democratic. Cross-national case stu-

dies contained in the book build on earlier research in problem structuring methods and community OR (Taket and White 1997) and support research and practice in public administration and public management as well as OR/MS.

These explorations within community OR are quite foreign to the traditional ‘hard-OR’ presentation of the discipline. In various ways, all of these theories provide a useful foundation to the community OR applications presented in the remainder of the Midgley and Ochoa-Arias text and throughout the community OR literature. Why, then is there a need for a new sub-discipline called *community-based operations research*?

There is a useful role for elements of traditional ‘hard-OR’ in community-focused applications that go beyond what has been achieved in community OR. In the US, policy analysis is oriented towards policy prescriptions and social interventions based on evidence of potential effectiveness, efficiency and equity (e.g. Bardach, 2005). There is a long tradition of quantitative decision modeling and decision support for public-sector applications whose best practices have been documented in prize competitions such as the INFORMS Edelman Awards and the practice-oriented scholarly journal *Interfaces*. Yet, as described above in the letters to the editor debate in *OR/MS Today*, many OR scholars are skeptical of models and methods that are not based on mathematical principles. A new view of OR/MS that is critical, uses multiple methods and which is rooted in community participation for problem formulation and problem-solving can generate insights for theory and practice that judiciously adapts traditional perspectives and generates solutions that can change the notion of appropriate and useful OR prescriptions. In addition, the field of community OR, which, for all of its innovations, had been a minority movement among UK-based practitioners all along, appears to have lost some momentum recently as some of its highest-profile thinkers have migrated to other tasks. Finally, one cannot ignore the increased attention paid to community-oriented research and practice efforts that may be associated with the recent election of a US president whose professional roots lie in community organizing. In the next section we present a theory of community-based operations research that incorporates the community OR perspective but is also consistent with traditional principles.

3 A Theory of Community-Based Operations Research

The usual representation of the steps associated with an OR/MS analysis (e.g. Winston and Venkataraman 2003, p. 5) consists of the following steps: problem formulation; observation of the system; design of a mathematical model of the problem; model verification; selection of decision alternatives; results presentation, and implementation. Liberatore and Luo (2010) broaden this definition

somewhat by proposing four collections of actions that comprise the practice of ‘analytics’. The first consists of data collection, manipulation, and extraction. The second, model-based analysis, comprises visualization, predictive modeling and optimization. The third set of actions focuses on insights derived from an understanding of events that have occurred in the system under study, estimation of future outcomes based on predictive models, and specification of future outcomes based on optimization models. The last set of actions addresses decisions made given current processes, changes to processes, and identification of new long-term strategies.

The theory of community-based operations research is based on four analytical steps distilled from the representations of the OR/MS and analytics processes listed above. The first step, *problem identification*, recognizes that situations which are not acceptable to stakeholders may not yield at first glance a statement of a problem to be solved, or may yield multiple problems whose statements may be contradictory or so messy as to defy representation in ways amenable to mathematical analysis. Determining what aspects of a system under consideration should be modified, and how, is an opportunity for a variety of problem structuring and values clarification methods, e.g. Keeney’s value-focused thinking (Keeney 1996), Checkland’s soft systems methodology (Checkland 2001) or facilitated modeling (Franco and Montibeller 2010).

One’s preferred method for problem identification should address the important role of place and neighborhood in determining the spatial extent of a problem to be solved. As an example, Briggs (2005) shows that place and neighborhood provide an entrée to economic mobility and social stability that serves as a contrast to a traditional focus on mobility and neighborhood change. In addition, community-based operations research must confront, where appropriate, race, ethnicity, class, gender and other largely-immutable community or social group identifiers associated with stakeholders affected by the problem under consideration. These may not, however, be associated with defined places or neighborhoods. Race and ethnicity, in particular, are so closely associated with social issues such as disparities in resources, social outcomes and discrimination, among others (National Research Council 2001a,b), that they deserve close scrutiny to determine whether conventional OR/MS analysis neglects the perspectives and lived experiences of key stakeholder groups.

Institutions and organizations, both formal and informal, often serve as conduits by which problems can be identified and solved, and platforms from which solutions may be implemented. Especially in community-based analysis, researchers must pay attention to the crucial role played by the not-for-profit sector, including government, 501(c)(3) non-profit organizations such as community development corporations, and other informal, ‘civic-sector’ organizations whose financing, structure, social role and understanding of problems and social values may be very different than those understood by analysts trained in the OR/MS tradition. Privett (this volume) and Vernis et al. (2006) provide important back-

ground on this important sector. Ignoring the role of geography, social groups and local organizations can lead to solutions in search of a problem, or solutions that do not address symptoms, such as disparities in social outcomes by race, class or ethnicity, of larger social problems.

Problem identification, through understanding the roles of personal and social values, the importance of place and neighborhood, the impact of social inequities and the nature of institutions and organizations must necessarily culminate in an appreciation of a critical perspective upon the problem at hand, the societal context within which the problem is to be solved, and the nature of the analytic methods to be applied. Mingers (2000a), in a philosophical examination of OR/MS, endorses ‘critical realism’ as a way to accommodate the realist perspective of reality (as opposed to the widely-discredited empiricist view) while allowing for interpretivist and subjective views of OR/MS, to support hard and soft approaches in OR/MS, and to recognize OR/MS’s identity as a basically applied discipline. Mingers (2000b) approaches critical thinking from a different perspective, that of undergraduate management education, but does so, through the lens of a new management course that embodies notions of critical action learning. This view, addressing critical thinking, critiques of traditional norms and processes, critiques of authority and critiques of objectivity, is key to formulating and solving socially-relevant problems that is the core of community-based operations research.

The second step, *problem formulation*, is most closely associated with traditional OR/MS practice; methods such as value-focused thinking, soft systems methodology and facilitated modeling can be applied here as well. This step has four characteristics that distinguish CBOR from other problem types. First, there are often multiple stakeholders; elements of the problem formulation such as decision variables, structural parameters and so on may reflect multiple social groups and organizations. One example of multi-stakeholder analysis for problem formulation is ‘decision conferencing’ (Phillips 1989) in which groups, in workshop model, engage with a facilitator to perform real-time expert modeling. Second, this process ought to be collaborative: the conventional consultant-led approach, appropriately critiqued by Franco and Montibeller (2010) neglects the fact that stakeholders, who may know little of OR/MS, nevertheless may understand their social and cultural environment, neighborhood and system very well.

