A SPATIAL DECISION SUPPORT TOOL AND EVALUATION OF SITES FOR FERRY INFRASTRUCTURE DEVELOPMENT IN THE NEW YORK CITY METROPOLITAN REGION

by

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Chapter 1: Introduction

Since the time of its earliest European settlers, the position of Manhattan Island, at the juncture of the Hudson River, Long Island Sound, and the wide protected natural harbor of Upper New York Bay has been significant in its development and character. Indeed, its unique geography first led the city to assume a position of international significance, as a port of trade. It has also led, though, to lasting challenges for transportation planners, who are faced with the task of moving millions of people onto and off of the island where they work and play on a daily basis.

In the 19th century, passenger ferry services, numbering in the dozens, were indispensable for the movement of an ever-increasing number of workers to jobs in Manhattan from homes across the Hudson and East Rivers. During the period of the major construction of bridges, tunnels, and highway projects in the region, beginning in the 1880’s and continuing through the mid 1960’s, these ferry services lost out dramatically to new roads and railways, which enabled faster access to the city. By 1967, three years after the completion of the Verrazano Bridge, the Staten Island Ferry was the sole surviving commuter ferry service to Manhattan (Regional Plan Association (RPA) 2006).

Over the next forty years the New York City metropolitan area experienced even greater economic and demographic growth. Accordingly, its roads have become congested and its rail lines reached or exceeded their capacity. As Manhattan drew workers from increasing distances, the geography of commuting shifted, for some, to a reduced relative efficiency of road and rail. This is the case for those coming to lower Manhattan from New Jersey’s Monmouth County, for example. As available land became scarce, real estate developers turned to areas poorly served by existing
transportation infrastructure, banking on their own ability to provide mobility for residents. These factors contributed to a resurgence of entrepreneurial ferry services in the region beginning in the early 1980’s, which continues today (RPA 2006).

At the same time, research on land use and transportation systems by planners and urban geographers has lead to increased understanding of their interconnections. Best practices now acknowledge that infrastructure development must facilitate access to residential and work destinations while protecting existing uses and populations in place. The urban experience of the latter twentieth century sensitized planners to the contested nature of the allocation of public development funds, as well as the ravages of automobile-centered planning.

Since 1990, at least eleven studies of the opportunities for new and reinstituted ferry services have been funded by public agencies in the New York metropolitan area, considering a diverse set of criteria for investment (Ramasubramanian et al. 2007). Since September 11, 2001, approximately the same number of new ferry services were launched and have remained viable. The time would appear ripe for a comprehensive plan for the development of ferry infrastructure as part of the overall transportation package of the region. Accordingly, in 2006, the New York Metropolitan Transportation Council (NYMTC), the Metropolitan Planning Organization (MPO) for the region, issued an RFP entitled *Ferry Parking and Landside Access*, calling for a region-wide analysis of the landside opportunities associated with such a long-term plan.

The research reported in this thesis constitutes a portion of the response to this need. Specifically, I describe (1) the design and construction of a comprehensive Geographic Information System (GIS) database spanning the New York metropolitan
region, containing land use, demographic and transportation related feature classes
germene to the evaluation of potential sites for ferry infrastructure development, (2) the
development of site evaluation and comparison models to query that database and
evaluate specific sites according to a set of expert-defined criteria which may be
weighted according to a user’s preferences, and (3) a ranking of eighty-five sites in the
region using the models in conjunction with expert- and stakeholder-derived criteria
weights.

This effort builds on the tradition of spatial decision support systems (SDSS)
using GIS, and the evolution of those tools as increasingly accessible to domain experts,
and appropriate to planning processes (Densham 1991, Malczewski 2004). At the same
time, the methodological approach taken continues the trend toward flexible model-based
analysis using GIS, which enables the reuse and recombination of analytical tools
(Maguire, Batty and Goodchild 2005, Jankowski et al. 2006).

In contrast to previous studies, the present research encompasses a very large and
populous study area and applies the tools of multicriteria evaluation (MCE) with GIS to a
site search and selection problem in the transportation domain, specifically targeting the
land-use related criteria proper to waterborne transportation infrastructure planning
(Malczewski, 2006).

The content of this report is structured as follows.

Chapter two will consist of a review of literature that provides context and
methodological underpinning for the present study. Specifically I will consider the
historical context for computer-assisted approaches to planning, GIS and SDSS for
planning applications, planning-specific extensions of SDSS such as Planning Support
Systems (PSS), and the recent development of models and approaches in Geographic Information Science appropriate to the contemporary context and questions of planning.

In chapter three I will describe in greater detail the specific methods applied in the present study. These fall into the following areas, which I will review in sequence: geographic databases and data models for urban research, spatial decision support techniques for planning applications, and a conceptual framework for modeling accessibility with GIS.

The fourth chapter will provide a description of the regional setting for the current study and the data used. Here I will discuss the role of NYMTC within the region and its goals for the Ferry Parking and Landside Access Study inasmuch as these bear upon the design of the current research and provide additional context. I will also address the set of limitations on the study as a result of the data themselves, including issues of currency and sources of potential error.

In chapter five I will offer a detailed description of the application of methods to the problem at hand. The larger steps of database development, the creation of site evaluation and comparison models, and site ranking will be broken down, and the procedures used in each phase will be detailed. An ontology for the siting of transit hubs based on the site evaluation criteria of the current study, but independent of mode, will be introduced.

Chapter six will present the findings of the analysis of potential sites using the site evaluation models developed. The primary product of this analysis is a short list of sites identified as possessing the greatest potential with respect to the future development of waterborne transportation (ferry) infrastructure. The combination of factors contributing
to the primacy of these sites and their locations will be visualized in graphs and maps. Site ranking results generated from alternate criteria weighting schemes will be compared to assess the effect of different weights on rankings.

Finally, in chapter seven, I will present an evaluation of my work and indicate directions for future research. The site evaluations and the rankings generated by alternate weight vectors presented in chapter six will be discussed. The choice of methods used will be assessed, and any necessary or advisable changes indicated. Finally, I will describe plans for the future use of the site evaluation models and database, and offer suggestions for the direction of new research related to the current study.
Chapter 2: Review of Literature

The uses of computer technology to support planning activities have evolved with the development of information technologies and the changing multi-faceted context of planning itself. The utility of GIS for planning practice became clear early, and it was widely adopted by planning organizations. However, the limitations of commercial general-purpose GIS packages for the special tasks of planners have also become clear, precipitating a host of theoretical, methodological and technical developments which promise to bring the technology ever closer to contemporary philosophies of planning. For a variety of reasons, recent authors have found that the application of dedicated, comprehensive planning software tools in real-world situations leaves something to be desired (Vonk, Geertman and Schot 2005, Brail 2006, Couclelis 2005). On the other hand, commercial off-the-shelf (COTS) GIS packages now provide support for the creation of increasingly complex analytical models. These capabilities facilitate the extensible, task-based customization of software tools already adopted within planning organizations. This chapter considers these developments as described in the literature, with an eye toward identifying a set of appropriate methods for the present study. The review begins with the early use of computing for planning tasks.