Third, the problem formulation process should be evidence-based: analysts should do descriptive analysis that deepens understanding of problem context and develop parameters and indicators that link actions with outcomes. While descriptive analysis is standard procedure for OR/MS, linking prescriptions with outcomes is not. Many public-sector applications have implied or explicit goals associated with improving social welfare, yet are limited in practice to conventional policy or practice interventions such as delivering meals more quickly to the homebound, or maximizing the number of clients in close proximity to a service facility.

It is often not at all clear that a change in an operational metrics or proxies such as reduced delivery time or distance-weighted demand above will have an appreciable impact on desired social outcomes such as reduced food insecurity or increased literacy, which are themselves approximations to more fundamental social outcomes such as improved health, or increased education performance or labor market participation. (The area of ‘policy modeling’ (e.g. Kaplan 2008) has however featured research that has taken special care to ground decision models in social science, public health and other disciplines.) There is thus a role for public policy analysis and other domains in linking changes in social or physical environments and resources to beneficial population outcomes, and adapting these measures to quantities that can be represented by entities which can be manipulated in reasonable ways through decision models.

Finally, problem formulation for community-based operations research should explicitly address issues of equity, fairness and ethics. As discussed earlier in this chapter, various measures of social inequity and economic disparities in the United States have increased in the first decade of the new millennium; any reasonable social intervention intended to improve the lives of individuals and communities should aspire, at least, to provide stakeholders with information about changes in the distribution of benefits to various stakeholders in the form of alternative measures of equity and fairness. While the social science literature on equity is extensive (LeClerc, McLay and Mayorga, this volume, present a brief survey of this area), there is less attention paid in typical expositions of OR/MS fundamentals regarding the role of equity. LeClerc, McLay and Mayorga, as well as Marsh and Schilling (1994) review a wide variety of equity measures that can be incorporated in a straightforward way into decision models. Mingers (2011b) presents ethics in OR as a means to clarify the values and norms that motivate and frame the problem at hand, and to engage a wide variety of constituents in discussions that determine what solutions can be derived, and how that can be done.

The next step of the CBOR process is *problem solution*. ‘Solving’ a CBOR problem can mean deriving a solution to a math optimization model, or evaluating the impact of different system configurations on queueing model performance measures, or even establishing consensus on changes to be made to a process, or common goals to be achieved. Great value can be provided to community members and community organizations simply by problem structuring and collaborative learning which enables community members to solve important problems in the best way they know how. Community operational research as developed and practiced in the U.K. provides many examples of problem solution distinct from optimal solutions to quantitative decision models.

CBOR problems can be solved through multiple research frameworks. Quantitative analysis, especially mathematical modeling, is commonly understood to be the *sine qua non* of operations research as well as analytics. However, other solution methods are possible. Case studies (Yin 2003, Meredith 1998) can document the impacts of changes in procedures or new operations or resource allocation de-

cisions with or without an explicit mathematical model of the system under study. Action research (Burns 2007) enables the researcher and the client to build theory, understanding and best practices jointly. A central belief of CBOR, represented by the original chapters in this book, but also by the review of literature which follows, is that ‘hard-OR’ and ‘soft-OR’ methods are compatible and in fact essential for high-impact community applications. What is important is an understanding of the system, of the problem to be solved, and of the anticipated outcomes of the analysis.

Within quantitative analysis, alternative solution approaches are represented by heuristics, optimization and hybrids of the two. The literature of quantitative solution methods in OR/MS is vast; it suffices here to note that community-based OR/MS should account for available expertise, technology and resources within the decision-maker’s organization. Doing so may result in the decision to use a heuristic that is simple to explain and easy to implement as opposed to an optimization-based method or heuristic that requires understanding of OR/MS theory, models and applications beyond that typically available in community-based organizations. However, it would be appropriate for a CBOR practitioner to present to the client the tradeoffs in terms of optimality, model complexity and computing resources of alternative solution approaches, especially if the client expects to use the solution method on their own. The importance of spreadsheets as potentially transformational in disseminating OR/MS models and methods across underserved areas (Caulkins et al. 2008) should not be minimized; however, in some contexts, even spreadsheet-based analysis can tax the resources of some organizations, and OR/MS analysts should understand that an entirely qualitative presentation of decision problems and solutions can provide substantial insight and benefit to community-based organizations.

In principle, OR/MS analysis consists of iterative solutions, each coming closer to achieving the goals of a client. However, the consulting paradigm of OR/MS may obscure the importance of this process. In policy analysis generally, and public-sector OR/MS specifically, iterative analysis is understood to be fundamental to ensuring that answers derived are subject to public review and appropriately modified as new data, theory or political concerns become available (Gass 1994). This is especially true of community-based OR/MS, in which community members, or community-based organizations play a central role in problem formulation, solution and implementation. Again, we borrow from community operational research an understanding that building community capacity to solve progressively more challenging problems, or repeatedly solving problems of a recurring nature is central to the process of CBOR.

The last step we consider is *implementation*. As argued above, ‘solutions’ to problems in CBOR may range from increased understanding of the problem under consideration, to agreement on objectives, goals and metrics associated with solving a problem, to generalized insights on existing processes and strategies, to revised rules-of-thumb and procedures, to problem-specific policies akin to those

derived from analytic solutions to multi-period problems, to well-defined prescriptions associated with values of decision variables arising from solutions to specific problem instances. In contrast to traditional private-sector OR, and consultant-style public-sector OR, the ultimate goal of CBOR is community change for the public good. This can be accomplished in three ways. Theory-building enables increased understanding of the relationships between problems, models, prescriptions and real-world impacts. Capacity-building, results in the increased ability of individuals and organizations to formulate models, solve problems and change operations and strategy without the assistance of external analysts. Social change is associated with tangible improvements in quality of life of community members and increased ability of community members and local organizations which serve them to advocate for their needs more effectively and to better design and implement programs that meet those needs.