2.1 The roots of technological praxis in planning

Batty describes the birth of computer models for planning applications in the heady days of scientific optimism of the late 1950’s (Batty 1994). A widespread interest in complex systems, the development of early computers, and theories of rational planning formed the setting in which a quantitative, technologically informed, and ostensibly scientifically approach to urban planning took hold (Hall 1996). Its proponents held that if the
components of the urban system could be understood, their interaction could be controlled and its improvement achieved. It is worth noting that geography’s quantitative revolution and the early development of regional science, both of which provided theoretical grounding for modeling urban processes (Klosterman 2001), represented concurrent preoccupations with systems thinking in the social sciences generally, and in the spatial disciplines in particular (see Harvey 1969, and Chorley and Haggett 1967). Klosterman (2001) characterizes this period in planning as one of “applied science,” where the role of information technology was primarily that of data processing in the interest of system optimization. Those terms appropriately suggest the influence of operations research and management science on the planning practice of the day (Batty 1994). Brail (2006) classifies the most ambitious modeling efforts in planning of the 50’s and 60’s as Large Scale Urban Models (LSUMs), defined by Lee (1973) as comprehensive land-use models of specific urban areas, and Urban Transportation Modeling Systems (UTMS), those designed to allocate trips among the links in a transportation network consisting of existing and proposed elements.

Both model types strove to numerically predict the outcome of alternative plans, representing what Malczewski (2004) has called the “instrumental rationality” of a positivist paradigm underlying the applied science conception of planning. In this view, the primary assumption of modeling efforts was, “the better data processing capabilities (and more information), the better is the quality of the planning.” In the case of the LSUMs, however, the relationship between data and results was often ill-understood, contributing to criticisms of some models as “black boxes” which returned whatever the modeler considered reasonable output (Lee 1973, Batty 1994).
This lack of transparency, combined with the difficulties of working with early computing systems, made urban modeling efforts expensive and time consuming, and their results often inconclusive. At the same time, the rapid pace of change in western society and during the 1950’s and 60’s meant that, in many cases, the fit of the early LSUMs to planning theory and practice barely exceeded the period required for their development. The backlash was pronounced, but not without product. Although Lee’s 1973 polemic against the earliest phase of computing in planning, *Requiem for Large Scale Models*, provided fodder for advocates of a reactionary disjointed incrementalism in planning generally (Harris 1994), it began to build criteria by which later tools for planning have been evaluated, and fostered a spirit of self critique among modelers. What Batty has called the “volatile context” of planning had shifted under the forces of economic, political and social change. In place of rational planning, management and small-scale projects took the fore (Batty 1994). The requirements for information technology in planning changed from data processing and system optimization to the provision of information for management practices and decision support (Klosterman 2001). The tools evolved accordingly.

### 2.2 GIS for planning: decision support

Revisiting that early history from the perspective of 1994, Batty could already point to the ubiquity of GIS in planning organizations and the incipient, though largely unrealized, potential for integrating more sophisticated models with its versatile database structure to meet the challenges of planning tasks (Batty 1994). How was the transition effected?
The adaptability of GIS to an immense variety of spatial concerns has been widely acknowledged, and its potential for decision support in particular was recognized relatively early (see Armstrong, Densham and Rushton 1986). This factor, as well as its utility for the organization and ready display of large collections of differently-themed, spatially associated data, contributed to its wide and early adoption in a planning-technology context which focused on managing information, project-based modeling, and visualization (Klosterman 2001, Batty 2001).

As early as 1990, the requirements associated with adapting a COTS GIS package to the tasks of planning were well understood (Scholten and Stillwell 1990). Geertman and Toppen (1990), for example, recognized the need for GIS decision support tools in planning to be accessible to non-expert users and flexible in their ability to answer questions. Their prototype for a tool to select and evaluate locations for new housing development is an early example of a task-oriented user interface built onto an existing GIS package. They underline the necessity, typical in planning, of extracting formal criteria from the provisions of a natural language policy document so that they can be evaluated in the GIS, and describe four typical users of GIS in the planning context: information specialists, policy designers, decision makers, and stakeholders.

Densham (1991) specified the general structure of a Spatial Decision Support System (SDSS) based on a GIS as consisting of a database management system, a model base management system, graphical and tabular report generators, and a user interface. He further stresses the importance of the ability of such systems to support a decision research process as opposed to a decision-making process, that is, to accommodate the flexible and extensible analysis of a problem. The SDSS template has been widely
adopted, and adapted, in applications for planning tasks (for more recent examples, see Ribeiro and Antunes 2002, Arampatzis et al 2003, and Eldrandaly 2003).

Of course one of the most essential modeling capabilities in many SDSS is effectively a-spatial: a means of comparing the merits of different spatial choices. A set of robust analytical techniques aimed at the objective and transparent evaluation of complex spatial decision alternatives has been developed under the rubric of multi-criteria evaluation (MCE), multi-criteria decision making (MCDM), and multi-criteria decision analysis (MCDA). These terms are considered collectively here, after Malczewski (1999) and Eastman’s (2005) description of their differing, though related, aims. Under these methodologies, complex spatial decisions are broken down into a multi-dimensional matrix consisting of goals, decision makers, objectives, and the attributes associated with a set of spatial alternatives existing under one or more states of environment (Malczewski 1999). The attribute values of decision alternatives are typically standardized, weighted according to the preferences of decision makers, and combined in a single value which facilitates the comparison of several alternatives. Criteria scores may be Boolean values, standardized measured quantities, or levels of membership in expert-defined fuzzy sets. A variety of mathematical “decision rules” may be used to combine the attribute scores and criteria weights, including weighted linear combination (WLC), and the ordered weighted average (OWA). The decision rule impacts the outcome of the analysis, making domain knowledge highly important in the choice of a rule appropriate to the problem at hand (Eastman 2005, Jiang and Eastman 2000). Malczewski’s (2006) recent review of the literature attests that the application and
extension of these methods in GIS-based decision support has been legion (for example Marinoni 2005, Jankowski, Adrienko and Adrienko 2001).

In concert with the evolving conception of planning practice and expanding technological capacity traced by Klosterman (2001), however, a new breed of tools has been developed around the SDSS concept, with the addition of components specifically chosen to facilitate a “collective design” approach to planning.

2.3 Back to large-scale, with pictures: PSS

The Planning Support System (PSS) concept was described as early as 1989 by Harris (1989), and has been defined as an extension of SDSS which suites and promotes the contemporary planning process. According to Klosterman (2001), a PSS must be developed specifically for the examination of long-term strategic plans and, in addition to the capabilities afforded by a conventional SDSS, it should also facilitate group interaction and discussion. A PSS, while “undoubtedly” based on a GIS, would constitute an “information framework” suited specifically to planning tasks and process. Extending the information framework conception of PSS, Geertman and Stillwell (2003, cited in Vonk, Geertman and Schot 2005) consider a PSS a collection of “theories, data, information, knowledge, methods, tools, etc” to support a unique planning task. In this guise, a PSS rivals the scope of an LSUM while updating it to fit the contemporary planning context and exploit current information technology. Brail (2006) contends that PSS are in fact the contemporary incarnations of the LSUM and the VIM (Visualization and Impact Model). Some of the efforts discussed by these authors as PSS entail a
considerable amount of non-GIS components, notably the UrbanSim effort (Waddell 2002).