The four steps of CBOR proposed in this section – problem identification, formulation and solution, and implementation – though extended in various ways to address issues of equity, critical perspectives, multiple methods, iterative analysis and capacity-building, among others, represents only an initial effort to create a proper theory of community-based operations research. These steps do not, themselves, constitute a rigorous collection of principles, variables and testable propositions leading to a deeper understanding of individual and organizational decision opportunities, methods and implementation strategies, as well as evaluation of decision modeling impacts upon communities of interest (see e.g. Von Evera 1997). Development of such a theory is a topic for future research.

4 Recent Research within CBOR

Johnson and Smilowitz (2007) reviewed journal articles and working papers whose methodological focus or substantive area appeared consistent with their definition of community-based operations research. They found approximately 52 papers which appeared over a range of 30 years that provided a diverse view of community-focused decision modeling. A review of the research literature from 2007 to the present reveals 32 CBOR-related journal publications, a significant increase in the rate of such work (This review also includes three articles that are germane to this chapter which appeared before 2007 but were not included in the Johnson and Smilowitz article.) Using the same application-area and methodology categories of Johnson and Smilowitz, we briefly review this recent literature and draw some conclusions about the state of the art of CBOR in peer-reviewed journals.

4.1 Applications

Human Services. There has been no recent CBOR work in public education, and only one application related to senior services and public libraries. Hare et al. (2009) develop a deterministic multi-state Markov model of home and community care services for the disabled in British Columbia to estimate the impact of an estimated doubling of the size of the senior population on HCC resources. The authors' model addresses home care and non-publicly-funded care, as well as the impact of related changes in age and health status. Bayley et al. (2009) perform an empirical investigation of academic library operations for routine decisions related to physical space, collections, staffing requirements, services and funding.

There has been, however, an upswing in publications in humanitarian logistics, which we now define to include disaster planning. Altay and Green (2007) review OR applications to disaster response across four life-cycle categories and identify disaster recovery as a particularly ripe area for research. Cole (1995) uses a social accounting matrix to investigate disaster preparedness to estimate the direct and indirect costs of damage-causing events, with a particular focus on small localities as opposed to the usual national or state-level analysis. He applies his model to the Caribbean island of Aruba and estimates potential disaster impacts such as water or oil interruption. Mills (2009) describes the efforts of the Louisiana State University GIS Clearinghouse Cooperative to develop geographic information systems applications that provide a way to measure disaster recovery across dimensions such as intent to return, actual return and quality of life. These applications are intended to provide information to residents as well as researchers using lower-cost technology wherever possible to support spatially-informed decisions by individuals and communities. Lee et al. (2009) examined how to dispense medical countermeasures in the face of a large-scale public health emergency where thousands of sick or injured people need medical attention. They designed a program called RealOpt that allows users to simulate, on a large scale, locations for dispensing-facility set up, facility layout design, staff allocation, and disease propagation analysis. Real Opt has been distributed to 1000 health departments and was used successfully during an Anthrax drill in Georgia in 2005.

Community Development. Since 2007, there appear to have been no CBOR applications in transportation, only one in housing, but five that wholly or in part address community and urban planning, and one more that addresses elements of the latter two categories. These latter papers are mostly applied to environmental planning, which did not receive much emphasis in the previous review. Johnson, Turcotte and Sullivan (2010) develop a multi-objective mathematical programming model to design strategies for acquiring and redeveloping foreclosed housing in urban areas to balance social objectives of aggregate social benefits, development costs that incorporate scale economies associated with clustered units, as well as equity, while accounting for limited financial resources. This model is applied to a small city in Massachusetts and demonstrates alternative development

paths that show useful variation in decision and criterion space. Ewing and Baker (2009) develop an Excel-based decision support application to support technology choice in construction of environmentally-friendly buildings. Their decision theoretic model accommodates multiple criteria, multiple stakeholders, and significant trade-offs between short-term and longer-term investments.

Within community and urban planning, Cole (1994) applies the social accounting matrix model introduced earlier in this review to determine the income and employment impact of individual projects on a lower-income community in the city of Buffalo, New York. His analysis revealed that the East Side neighborhood represents a locus of disinvestment, with African-American residents particularly not benefitting from local investments. In a later paper (Cole 2002), he uses the same method to assess alternative development strategies for the Chinese Yellow River Delta region that address flooding and instability in the region, impact of pollution emissions in the water and competition for the available land. Evaluating four development scenarios, he accounts for the environmental costs of economic development as well as the cost of restraints for environmental preservation. Foote et al. (2007) apply a new method called boundary critique to the problem of management of ongoing water shortages in a small town in New Zealand. By addressing the issue of inclusion, exclusion and marginalization of people and issues, the authors demonstrate how problem structuring methods can be applied in novel ways to define the problem context from multiple conflicting viewpoints and to develop workshops that achieved consensus on water conservation strategies. Mills (2009), described above, clearly has a focus on community and urban planning and development rooted in local participation and appropriate spatial technologies. Wang and Zou (2010) describe an urban planning spatial decision support system that uses spatial data mining methods to identify new trends in urban economic development, opportunities for underground developments such as subways that would not conflict with existing infrastructure, and proposing novel mixes of high-rise and low-rise residential developments that would preserve living spaces for long-time residents.

Public Health and Safety. Recent research in CBOR has focused almost entirely on public health applications, with no work done in emergency services and only single applications in criminal justice, hazardous and undesirable facilities and food security, which had received much more emphasis in the earlier CBOR review. We discuss these latter applications first. Grubestic and Murray (2010) discuss, as in this volume, the problem of determining, through spatial optimization models, the likely allocation of sex offenders subject to certain residency and saturation limits. These models are used to test the extent to which sex offender residency rules provide for separation of offenders and vulnerable populations while allowing offenders to integrate into society. Model results indicate that these rules tend to concentrate and isolate potentially dangerous individuals in areas that have more vulnerable populations, less law enforcement capacity and fewer community resources to oppose such allocations. Schweigman (2008) applies operations research methods to food security in sub-Saharan Africa and finds opportunities for

productive applications to a large-scale problem at the intersection of demography, agriculture and politics if modeling activities are integrated in an interdisciplinary approach in interaction between farmers, policy makers at the local level, and researchers.