For all the promise of PSS, however, it has been suggested that development and adoption of the tools are moving slowly. Vonk, Geertman and Schot (2005) identify specific “bottlenecks” to the adoption of PSS in practice, including lack of awareness of and comfort with the technology among potential users. In trying to explain these factors, they point to differences between the exploratory, developmental nature of academia, where the technology originates, and the pragmatic, time-limited nature of professional planning. Brail (2006) asserts that planning support systems have “not reached their full potential,” noting the absence of significant governmental support for the technology, as well as the need for education targeted at building the skills and comfort of practicing planners with the tools. He also balks at the costs of implementing full-fledged PSS, concluding, “Local governments with limited resources need simple and workable tools to assist the decision process. It is still unclear to me if it is even reasonable to assume that locally focused VIMs will be useable in places where significant growth is expected.”

2.4 Contemporary GIS and Planning

Concurrent with the development of PSS have been methodological and theoretical trends in Geographic Information Science driving the increased use of GISystems for planning problems. On the one hand, the last several years have seen plentiful combinations of GIS and modeling, the appearance of model building tools in COTS GIS packages, the increasingly seamless integration of geocomputational techniques with
GIS, and extensions of standard data models for specific domains, including planning. On the other hand, critical examination of the expanding use of GIS in society attempts to reconstitute the technology in forms more coherent with the democratic imperatives of contemporary planning.

Following on widespread calls for greater integration of GIS and analytical methods, a host of approaches have been explored. Maguire, Batty and Goodchild (2005), for example, collect a range of descriptions spanning the scale from “loose” to “tight” coupling of GIS and modeling tools. As might be expected of an industry publication, many of these give special attention to ESRI’s ModelBuilder, a graphical modeling environment included in that company’s ArcGIS package (see for example Israelsen and Frederiksen’s (2005) transportation demand modeling study), although other arms of the GIS industry are likewise incorporating modeling tools in their COTS software, including ERDAS IMAGINE and TransCAD. Meanwhile, the very active research community in geocomputation makes use of GIS as a base for increasing realism in modeling urban as well as environmental processes (Albrecht 2005), employing agent-based simulation and cellular automata approaches especially (Frihida 2002, Torrens 2001, Ahearn 2001, Clarke 2003). As these approaches flourish in academic settings, more young planners and geographers are likely to become conversant in them.

Worboys (2005) describes the underlying database structure of a traditional GIS, pointing to the abilities and limitations of the relational model, which result from a lack of semantic constructs and the high performance overhead associated with geospatial data processing. While the major commercial GIS packages are still not strictly object-oriented, significant extensions of the relational database model have been made in both
development and applications phases to facilitate the semantic cohesion of spatial entities. Commercial systems now widely support network analyses based on modeling of topological relationships at the database level (see for example Arctur and Zeiler 2004). Such abilities form the foundation of further customization to suit the needs of specific domain areas and projects, as in New Jersey Department of Transit’s highway data model (New Jersey Department of Transit 2003). In a more conceptually-oriented vein, Hopkins, Kaza and Pallathucheril (2005) describe a GIS based planning data model (PDM) to represent non-spatial objects including plans, actors and organizations, together with the spatial objects with which they interact, in a common database. Further extensions of traditional GIS data models include ongoing developments in modeling entities in space-time (Koncz and Adams 2002) and models of processes (Reitsma and Albrecht 2005), both of which have implications for modeling urban space.

A contextual turn in GIScience is also leading the way toward new understanding and nuanced applications of geospatial technology in planning. With its increasingly important place in the functional workings of society and its institutions, and in response to critical forays by social geographers (see for example Pickles 1995), a series of calls for examination of the roles and uses of GIS in society have been issued (see those of NCGIA at http://www.ncgia.ucsb.edu/other/ucgis/ed_priorities/access.html and UCGIS at http://www.ucgis.org/priorities/research/research_white/1998%20Papers/soc1.html). One response to such imperatives is embodied in the field of Participatory Geographic Information Science. Jankowski and Nyerges (2001), working in this realm, describe the use of structuration theory to facilitate both descriptive and normative understanding of the use of GIS for group decision making, emphasizing the importance of research
balanced among the three domains of theory, method and substance. Public Participatory GIS extends the concern with participation to include the public stakeholder (Ramasubramanian 1999), improving the fit of data-centric decision making to the contemporary planning philosophy of collective design described by Klosterman (2001).

Still, not all ideas about GIS and planning play nice together. Malczewski (2004) describes a conflict between two conceptions of rationality in the use of GIS: a communicative or procedural one represented in socially-oriented GIS decision support tools, and an instrumental one underlying their development and the advancing analytical techniques of GIScience. It is this dialectic that contemporary researchers and developers concerned with a spatially integrated social science must negotiate. Statistically derived cellular automata transition rules may not be suitably transparent for simulation use in public participatory settings, for example, and development-intensive methodological approaches in general may not meet the temporal and budgetary constraints of planning work on the ground. The task for applied research using GIS for planning decisions, then, appears to be that of identifying and adopting from the wealth of technique and theory available the set of suitable, and feasible, tools to meet the immediate need, while laying the groundwork for future extensions.

In the case of the work presented here, budget and time limitations argue against the implementation of a full scale PSS, although one might be considered highly desirable for the region. The development of intuitive custom tools for multicriteria spatial decision support within the integrated modeling environment of a COT GIS package, on the other hand, is chosen as an efficient and extensible solution, with the potential to facilitate the future use of site evaluation models by GIS professionals in
local planning agencies. In the interest of transparency and out of concern for the planning context within which the study takes place, a conventional methodology for accessibility analysis is chosen over agent- or process-based modeling approaches. A custom data model drawing on object oriented design principles is developed for the domain of interest, both to facilitate the current analysis and as a contribution to related future work. Finally, although the current analysis does not incorporate input from the public in the widest sense, expert stakeholder involvement strategies drawn from participatory collaborative approaches to spatial knowledge production underpin the design of the site evaluation models. The following chapter discusses the methods used in detail.
Chapter 3: Methods

This chapter describes in greater depth the methods employed in the current study, following on the contextual and methodological background provided by the review of literature. It is partitioned into sections corresponding to (1) the design of urban geographic databases and data models, (2) several methods for the development and implementation of spatial decision support tools for planning, and (3) a discussion of modeling the concept of accessibility, a key element of the current research, in a GIS environment. These segments provide detailed background information on the methods that will be used in the remainder of the study.