In the area of public health, Baltussen et al. (2010) discusses recent literature on the application of multi-criteria decision analysis (MCDA) on ranking of health priorities, both within the context of specific health interventions and for more generalized policy design. They suggest that the use of such models could be expanded to set national priorities through methods such as focus groups that might provide the basis of a multi-country database on health interventions that address local preferences. De Vericourt and Lobo (2009) use the example of eye hospitals in India to investigate the optimal allocation of resources in an organization between profit-generating and free services. They suggest that a threshold value of resources below which all resources should go towards profitable ventures is most efficient, accounting for the importance of free services to the organizational mission. When such a threshold is incompatible with organizational mission, organizations can alternatively structure the pricing of their for-profit ventures to cover non-profit activities according to total resource availability, but with less optimal results. Hare et al. (2009), reviewed above, use Markov models to estimate demands on services for British Columbians with acute, chronic, palliative or rehabilitative health care needs as a result of predicted increases in the size of the elderly population. Jehu-Appiah et al. (2008) use multicriteria decision analysis to set priorities for the Ghana Ministry of Health while considering both efficiency and equity. They find that interventions targeting serious diseases, vulnerable populations, or that are cost effective are more likely to be chosen. The study found that utilizing such an analysis was a step forward for the transparency and accountability of the ministry. Kramer et al. (2009) uses decision analysis to control the spread of malaria in Tanzania that considered the five critical challenges to controlling vector-borne diseases. In particular, this analysis addresses the presence of multiple actors at multiple scales and recognizes the impact of interactions between the environment, individuals and communities, as opposed to a traditional focus on the disease vector or treatment of the disease itself. The Health Foundation (2010) uses multi-criteria benefit-cost decision conferencing with high stakeholder involvement to choose health interventions that give the highest impact in life expectancy, lifetime quality of health and lowered infant mortality. Application of this method to an isolated, disadvantaged and underserved region enabled stakeholders to choose three interventions that were most affordable yet most likely to make a substantive difference. Silva and Johnson (2009) apply hierarchical facility location-allocation models to propose reconfigurations of the primary health system in the urban and rural portions of Davao City, Philippines that increase population coverage, reduce travel distances and reduce system costs through fewer facilities.

In US applications, Rawal et al. (2008) observe that blacks and Hispanics utilize children's mental health services less often than Caucasians. Using data from

the Illinois Department of Children and Family Services and information from a standardized assessment screening tool of patients, they predict hospitalizations based on multiple medical criteria and so that more children who need such services actually access them, reducing the incidence of racial disparities in psychiatric hospital admissions. Motivated by large and increasing gaps in breast cancer mortality rates between black and white women, Sheppard et al. (2010) performed interviews with a racially diverse set of breast cancer patients and health care providers to understand barriers to usage of an effective therapy. They found that cultural identity, relationships and expectations, and cultural empowerment were significant factors in improving communication about and increasing participation in effective cancer treatment regimen. This results in the design of alternative intervention strategies, a community-based decision support mechanism.

The application-area reviews above reveal two areas of emphasis absent in the 2007 review: underserved populations, especially racial and ethnic minorities (Sheppard et al. 2010; Rawal et al. 2008; Cole 1994), and developing countries (Jehu-Appiah et al. 2008; Kramer et al. 2009; as well as Caulkins et al. 2008, though the latter paper focuses on methods of disseminating OR in Africa rather than particular applications). Finally, we observe a single example CBOR focused specifically on nonprofit management (de Vericourt and Lobo 2009).

4.2 Methods

The current review takes a more expansive view of analytic methods associated with CBOR than the 2007 review; there appears to have been a relative explosion of new tools for decision-making in community-oriented contexts.

Qualitative methods. As discussed above, Foote et al. (2007) develops the notion of ‘boundaries’ that determine what information is relevant and what is superfluous when applying problem structuring methods to the needs of marginalized groups. This method allows the use of multiple interventions that accommodate diverse values and institutional critiques. Bartolucci and Gallo (2010) address world and regional peace and freedom as an OR/MS ethical responsibility and apply system dynamics models, combination logic functions, Boolean optimization and multicriteria clustering to humanitarian logistics and management, conflict analysis and prevention and sustainable development. Hermans and Thissen (2009) focus on the roles that stakeholders play in defining and solving problems. They address networks of actors, perceptions and beliefs about the environment within which a problem is to be solved, internal motivations (‘values’) of actors, and the resources available to actors to realize their objectives. Their survey of recent applications along these dimensions includes methods in network analysis, preference elicitation, stakeholder analysis, conflict analysis, transactional analysis, discourse analysis and cognitive mapping. They assess tradeoffs between practical usability and analytic quality among these different methods. In an introduc-

tion to a special issue on the topic, Le Menestrel and Van Wassenhove (2009) discuss the role that ethics plays in designing operations research studies, the importance of recognizing value conflicts in OR, and the question of whether the core focus on efficiency as a performance metric in OR methods ignores diversity of values and limits the practical utility of OR studies. One paper in that collection, by Wenstop and Koppang (2009) focuses particularly on the role that emotions play in conflicts intended to be resolved through OR methods. Based on recent results in neuroscience, the authors develop five ethical rules for OR analysis of value conflicts that address engagement of researchers with decisions to be analyzed, the fundamental, as opposed to instrumental, role of stakeholders, and an increased focus on the consequences of decisions. Mingers (2011b) discusses the role that a particular process called 'discourse ethics' plays in operations research, particularly soft-OR (and by extension CBOR), in examining morals that underlie questions regarding what ought to be done in a particular problematic situations, and the societal norms that dictate how fundamental rights can shape the formulation of decision problems. He argues that discourse ethics can support debate and discourse among the widest possible set of stakeholders and decision makers, and can address pragmatic, ethical and moral issues that encompass the diversity of problems addressed by OR.