3.1 Geographic databases and data models for urban research

Huxhold (1991) describes the need for geographic databases to facilitate storage, integration and access to large quantities of data accumulated about urban and metropolitan areas. These structures horizontally integrate data originating in diverse agencies, and enable their vertically integration through analysis to generate multi-thematic data products.

Huxhold underlines the necessity of a highly detailed, accurate geographic base file (GBF) to serve as a locational reference for a geographic database, noting that in urban applications GBFs typically represent street segments or small census areal units. Both are examples of planimetric data types, those derived from observable physical feature on the earth as registered through remote sensing. Conversely, property data, which also tend be important in urban geographic information systems are examples of cadastral data. These represent “interests in land” by owners and other stakeholders and are often digitized from legacy documents and paper maps, and hence prone to spatial
errors. The combination of cadastral and planimetric data can be problematic, but is often required by the application at hand (Huxhold 1991).

Relational database management systems (RDBMS) are described by Worboys as the foundation of the majority of current geographic information systems (Worboys 2005). Relational database logic has been touted for minimizing redundancy in multi-function data environments by allowing users to create custom views on data using queries, and form linkages (relations) between tables of data based on common fields (Huxhold 1991, Galati 2006). Relational databases also facilitate the integration of spatial and non-spatial data holdings (Galati 2006).

Worboys, however, points to the limitations of relational databases, particularly for GIS, because of their lack of semantic constructs capable of mimicking human understanding of the real-world objects modeled, and the inefficiency of traditional RDBMS methods for manipulating spatial data. As a solution to the former, he prefers structures derived from object-oriented programming languages for the storage and manipulation of geographic information, advocating fully object-oriented database management systems and object-oriented extensions of relational databases as two improvements over RDBMS for GIS. In the same space he mentions the wide utility of object-oriented approaches to semantic data modeling, “data models whose primary roles are to represent the meaning of the application domains as closely as possible.” These communicate the ontology of a given application area and are often developed as preliminary to functional databases designed to model that area.

Chang (2008) considers the geodatabase data model implemented in the current version of ESRI’s ArcGIS software an “object-based” data model, which provides many
of the advantages of object-orientation described by Worboys while integrating seamlessly with the major relational database systems. Specifically, the ESRI geodatabase facilitates logical/thematic organization of datasets, enforces a common spatial reference among diverse source data, maintains geometric attributes of features, and provides support for network analysis operations, subtyping, spatial subsetting of a database, database schema export, and self-documentation in diagrammatic form (ESRI 2008).

A procedure for designing application area-specific data models based on the geodatabase is described by Arctur and Zeiler (2004), consisting of three high level phases: conceptual, logical and physical design. Their conceptual design phase includes the tasks of identifying intended data products and their associated thematic data requirements and spatial representations, and grouping them according to data type and the conceptual divisions of the domain being modeled. Logical design includes the specification of the tabular structure of tables within the database, the constraints on attribute values and the behavior of spatial objects, and the relations between tables. The physical design phase is essentially implementation and maintenance of the database and the documentation of the final design, which can then be shared and reused.

3.2 Spatial Decision Support Techniques

Over time the accumulated experiences of land managers and planners with spatial decision support have been integrated with Armstrong et al.’s (1986) original formulation of the tools to develop a body of robust theory and technique informed by a wealth of lessons learned. Those with special pertinence to the current study, and reviewed here,
include 1) methods for preliminary-phase design of a spatial decision support system or tool for planning applications, 2) multicriteria evaluation techniques for the comparison of spatial alternatives, including the use of the Analytical Hierarchy Process for the derivation of criteria weights, and 4) the elements of user interaction with a software spatial decision support tool.

3.2.1 Development phase decision research for spatial decision support system/tool design

Densham (1991) underlined the notion of “decision research” in opposition to a more instrumental and inflexible “decision-making,” asserting the importance of the former in true spatial decision support (see above). This approach has formed an enduring aspect of spatial decision support systems, contributing fundamentally to the differentiation, in the minds of many developers, between SDSS and Geographic Information Systems (Jankowski et al. 2006). Intended originally as an aspect of the functioning of a decision support system, the notion of “decision research” can be expanded to the design phase as well, in what might be called “development phase decision research methods”.

Geertman and Toppen (1990), in their discussion of a tool to evaluate sites for new housing development in the Netherlands point to the importance of extracting criteria spelled out in policy documents in such a way as to measure and compare alternatives along those criteria using data in a GIS. This operation, they note, is essential to decision support in the planning realm, in which problems and desirable states are typically formulated in the language of policy. In actual practice, criteria may be stated more colloquially. The translation of such language into the specification of
measurables and operations within a GIS thus forms one of the most essential aspects of development phase decision research. This process is an aspect of the formalization process more generally.

Formalization here refers to the process of assigning unambiguous logical concepts which may participate in computational processes to the ambiguous language and ill-defined concepts employed by human decision makers. This process is required in any modeling exercise, but tends to be more difficult in modeling higher level social phenomena than in models of physical processes (Richmond 2001). Planning criteria for use in a spatial decision support system are typically the former, and merits careful consideration in the process of system design.

More recently, these issues have been discussed with a focus on developing ontologies (Kuhn 2005, Albrecht, Derman and Ramasubramanian forthcoming). Ontologies of information systems define the fundamental concepts in a domain and the possible relationships between them. Kuhn (2005) likens them to conceptual coordinate systems, or “frames of reference for positioning concepts in a certain context,” and points to their importance in promoting the interoperability of analytical services as GIS moves from desktop to distributed environments. Ontologies have become an important part of data modeling research in GIS and elsewhere.

Formalization in general, and ontology building as one of its phases, contributes beyond its practical use in the implementation of a given project. It has the added benefit of contributing unambiguous communicability of the concepts modeled. Ontologies in particular promote the standardization and reusability of a given set of concept definitions across projects. For example, the development of an ontology for a GIS waterborne
transportation infrastructure planning database (or land use-aware transportation planning
database more generally) in the context of one region or project might enable its re-use in
another region with its own specific characteristics later, promoting the standardization of
concept definitions and the efficient implementation of similar studies.

In their presentation of an integrated software tool for multicriteria land use
planning based on a GIS, Pettit and Pullar (1991) describe their use of surveys of
practicing planners as an aspect of development phase decision research. Their survey
measured respondents’ preferences in the areas of planning problem conceptualization,
methods of evaluating alternatives, and software graphical user interface components.
They also describe concealing the GIS operations involved in evaluating planning options
behind what they term an \textit{intuitive} user interface, meaning one which replicates the
planner-users conceptualization of the problem domain. This approach serves to
maintain the user’s ontological conception of the domain all the way through the process
of analysis.

Jankowski et al. extend the theoretical underpinning of development phase
decision research by focusing on the solicitation of stakeholder concerns early in the
development process (Jankowski et al 2006). In their approach stakeholder concerns,
considered as emanating from values, “deeply held beliefs and moral convictions
affecting the user behavior,” are used to derive the information requirements of the
decision problem, and hence drive the design of appropriate supporting technology. In
the same paper, the authors suggest the use of modular software systems for decision
support to alleviate the often prohibitive cost of comprehensive systems, and ultimately
to drive the development of reusable yet customizable solutions.
3.2.2 Multicriteria evaluation techniques

Multicriteria evaluation techniques have been widely applied in spatial decision support with GIS, particularly in studies of land use suitability. Malczewski (2004) describes a multicriteria technique generally as “a process that combines and transforms spatial and aspatial data (input) into a resultant decision (output)” in such a way as to utilize the “geographical data, the decision maker’s preferences and the manipulation of the data and preferences according to specified decision rules.” The essential function of these techniques is to reduce the dimensionality of alternatives such that they can be compared or ranked along a single measure.

A variety of multicriteria evaluation approaches may be taken in spatial decision depending on the characteristics and number of alternatives, the number of decision makers involved, and the expected uncertainty associated with decision outcomes. At the highest level, Malczewski draws a distinction between multiattribute and multiobjective techniques. The former correspond to discrete decision making situations, in which a known finite number of alternatives are to be compared, while the latter corresponds to a continuous field of alternatives, and amounts to a solution search across that field. Multiattribute decision techniques are simpler and have been more widely implemented in GIS decision support applications (Malczewski 1999, 2004, 2006).

A mathematical decision rule must be used to assign a commensurate unidimensional value to the set of alternatives under examination in a multiattribute evaluation, incorporating the preferences of criteria importance held by the decision makers or maker. A variety of decision rules exist, among which the most common is the
Weighted Linear Combination (WLC), which weights a set of standardized criteria values according to the relative preference structure of the decision maker(s) and sums them to a composite score:

\[
\text{Composite Score} = \sum w_i X_i
\]  \hspace{1cm} (1)

Where \( w_i \) = weight assigned to factor \( i \) and \( X_i \) = criterion score of factor \( i \)

(Eastman 2005)

With sufficient expert involvement to define criteria thresholds and differentiate the criteria preferences structure for individual alternatives, the Ordered Weighted Average (OWA) technique, and fuzzy membership functions for criteria standardization may be used to control the degree of tradeoff between values of the individual criteria for each location, adding a level of modeling flexibility lacking from the basic technique (Eastman 2005, Malczewski 2004).

The Analytical Hierarchy Process (Saaty, 1980), based on the pair wise comparison of elements at each structural level of a decision process, has been used in GIS multicriteria decision support to facilitate the collaborative determination of criteria weights to be used in a decision rule (Malczewski 2004). In this process, participants assign relative weights to each pair of criteria in a symmetrical matrix in which the columns and rows each represent the full set of criteria. The weights of each criterion relative to the others are summed and standardized to derive an overall weight for that criterion. This procedure allows a considered, comprehensive comparison of a large number of criteria which would otherwise be difficult to rank by precedence. The different derived criteria weightings of each participant can then be averaged to arrive at a measure of the group’s combined criteria preference structure.
These methods are not without criticism. Specifically, it has been shown that the results of MCE decision-making can be highly sensitive to inaccuracies in data and the criteria standardization methods employed, not to mention the weights themselves. Sensitivity analysis has been advised as a method of testing the influence of such technique-induced bias in decision results (Malczewski 2004).

Although the purpose of MCE is to deliver a unidimensional ranking of alternatives, and this would seem to be a requirement of a data-informed decision process, Pettit and Pullar’s (1999) survey shows that professional planners typically prefer matrix comparison over ranking alone in the presentation of the results of a decision analysis. Matrix comparison was thought to facilitate an assessment of the interaction of the criteria among alternatives. Given the tabular operations necessary to arrive at an MCE ranking of alternatives, however, it is relatively simple to provide decision makers with both forms of output.

3.2.3 Human computer interaction for spatial decision support

In their classification of human-computer interaction paradigms, modalities and styles employed in GIS software interface design, Egenhofer and Kuhn (2005) note the high importance researchers have assigned to this aspect of GIS use and development in recent years. They laud the progress made in usability over the previous decade, while bemoaning the fact that higher-level GIS tasks still generally require an expert user: “the user interface itself too often remains an impediment to effective system use in problem-solving or decision-making.”
Densham (1991) described the user interface of an SDSS as one of the fundamental components of the technology, noting the importance of ease of use and the ability to portray “objective,” or quantitative, as well as mapped space. Pettit and Pullar (1991) state that “the most important components of the MCE Planning prototype [the software tool presented in their article] are those that involve interaction with the user.” Their approach is to use the scripting language of the underlying GIS application to build a series of dialogue boxes that guide the user through the process of generating and evaluating planning options. These boxes, which present tasks in the language of the planner as opposed to the GIS professional, represent tools that run within the GIS software package.

Jankowski et al.’s (2006) collaborative spatio-temporal decision support system WaterGroup allows users to iteratively enter queries and view results, including capabilities for switching between thematic displays.

Both tools exploit what Egenhofer and Kuhn refer to as graphical user interface (GUI) interaction styles, which facilitate human-computer interaction relying on text and graphics modalities, to accomplish tasks within the analyzing and querying interaction paradigm appropriate to the problem. This is by far the preferred current solution to the usability/functionality dilemma in GIS, although Egenhofer and Kuhn suggest that new developments are just over the horizon, including the increasing presence of geoprocessing and spatial terminology, both in GIS environments and in human-computer interaction more broadly.
3.3 Modeling accessibility

The concept of accessibility is central to the formalization of several criteria involved in the evaluation of potential waterborne transportation infrastructure sites in the current study. The reasons for its importance stem from the preliminary decision research process undertaken in preparation for the design of an appropriate software tool for the study. These will be discussed in chapter 5 (Application of Methods). This section focuses on a method for implementing the concept of access and accessibility, and evaluating the accessibility of sites through a geographic data model.

Lui and Zhu (2004) present a conceptual framework for analyzing accessibility in the context of a GIS for transportation planning, and a custom software tool designed for that purpose. Their integrated methodology relies in large measure on transportation, land use and socio-economic data. The software tool they describe is developed as an extension for use with ESRI’s ArcView GIS software package, and interoperates with its other extensions.

Lui and Zhu’s conceptual framework follows a generalized multi-step procedure for accessibility analysis, consisting of: “formulating the concept of accessibility, selecting or developing accessibility measures, specifying the accessibility measures, deriving the accessibility values using the selected or developed accessibility measures, and presenting and interpreting the accessibility values.” Some steps in the process merit closer examination for their utility in the present study.

The first two steps relate to the notion of formalizing natural language terminology for implementation in GIS decision support as discussed above. Specifically, step one involves “defining the purpose of accessibility analysis,
understanding the planning context within which the accessibility analysis is to be conducted, and formulating the concept of accessibility.” Step two involves selecting and specifying accessibility measures which can be used to implement the definition of accessibility derived in step one. As the authors write, “an accessibility measure is usually formulated in terms of a set of destinations representing activity sites and set of origins representing potential users of the facilities at the activity sites” and its specification may include elements such as: “a spatial unit for analysis, the definition of socio-economic groups, the type of opportunities, the mode of travel, the definition of origins and destination, and the measure of attractiveness and travel impedance.” The authors describe the attributes of socio-economic groups considered in transportation planning studies as typically including family income and car ownership.