Quantitative methods. Kaplan (2008) reviews many applications of policy analysis, a collection of tools to analyze policy-relevant problems using stylized representations of the real world and adaptations of methods such as queueing models and optimal control to derive practical insights into policy-relevant problems with local impact. As discussed earlier in this chapter, Liberatore and Luo (2010) summarize the analytics movement, a superset of traditional OR analysis, to leverage large amounts of operational data to generate practice insights based on descriptive and prescriptive models and especially to develop changes to high-impact actual business processes. Though the authors' examples are drawn mostly from the private sector, analytics has the potential to revolutionize government and nonprofit service design and delivery through a focus on data, processes and implementation that goes far beyond traditional prescriptive mathematical modeling.

Mixed methods. We end our review of the recent CBOR literature by revisiting the debate between quantitative and qualitative methods in OR and multiple approaches to combining diverse analytical methods. As discussed previously, Kirby (2007) addresses the historical evolution of "soft" OR approaches, initially as an alternative to classical "hard" OR, and eventually as a complement to less rigid and more adaptive forms of standard OR techniques. Mingers (2001) explains how multiple methods can enable analysts to flexibly address multiple phases of a project, from understanding the problem from the perspective of stakeholders, analysis to understand and explain the current situation, assessment of proposed explanations, and actions to bring about changes. Multiple methods also allow analysts to productively intervene in situations comprising aspects that can be observed and modeled, aspects that are socially constituted, and aspects that reflect

individual beliefs and values. Namen, Borstein and Rosenhead (2009) apply robustness analysis, a method that combines a qualitative and subjective understanding of a problem from the perspective of stakeholders and a quantitative approach to identifying sequences of decisions that may yield desirable outcomes. This method incorporates the competing concepts of ‘robustness’, i.e. fraction of acceptable configurations, or sequences of decisions, that are achievable, and that of ‘debility’, the fraction of unacceptable or undesirable configurations achievable after an initial decision. The authors apply this method to a community based malnutrition problem in a Brazilian community. A most-preferred solution involving sustainable community food production balances robustness and debility. The discussion of a critical approach to OR earlier in this chapter (Mingers 2000a,b) is also salient here, as these critical approaches accommodate multiple views of the problem and multiple methods to solve it.

This review of recent literature that we classify as community-based operations research indicates that there are multiple opportunities for decision modeling applications across application areas and analytical methods that address the needs of diverse stakeholders, values, social contexts, data types and decision frameworks. It is encouraging to note the increasing rate of CBOR-related publications in recent years.

5 CBOR’s Profile within Research, Education and Practice

Johnson and Smilowitz (2007) reviewed articles published between 2002 and 2007 in top-tier disciplinary journals within OR/MS and found that the presence of papers that could be classified as community-based operations research was very low. They also reviewed top-ranked undergraduate and graduate programs in the fields of business, industrial engineering/operations research and public policy and found, as of 2007, very few courses that appeared to have substantial CBOR content. We have revisited this analysis for the years 2007 – 2010 and expanded our scope to address the presence of CBOR in OR/MS practice.

5.1 Research

Johnson and Smilowitz found only four articles in four main industry journals by 2007. This work was expanded using a list of the 28 top-ranked relevant journals in OR/MS compiled by Josephine E. Olson at the University of Pittsburgh (Olson 2000). A review of eight of these journals, judged most likely to have

CBOR-related articles from 2007 – 2010², as well as a new journal (*Decision Analysis*) not on the list at the time it was created yielded only a single article out of 3,404 articles published during this time whose topic coverage approximates the criteria for CBOR provided at the start of this chapter (though six others have the potential to support CBOR-related extensions). We note the contrast between this count, and the 32 CBOR-related journal articles, discussed in the previous section, which have appeared between 2007 and 2010. It appears that CBOR, though increasing in popularity in recent years, has not had a commensurate presence in top-tier journals in OR/MS.

5.2 Education

Johnson and Smilowitz argued in 2007 that community-based OR had a low profile in the academic community. They conducted a survey of the top 25 industrial engineering undergraduate programs, top 25 business undergraduate programs, top 10 industrial engineering graduate programs and the top 25 business graduate programs, based on the 2007 rankings of U.S. News and World Report, and found that only one graduate industrial engineering program and only one undergraduate business program offered a class with content that addresses community-based OR. An update of these schools in 2010, showed little change. However, since 2007, four undergraduate industrial engineering programs have added courses that resemble public sector-OR, but three undergraduate engineering schools seem to have eliminated OR from the curriculum altogether. Mingers (2011) notes that there appear to be no courses in US-based master's programs that address topics in soft OR.

5.3 Practice

INFORMS has many societies and sections associated with disciplinary and application-area interests of its members. Prior to 2008, there was only one section with interests related to CBOR: the section on Public Programs and Processes. In 2008, INFORMS worked with members to create a new section from Public Programs and Processes, and two newly-proposed groups with overlapping mandates: the Community of OR for Public Service Efforts, and the Section on Humanitarian Applications. The resulting group, the Section on Public Programs, Services and

² *Operations Research, Management Science, Manufacturing and Service Operations Management, Decision Analysis, European Journal of Operational Research, Mathematics of Operations Research, Mathematical Programming, Journal of the American Statistical Association, Annals of Operations Research.*

Needs, has greatly increased its membership, number of sponsored sessions at recent INFORMS conferences, and presentations with CBOR content.

In addition, in 2009 INFORMS inaugurated the “Doing Good with Good OR – Student Paper Competition”, which emphasizes student-led research using OR/MS methods, considered broadly, which has significant societal impact. INFORMS has also inaugurated a Governmental/Non-Profit Task Force whose mission is to identify projects and partners in the not-for-profit sector that have the potential to leverage the expertise of the INFORMS membership. Finally, the INFORMS journal *Operations Research* is preparing a special issue titled “OR for the Public Interest”, and its journal *Interfaces* will publish a special issue titled “Humanitarian Applications: Doing Good with Good OR” to be published in 2011.