Travel impedance, or cost, may be measured using network distance (also known as shortest path distance), along real travel routes as opposed to straight line distance. Liu and Zhu’s methodology interprets this distance between origins and destinations to consist of three parts: the distance $d_1$ between the origin and the nearest point on the travel network, termed the boarding point; the network distance $d_2$ between the boarding point and the point on the network nearest the destination, the alighting point; and the distance $d_3$ between the alighting point and the actual destination. This approach is used to account for the spatial offset between actual origin and destination points and the network links traveled.

Lui and Zhu’s ArcView extension calculates and returns a set of accessibility measures after those measures have been specified for the given problem. Among the accessibility measures are a Catchment Profile Analysis tool, which finds the nearest
destination to each origin, and a *Cumulative-Opportunity Measure* which returns the number of opportunities accessible within a given time or cost from an origin. For step four, *interpretation and evaluation*, the extension utilizes the native visualization capabilities of ArcView as well as generating custom charts summarizing the accessibility of chosen destinations. The extension is divided into tools which may be run independently or combined to achieve the integrated conceptual approach the authors describe.
Chapter 4: Study Region and Description of Data

4.1 Regional Setting

4.1.1 Physiography, Economy, Population

The study area for this research is situated in the three-state metropolitan New York City region (Figure 1). The unique physical geography of this region led originally to its early importance as an economic center, and continues to shape the pattern of its land uses and transportation system. The several waterways lining the region have created transportation and shipping opportunities, while at the same time separating and directing the flow of its population and resources. The linear character of its physiographic features, especially the Hudson River, Long Island Sound and the island of Manhattan have contributed to the development of settlement and industry along corridors, and the location of important economic zones, such as the central business district (CBD) of Manhattan in close proximity to the waterfront (Adams 1996).

The centers of industrial production once located along the Hudson north of New York City have largely closed as the region has shifted toward an economy based on producer services, especially finance and media. With this change has come the increased concentration of economic activity and employment opportunities in Manhattan (Adams 1996, Weil 2004). At the same time, the population of the region has continued to grow dramatically. The ten New York State counties in the area alone are home to 11.3 million people (New York Metropolitan Transportation Council (NYMTC) 2008). The population of New York City alone is projected to increase by over a million by 2025 (City of New York 2008).
With population growth and economic restructuring the region is seeing significant changes in the use of its waterfront. Areas which were once primarily devoted to industrial production and shipping are being transformed for residential and recreational uses, locating both residential and commercial development closer to the waterways. With increasing numbers of residents living along the shoreline, and greater concentration of employment opportunities in Manhattan, the waterways appear increasingly viable for commuter transit services (Camay et al. forthcoming).

Figure 1. The tri-state metropolitan New York City region. The area in green defines the boundaries of commuter origin-destination census tract pairs considered in the current study.
4.1.2 Transit in the Region

The transportation system of the region is diverse, including roadways, commuter railways, local and express (micro-regional) bus services, New Jersey’s Path train system and the New York City Subway, more than thirty existing private commuter ferry services as of June, 2007 and one public ferry service (the Staten Island ferry). The region accounts for a third of the nation’s mass transit usage and two thirds of its commuter rail ridership. Nearly all of these modes are judged to be at or near their capacity, and reliant on aging infrastructure. Thirteen of the twenty-five large US counties with the longest commuting times are within the New York metropolitan area, and among global cities like London, Singapore and Tokyo, New York is seen to have fallen behind in investment in, and quality of, its transit system (Camay et al. forthcoming).

For all of these reasons, and in the hopes of becoming a model of the sustainable global city, Mayor Michael Bloomberg has made improved transportation a major facet of PlaNYC, New York City’s long range plan (City of New York 2007). It has been suggested that new ferry services could play an important role in achieving these goals (Lader 2006, Rivera 2008).

4.1.3 Planning in the Region

The area within the New York City (NYC) metropolitan region is under the aegis of several units and multiple levels of government, including municipal, county, state and federal agencies. As in many areas of the United States, local governments exert a high level of control over land use planning decisions. In the NYC metropolitan region, for
example, zoning decisions are the province of local government. Transportation planning and operations are variously undertaken at the city, county and state levels. Much of the funding for transportation projects administered by the state agencies flows from the federal government. In some cases state agencies oversee land use plans, as in the New Jersey State Plan (State of New Jersey 2007).

The daunting task of cross-jurisdictional regional planning is undertaken by the Regional Plan Association (RPA) and the New York Metropolitan Transportation Council (NYMTC). The RPA, a private non-profit, has undertaken numerous studies and white papers in its eighty-six year history, focused on regional planning issues with a particular interest in economic development (RPA 2006). NYMTC is the federally-authorized Metropolitan Planning Organization (MPO) for the region including New York City, and is primarily concerned with transportation planning (NYMTC 2008).

With the exception of the Staten Island Ferry, which moves commuters between the borough of Staten Island and lower Manhattan, ferry services in the region have been unsubsidized ventures by entrepreneurial operators. In the current context, these services utilize public landside infrastructure for docking and passenger pickup, or private facilities where partnerships with real estate holders have been developed. Without the benefits of public subsidy enjoyed by operators of transit modes, ferry operators are reliant on such real estate connections, as well as a clientele which can support the relatively high cost of fuel and boat maintenance.
4.2 NYMTC and the Ferry Parking and Landside Access Study

4.2.1 The New York Metropolitan Transportation Council (NYMTC)

NYMTC’s website describes its mission:

To serve as the collaborative forum to address transportation-related issues from a regional perspective; to facilitate informed decision-making within the Council by providing sound technical analyses; to ensure the region is positioned to capture the maximum federal funds available to achieve the goals of the Unified Planning Work Program, Regional Transportation Plan and Transportation Improvement Program; and to focus the collective planning activities of all Council members to achieve a shared regional vision. (NYMTC 2008)

In its capacity as a facilitator of collaborative planning, NYMTC brings together as voting members Nassau, Putnam, Rockland, Suffolk and Westchester counties (in New York State); the Metropolitan Transportation Authority (MTA) of the State of New York, The New York City Departments of Planning and Transportation; and the New York State Department of Transportation. It also includes non-voting member agencies from New York State, New Jersey and the federal government.

NYMTC was created in 1982 after the dismantling of the Tri State Regional Planning Commission, an MPO which included areas within New York, New Jersey and Connecticut. Although it is the MPO for the region surrounding New York City, its mandate is restricted to a ten county area within New York State, and therefore excludes the areas of New Jersey and Connecticut which send large numbers of commuters to New York City on a daily basis. NYMTC has recently signed a cooperative agreement with New Jersey; currently representatives of New Jersey and Connecticut sit on the NYMTC Board, albeit with limited authority. The lack of formalized inter-state cooperative planning has posed operating difficulties for the MTA and the Port Authority of New
York and New Jersey, the two inter-state agencies in the region. Efforts at collaborative planning between NYMTC and the other MPOs in the region are ongoing (NYMTC 2008). The area under NYMTC’s jurisdiction is pictured in Figure 2.

Figure 2. The ten-county NYMTC jurisdiction and an overview of study site locations.

4.2.2 The Ferry Parking and Landside Access Study

The Ferry Parking and Landside Access Study (FPLAS or the Landside Access Study) represents a comprehensive effort on the part of NYMTC to inventory and evaluate existing and potential locations for waterborne transportation infrastructure in its ten-county region based in large part on the land-use characteristics of sites. It is one of a set
of research projects sponsored by NYMTC and undertaken by academic consultants through the University Transportation Research Center, Region II (UTRC). This arrangement is meant to enable goals of objective, scientific, technologically progressive methodologies (UTRC2 2007).

The aims of the FPLAS project include 1) a comprehensive review of previous research about waterborne transportation needs and opportunities in the region, 2) the development of evaluation criteria to assess the viability of both existing and potential sites for the development of waterborne transportation infrastructure, and 3) the evaluation and prioritization of sites for development. Accordingly, a thorough review was made of previous studies of waterborne transportation planning in the metropolitan New York region, nationally, and internationally; and criteria for the evaluation of sites were developed based on that literature and a series of local expert interviews. This paper presents the methodology and results satisfying, in part, the third goal by objectively evaluating and ranking sites. The objective methodology presented here will be followed by public outreach and impact assessment, which may result in revisions to the prioritized list. Camay et al. (forthcoming) describes plans for public outreach as well as other details of the Landside Access Project.

Going beyond the original requirement of the FPLAS project for the one-time delivery of a prioritized list of sites, the work presented here includes the development of a geographic database and a set of site evaluation models for planning decision support capable of assessing sites according to the Landside Access Study criteria and providing additional detailed information, and multicriteria models for the flexible comparison of
sites. At the conclusion of the Landside Access Study, the database and models will be given to NYMTC to use in future site analyses.

4.2.3 FPLAS-determined criteria for site evaluation

Based upon review of regional, national and international studies of ferry landing requirements and interviews conducted with local domain experts, criteria were identified for the evaluation of potential sites for ferry infrastructure development in the study region. Several of the interviewees described two types of sites, each with specific evaluation criteria: origin sites, at the home end of a commuter’s trip, and destination sites, at the work end.

At origins, accessibility to a site was determined to be of utmost importance. Three modes of access were identified as important: driving, walking and bicycling. Access by another mode of mass transit was considered relevant but less important. Associated with accessibility by automobile were requirements for parking and road access. Available space for the construction of new parking facilities was considered highly desirable in the absence of or in conjunction with existing parking. Residential density near origin sites was also considered highly important as a determiner of the number of likely users of a site by each mode.

Interviewees associated destination sites with workplaces. Viable existing destination sites were seen to be typified by those which served lower and midtown Manhattan. Correspondingly, destinations were considered viable if they were within walking distance of many workplaces and/or within walking distance of intermodal connections, for example New York City’s subway and bus systems.
More detailed information on the interview methodology and derived criteria are available in Camay et al. (forthcoming) and at the FPLAS project website (NYMTC 2008).  

4.3 Data

The major categories of data which participate in the GIS model-based site evaluations are land use, transportation, socio-economic, origin-destination commuter flows, and site locations. These data originate with diverse organizations, in a variety of GIS data formats, and creation dates. Site data have been compiled for the project.

Spatially, land use data consist of polygons representing land parcels. For some areas spatial data files are available classified by land use category. For others, tables matching parcel identifiers with land use classifications are available in conjunction with polygons containing parcel identifiers. Sources of land use data vary significantly across the study region, and include the City of New York, Rockland, Suffolk and Nassau Counties, individual municipalities within Westchester County, and a private vendor.

Transportation data consist of representations of the multi-model regional transit system. These include lines representing the full set of streets in the study region, the commuter rail routes, local bus routes, subway routes, and existing ferry routes; and points representing bus stops, subway stops and commuter rail stations. The sources for these data are the City and State of New York, Westchester, Rockland and Nassau County, and NYMTC.

Socio-economic and commuter flow data are obtained from the 2000 census. Counts of residents and housing units, rates of vehicle ownership, and median household
income associated with census tracts and block groups come from the census website. Counts of commuters associated with origin and destination census tract pairs in the full New York City metropolitan area (including New Jersey and Connecticut) are extracted from the Census Transportation Planning Package data CDs (U.S. Department of Transportation 2007).

Finally, a set of points representing potential and existing ferry landing sites were created for the study. The locations of existing sites were identified through the Web sites of ferry service operators and visual inspection of satellite images. Potential sites come from descriptions and maps in previous studies and the recommendation of interviewees, in conjunction with satellite imagery. These points are attributed with site names, existing versus potential service status, and latitude and longitude, and combined with a point file of known landing sites in the region obtained from the US Army Corps of Engineers. The latter contain additional attributes including type of use and existing structures. The distribution of sites across the study region can be seen in Figure 2. A complete list of the sites analyzed, their use-status at time of writing, and maps of their locations are in Appendix A.

Beyond what is used for the model-based site evaluations, the geographic database contains reference data such as polygons and point features representing counties, municipalities, census-defined places and facilities, and orthophotos.

Certain limitations on the study exist as a result of characteristics of the data used. First, there are significant differences in the creation dates of data sources. This is of special concern with respect to the land use classification of parcel data. Second, some differences exist in the land use classification systems employed in different subsets of
the study area. In most cases these are resolved through the creation of a comprehensive classification schema which incorporates the multiple classification systems. In the case of Suffolk County’s land use data, however, it is not possible to derive information about the existence of parking areas or public vs. private ownership status. Third, the 2000 census data is almost eight years old at time of writing. Relevant changes in the socio-economic and commuter flow data may have occurred during that time period. In particular, the census data pre-date the events of September 11th, 2001 which is known to have impacted commuter numbers to lower Manhattan, although business, and therefore commuters are now returning. The future use of the site evaluation models will benefit from updating census data as soon as it is available for 2010. Finally, there are potential locational discrepancies between objects in the planimetric data sources (roads, census geographies) and cadastral data sources (parcels) in the database. Visual inspection suggests that these are likely to be minor.
Chapter 5: Application of Methods

This chapter describes the implementation of the current study, utilizing the methods outlined in Chapter 3. It is divided into sections corresponding to the major task groups: (1) the development of a domain ontology appropriate to the problem, (2) the definition of data products and requirements, (3) the design and assembly of a geographic database to support the analysis, (4) the development of site evaluation and comparison models, (5) the derivation of criteria weights, and (6) the multicriteria ranking of sites.