In contrast, the older subfields of community OR and soft OR have had significant profiles in non-US-based journals, universities and professional societies. Journals such as *Omega*, *European Journal of Operational Research* and *Journal of the Operational Research Society* have published papers on community OR, soft OR and related areas since the 1970s; authors such as Rosenhead and Mingers (2001), Midgley and Ochoa-Arias (2004a) and Taket and White (2000) have published books on these topics. Initiatives such as the Community OR Unit at Lincoln University, the Centre for Community OR at University of Hull (later merged with the Centre for Systems Studies) and the Problem Structuring Methods (PSMs) Study Group at University of Warwick and have provided scholarly support for this topic. In addition, the *Wiley Encyclopedia of Operations Research and Management Science* (2011) has several entries on various topics within soft-OR and application areas related to community-based operations research (though neither CBOR nor COR are addressed directly in this encyclopedia).

While CBOR continues to have a low profile in top-tier academic journals and in top-ranked OR/MS degree programs, an increased emphasis on public-sector research and applications within the largest OR/MS professional society provides hope that CBOR, and public-sector applications in general, will achieve increased visibility in research journals and education programs in years to come.

6 Book Chapters

The twelve chapters to follow in this book, eleven of which are previously unpublished, emphasize a number of distinct themes across their diverse application areas. In this section, we summarize these contributions according to thematic category and then discuss the extent to which these chapters reinforce the motivating themes of this book which were introduced at the start of this chapter.

6.1 Models and Analytic Methods

This book places special emphasis on research that develops new ways of abstracting real-life organizations, systems and processes into models, and designs and/or adapts novel analytic methods by which such models may yield prescriptions or policies that are relevant to practice.

“Community-Based Operations Research”, by Michael Johnson and Karen Smilowitz (first published in 2007) is an initial effort to place a name on OR/MS applications that emphasize issues of place and space, of minorities and disadvantaged groups, and of the role of community in identifying, formulating and solving problems and implementing solutions derived from them. This tutorial paper develops a theory of CBOR, presents a hypothetical CBOR application to urban public education and reviews the scholarly research in the field defined as CBOR starting in the early 1970s. The authors then discuss two actual CBOR applications and emphasize the linkages between the applications and key elements of CBOR. The first application is a mathematical programming model for the design of delivery routes for donated food to food pantries that balances concerns of efficiency and equity. The second application is a spatial decision support system providing guidance for low-income families who seek to relocate using rental housing vouchers, based on analysis of typical clients’ ability to do elementary spatial analysis and analysis of decision alternatives, culminating in a prototype Web-based SDSS.

“Operations Management in Community-Based Nonprofit Organizations”, by Natalie Privett builds theory, identifies applications and makes links to other disciplines in exploring how the basic metaphor of operations management and logistics – the supply chain – can be applied to the nonprofit sector. This chapter is divided into topics that correspond to three portions of the supply chain. The first, supply – or inputs – is represented by fundraising, earned income and foundation grants. The second, nonprofit production – or activities – is organized according to objectives, coordination and centralization, and production processes by which services are provided to client populations. The last category, consumers and markets of nonprofit goods and services, provides insight into the role that supply and demand play in decisions regarding resource acquisition, service design and collaboration and competition, and how the work of nonprofit organizations can be quantified and evaluated using principles of performance measurement. The chapter concludes by summarizing the similarities and differences between for-profit supply chains and nonprofit organizations providing goods and services for the public good, and identifies some promising areas of future research, including the role of risk, multiple organizational objectives, and the interplay between for-profit and non-profit organizations and services.

“Modeling Equity for Allocation in Public Resources” by Philip Leclerc, Laura McLay and Maria Mayorga provides a theoretical foundation for consideration of equity as a co-equal criterion for allocating public resources along with traditional

concerns of effectiveness and efficiency. The authors define equity as addressing three elements: the resources to divide between recipients, the sets of recipients by which resources will be divided, and time periods across which resources are provided. By closely examining how stakeholder perspectives change over time, they define a fundamental distinction between the equity of the resource allocation process (*ex ante* equity) and the equity of the outcomes produced by the process (*ex post* equity), and show that allocations that may be *ex ante* equitable may not be *ex post* equitable, and vice versa. These concepts are illustrated using an example from emergency medical services in which uncertainty plays a fundamental role in service delivery time and patient survival. The authors then provide illustrative mathematical formulations of equity objectives and discuss issues of mathematical tractability and incorporation into multi-objective mathematical programs. They recommend that other researchers extend this work through a systematic analysis of equity objectives that would extend the foundational work of Marsh and Schilling (1994), investigation of the implications of use of equity as a constraint rather than an objective in math programming models, incorporation of process equity in operations research models, development of a “toolbox” of a core set of equity functions of broad applicability to OR/MS, and investigation of how equity can be incorporated into a wide range of applications apart from EMS.

6.2 Facility Location and Spatial Analysis

Community-based operations research finds a natural home in the areas of facility location and spatial analysis. Goods and services are often provided to localized populations through spatially fixed sites such as libraries, health centers and schools. Since many services, and the facilities by which they are provided, have spatial extent, issues of the spatial distribution of client populations and proximity of clients to service providers, and the ways in which both are measured, and the policy implications of both, are of importance. We note that each of the papers discussed below also address concerns of disadvantaged and/or stigmatized or under-represented groups as well as service delivery.

“Spatial Optimization and Geographic Uncertainty: Implications for Sex Offender Management Strategies”, by Alan Murray and Tony Grubestic is related to their recent (2010) work on decision models for measuring the spatial impacts of rigorous enforcement of laws relating to allowed residential locations for persons convicted of serious sexual offenses. Here, though, the authors examine the nature of measurement itself in geographic information systems and discuss the impact upon residential prescriptions for sex offenders of uncertainty in approximating proximity and physical location within GIS. In reaction to four categories of such uncertainty – object geometry, data precision, distance measurement and proximity interpretation – the authors propose improvement of data and/or model quality along each of these dimensions, as well as changing the language of statutes them-

selves. By doing so, policy analysts, law enforcement and offender advocates can ensure that laws are designed and enforced effectively and fairly.

“Locating Neighborhood Parks with a Lexicographic Multiobjective Optimization Method”, by Jorge Sefair, Adriana Molano, Andrés Medaglia and Olga Sarmiento turns the focus directly to spatial decision modeling. The authors address the question of identifying and assembling land parcels in urbanized areas into parks in order to meet minimum threshold requirements of parkland per resident motivated by documented benefits of proximity of residents to parks, green spaces and recreation. This is a discrete multiobjective facility location problem, the objectives being geographic coverage, level of, and proximity of parks to, positive and negative local externalities, number of beneficiaries, physical accessibility, and total cost, subject to limits on the total size of the park as well as of component parcels. The authors apply an ϵ -constraints approach as well as a priori lexicographical ordering of decision criteria based on consultations with planners to measure and control the deviation of objective values from best-possible values across various feasible solutions. These methods are applied to urban park planning in Bogotá, Columbia; it is demonstrated that the model instances can be designed with an acceptable level of technical difficulty, solutions generated that clearly show variations in performance across multiple objectives, and spatial and policy impacts of alternative park infrastructure strategies illustrated in insightful and innovative ways.

“Using GIS-Based Models to Protect Children from Lead Exposure”, by Douglas Hastings and Marie Lynn Miranda, represents the strongest link to the themes of minority and disadvantaged groups and service delivery. Given the significant negative health impacts upon children of exposure to even very low levels of lead, primarily associated with lead-based paint in the home, the authors introduce a model to measure levels of childhood residential lead exposure. This model uses GIS to assemble spatial data on residential parcels and associates with these parcels data on documented risk factors for childhood lead exposure as well as actual geocoded blood surveillance data. These data are used in a regression model to forecast lead exposure at the parcel level; model results are displayed using GIS to provide public policy and public health insights unavailable through other display or description methods. This forecasting model, appropriately validated, has been used by organizations to design localized lead poisoning prevention strategies such as targeted blood screening, lead paint abatement and educational programs and community outreach. The authors, though focused on public health implications of their model, provide suggestions for decision modeling applications that can enable users to make policy decisions for public health interventions that balance multiple decision criteria.

6.3 *Minorities and Disadvantaged Groups*

A central motivation for community-based operations research, as for community operational research, is the role that decision modeling can play in designing policies and prescriptions that affect the lives of individuals and communities who, by virtue of socio-economic disadvantage, political marginalization or stigmatization on the basis of race, ethnicity, class or other personal or group characteristics, are not traditionally the focus of public-sector OR/MS. The papers in this section are motivated most strongly by the lived experiences of disadvantaged groups and are intended to improve outcomes for these groups.

Lee Stenson's "A Model for Hair Care In the African American Community" is motivated by the fact that hair care, a service reflecting conflicting cultural values of beauty and assimilation, is simultaneously a fundamental pillar of minority communities and often time-consuming and expensive. Using queuing models, Stenson investigates the ways that operations of hair care salons serving African-American populations be improved so as to increase throughput and revenue to operators and reduce the cost, in time and money, to patrons. Surveys of hair care salon owners and observations of actual salon operations enable the author to apply discrete event simulation to a stylized representation of a hair care salon with performance parameters that reflect real-world operations. The author recommends that salon operators reduce the practice of 'stacking' customers who arrive in close time proximity, partition services provided according to processing times, and hire assistants, in order to maximize profits and throughput. The author also recommends that clients consider choosing hair styles that require less processing time and maintenance. These recommendations have significant cultural and policy significance: in the US generally, minority women's hair styles that communicate values of cultural assimilation are the most expensive and time-consuming. Also, minority women serving in the armed forces have limited access to hair care salons that provide culturally-appropriate services.

"A Modeling Approach to Evaluating 'At Risk' Youth and Communities", by B. Jacob Loeffelholz, Richard Deckro and Shane Knighton, addresses another marginalized group in America: youth at risk for membership in street gangs. The authors adapt Ishikawa, or cause-and-effect diagrams to classify risk factors for street gang membership based on the voluminous social science literature on this subject and create stylized profiles of 'at-risk' youth. On the basis of these risk factor hierarchies, the authors apply Keeney's (1996) value-focused thinking methodology to identify specific measures for individual-level risk factors and calibrate single-dimensional value functions to translate levels of risk factors into scores which are then aggregated into weighted risk scores. The authors adapt this methodology to community-level factors associated with gang activity and similarly compute weighted risk scores by which communities at highest risk for gang activity can be identified. The goal of this modeling exercise is to design gang prevention programs with the greatest likelihood of reducing gang activity, as well

as identifying risk factors for individuals and communities of gang affiliation that may support other social service interventions.

“Fair Fare Policies: Pricing Policies that Benefit Transit-Dependent Riders”, by Kendra Taylor and Erick Jones, focuses on another disadvantaged population: minorities and persons of low income who are most likely to depend on mass transit to meet their transportation needs, and least likely to purchase high-discount transit passes that require significant initial cash outlays. Motivated by increased investments by mass transit systems in ‘smart card’ systems for automated fare collection as well as fare increases intended to reduce operating deficits that can disproportionately affect transit-dependent patrons, the authors propose pricing schemes that can ensure that even patrons who do not purchase expensive multi-ride discount plans pay little or nothing for additional rides that would have been free under transit pass schemes. Using research on price elasticity of transit fares and cross-fare elasticity between various transit products, the authors solve a non-linear program to determine the optimal increase in the price of various fare products, and the increase in all prices, to maximize revenue subject to limits on demand levels for a new ‘best fare’ product and overall increases in fares. The authors apply their model to real-world transit data and demonstrate that a new fare policy with benefits especially for the transit-dependent can result in increased revenues, and may attenuate decreases in ridership as compared to outcomes for conventional fare increases without such fare products.

6.4 Service Delivery

Community-based operations research, like most of OR/MS, addresses the delivery of services as well as physical goods. Public-sector OR/MS has traditionally emphasized delivery of services, such as emergency medical service, transportation, natural resources and education which are often not traded in conventional markets, or for which there are significant positive or negative externalities. CBOR’s focus on service delivery includes in addition impacts on disadvantaged, localized or traditionally under-studied populations and an emphasis on equity.

“Decision Making for Emergency Medical Services”, by Hari Rajagopalan, Cem Saydam, Hubert Setzler, and Elizabeth Sharer is a review of recently-published research on ambulance relocation models to improve response times and thereby patient survival rates. The authors explore improved methods to forecast calls for EMS service that incorporate uncertainty regarding the time and location of such calls, and, given better demand forecasts, decision models for deploying and re-deploying EMS servers to balance proximity to call locations and the need to reduce fatigue and improve morale of EMS employees. The authors use data from Mecklenburg County, N.C. to demonstrate novel forecasting models using artificial neural networks, and two competing ambulance location models: the Dynamic Available Coverage Location Model (DACL) and Minimum Expected Re-

sponse Location Problem Model (MERLP). ANNs provide benefits over conventional models because of modest modeling assumptions and applicability to complex data patterns. In addition, while DACL determines the minimum number of servers (ambulances) that are needed to cover demand given a time standard threshold, MERLP additionally minimizes the total overall travel distance for a fleet of ambulances. The authors' results are shown to have promise for urbanized communities showing significant changes in demand levels, and for extensions that address equity and variable service levels for especially vulnerable populations.

“Capacity Planning for Publicly Funded Community Based Long-Term Care Services”, by Feng Lin, Nan Kong, and Mark Lawley, develops an optimal control model for allocation of elderly persons to alternative long-term care (LTC) services: home and community-based services (HCBS) and institutional care, in particular, nursing homes. This is done by making assumptions about the rate of transitions from the overall population of older public insurance beneficiaries (Medicare) to the two LTC alternatives, and the rate of transitions from the larger population of beneficiaries to the status of death and between the two LTC services, as well as the death state. The optimal control model minimizes the sum of fixed and variable costs associated with LTC options subject to balance equations on the rate of change of levels in the four categories and a boundary condition. Results based on Medicaid recipients in the state of Indiana demonstrate that a substantial increase in the capacity of the HCBS system from the base case results in modest decreases in annual expenditures.

“Educational Costs and Efficiency of Illinois Schools: A Nonparametric Analysis”, by J.S. Flavin, Ryan Murphy and John Ruggiero, is an application of the well-known data envelopment analysis method to public education. To the usual DEA technology description of discretionary inputs such as labor and capital transformed into outputs such as performance on standardized tests and drop-out rates the authors incorporate non-discretionary inputs such as parental education or involvement, poverty, income and minority status. These non-discretionary inputs define ‘environment levels’ that affect efficiency: a more adverse environment requires higher expenditures to create a given level of output. The authors develop a teacher price index from a first-stage DEA model that maximizes reductions in observed expenditures consistent with observed production allowing variable returns to scale; they then calibrate a regression model in which the dependent variable is the teacher price index and independent variables are non-discretionary inputs. Parameter estimates from this regression are used as weights on the values of non-discretionary inputs to create an overall environmental index; this index is used in a third-stage DEA model that accounts for the impact of favorable environments upon observed efficiency. This model is applied to data on elementary school districts in Illinois. The authors identify substantial inefficiency and show that environmental costs are driven by teacher prices, as well as student composition and socio-economic conditions.

6.5 Relation of Book Chapters to Motivating Themes

The introduction to this chapter identified six themes which have motivated the development of this book: the importance of space and place in policy design and service delivery, a focus on under-served, under-represented or disadvantaged populations, international and transnational applications, multi-method, cross-disciplinary and comparative approaches and appropriate technology, the role of community in collaborative decision modeling and the potential positive impact of analytics on community-based applications. These themes are intended to strike a balance between the traditional focus of US-style OR/MS on mathematical rigor and a focus on stratified decision contexts (the ‘mechanical-unitary’ type of OR/MS application as defined by Jackson (2004)), and more expansive notions of decision-makers, stakeholders, community and analytic methods as represented primarily by community-based operational research, soft-OR and problem structuring/facilitated modeling methods that are more popular outside of the US.

The contributions to this book can be classified into three levels of emphasis on these motivating themes. The themes of multi-method, cross-disciplinary and comparative approaches and appropriate technology and under-served, under-represented or disadvantaged populations receive a high level of emphasis, being a focus of seven and nine of the twelve chapters, respectively. In contrast, the themes of space and place and analytics are an important component of five and three chapters, respectively, yielding a medium level of emphasis. Finally, the lowest level of emphasis in this volume are the themes of international and transnational applications and the community’s role in collaborative decision modeling, which are addressed in detail in only two and one of the chapters, respectively.

Based on previous discussion, these results perhaps should not be surprising. It will lie to future researchers to remedy this deficit in research emphasis.

7 Summary and the Future of CBOR

Community-based operations research is a sub-discipline of OR/MS that is rooted in diverse research traditions, that may serve as a ‘middle-ground’ between ‘hard-OR’ and ‘soft-OR’, thus appealing to US-style adherents of OR/MS, and which derives its research rigor from theory-building and testing, novel methods of data gathering and analysis and an emphasis on demonstrable, tangible social impacts and creative development of appropriate decision technologies. This chapter has demonstrated that CBOR has matured significantly since the 2007 introduction to the field. CBOR is gaining increased prominence in the research literature and in professional practice; it is hoped that its presence in top-tier journals and educational programs will improve similarly in the coming years. The theory

of CBOR, though quite preliminary at this time, provides a framework for innovative research that crosses disciplinary boundaries and places increased emphasis on the role of stakeholders, analysts and decision-makers to develop decision models that are rooted in expansive notions of community and decision-making.

This chapter acknowledges that certain thematic areas of CBOR, such as international and transnational applications and the community's role in collaborative decision modeling are not reflected in the CBOR research literature to the level of others such as interdisciplinary approaches and the role of underserved and disadvantaged populations. We also acknowledge that there are relatively few published applications, especially at top-tier journals, that address all or even most of the characteristics of CBOR described earlier in the chapter.

There are substantial opportunities for research in the decision sciences that is community-engaged and action-oriented, that leverages a current interest in analytics to draw stronger links with work in social sciences, public management and community and urban planning, and which addresses comparative and transnational approaches to explore impacts across sectors, communities, regions and countries. Current work by this author in the areas of multi-method modeling models for foreclosed housing acquisition and development (Johnson et al. 2010), and residential planning to address municipal shrinkage (Johnson and Hollander 2011) are examples of research in CBOR that may serve to broaden the field and increase links between traditional U.S.-style OR and alternative approaches.

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