5.1 Development of ontology for transit hub siting

In this section, an ontology is developed to define the central concepts in the evaluation of sites as hubs for waterborne transportation, and guide the design of a GIS database and site evaluation model. The concepts are derived from the site evaluation criteria developed for the FPLAS study. These criteria are described in section 4.2.3 and may be summarized as follows: For origin sites, accessibility is of utmost importance, and should be considered in terms of three modes of access: automobile, bicycle and pedestrian. To facilitate access by automobile, road access and parking (either existing or developable) are essential. Residential density is an important part of the accessibility of origins, in that it defines how many people have access to a site by each mode. At destinations, the availability of workplaces and local transit network (e.g. NYC subway and bus) connections within walking distance are considered essential to the viability of sites.

The definition of concepts underlying the site evaluation criteria is based on the literature review and summary of interviews conducted for the FPLAS project, selected previous studies of waterborne transportation planning, the conceptual approach to
accessibility analysis formulated by Liu and Zhu (2004) described in Chapter 3, and discussion involving members of the FPLAS research team. Research team members, planners and geographers, drew on their disciplinary training and experience, familiarity with the group’s interviews and literature review, and knowledge of the data likely to become available. The concepts underlying the site evaluation criteria are defined as follows.

5.1.1 Parking and Other Land Uses

Existing parking includes both structures and surface parking lots. Developable, or potential, parking was conceived as vacant land which could, ideally, be purchased cheaply and developed as parking.

Land parcels are the entities to which property and development rights are typically attached. Therefore, the potential need for development of parking and other support facilities (waiting areas, ticket booths, service buildings) at potential ferry landing sites dictated the choice of the parcel as the spatial unit of interest for land use-related information.

In addition to existing parking and land suitable for the development of parking, planners on the FPLAS team are concerned with the mix of residential, commercial and vacant land, and the private/public ownership status of land within walking distance of potential sites.
5.1.2 Potential Origin Site Users

The transportation of commuters is seen as the primary purpose for new ferry services in the region by the vast majority of interviewees. As such, users of potential origin sites are conceptualized as commuters first and foremost. Because of the primacy of Manhattan as a work destination within the study region, and its several existing ferry landings, commuters to Manhattan are of particular interest.

Other key attributes of the potential user base with access to origin sites are median household income, car ownership (for its impact on the choice of alternative transportation modes), and the number of housing units.

5.1.3 Workers and Workplaces near Destination Sites

In the absence of available employment numbers associated with spatial units of a sufficiently fine grain, employment opportunities near destinations are represented by counts of incoming commuters (to census tracts), as well as the office, retail, and factory space within individual parcels.

5.1.4 Mode-change opportunities

Opportunities for transfer to or from other transit modes within walking distance of sites are conceptualized as nodes on the networks of other transit systems. Relevant information associated with mode-change opportunities are the name of the node, the type of service provided, the system(s) and line(s) served, and schedule and ridership numbers associated with those lines at the node.
5.1.5 Access Roads

Road access to sites is generally seen as important in facilitating parking and passenger drop off, as well as the construction and maintenance of new and existing infrastructure. Yet previous studies and the experience of FPLAS team members suggest that local residents would suffer negative impacts if the development of new facilities resulted in increased traffic, especially on residential streets. Therefore both length and type of roadways near a proposed site are seen as important, and potentially limiting, factors for site evaluation. Residential roadways are excluded from those considered as access roads to sites.

5.1.6 Accessibility

Sites are analyzed as origins to characterize the population with walking, bicycling, and driving access; existing and potential parking area; and opportunities for mode change. As destinations, the interest focuses on workplaces and transit connections that are accessible from a potential site. Accessibility is defined here as the desirable quality of affording users with efficient multi-modal movement between potential sites and their homes, workplaces, communities and other transit opportunities. In the current context accessibility is considered a property of sites.

Transit nodes, including potential and existing ferry landings, are conceptualized as point locations. Transit users are then uniformly distributed within census block group areas, while workplaces as similarly located within parcels, and commuter destinations are approximated by census tracts centroids (census tracts are the smallest unit for which commuter flow data is available). Units of travel impedance are defined as driving time.
or distance for the calculation of automotive accessibility, and distance for walking and bicycling accessibility. Travel cost/distance is measured along a detailed street network filtered by type of link according to the mode of travel.

Figure 3 represents these concept definitions within an ontology for land use- and socio-economically-aware waterborne transportation hub siting. Because of the emphasis on land use and user-base criteria in the current study, the model is generalizable to transportation hub siting applications independent of mode.
Figure 3. An ontology for transit hub siting.
5.2 Definition of data products and requirements

The primary data product of the analysis is a ranking of a long list of potential sites according to a multicriteria decision rule combining a set of measurable indicators chosen to address the FPLAS site evaluation criteria for origin and destination sites, and user-defined weights for each indicator. The ranking is in matrix form, including scores for each indicator, to facilitate an assessment of the interaction of individual factors contributing to overall site scores. In addition, newly generated GIS datasets represent opportunities and user characteristics associated with sites by theme (land use, user base socio-economic characteristics, workplaces, etc.). These can be used for mapping and further analysis.

The key data requirements to create these products are:

- A detailed street network for the entire study area with impedance and mobility/access attributes
- A comprehensive dataset of parcels with land use classification; ownership type (public vs. private); and office, factory and retail space attributes
- A point file of transit nodes with name, type, line(s) served, frequency of service and capacity attributes
- A feature class of census block groups with median household income, housing units, and car ownership attributes.
- Census Transportation Planning Package commuter flows and a census tract feature class for the study region

Additional data necessary for visualization of analysis results include:

- A detailed representation of the shoreline
• State, county and municipal boundaries
• Lines representing the transit network by mode and operator

5.3 Database design and implementation

The geographic database has been assembled according to the conceptual model of land use- and socio-economically-aware transportation hub siting, and the data products and requirements described above. This database is used to support the evaluation and multicriteria comparison of sites using geoprocessing models.

The ESRI geodatabase format was chosen for the underlying physical data model because of its support for the relational and object-based functionality described in Chapter 3, and because, since ESRI products are already in use by NYMTC GIS professionals, the finished database would be more easily transferrable to the organization for their future use.

Within the geodatabase shell, thematic categories (feature datasets) were established for the organization of the various data, including boundaries and reference data, census, land use, and transportation.

New York State’s ALIS street segments line file was chosen to serve as the geographic base file for the database because of its high level of detail, comprehensive coverage of the study area, and the importance of the street network in the definition of areas accessible from hub locations. The coordinate system of the street segments file, NAD 1983 UTM18N is therefore used for the geodatabase as a whole.

Three topological networks were created from the ALIS street segments, each incorporating only those segments traversable by a single mode: driving, bicycling and
walking. The street segments appropriate to each mode are determined by their US Census Feature Class Code (FCC) classification.

A relationship class links the Arterial Classification Code (ACC) classes of the ALIS street segments with the number of lanes associated with each code. This table is then linked to the drivable street network for use in summarizing the access roads near sites by number of lanes.

Feature classes and shapefiles representing tax lots were collected from various agencies throughout the study area. In some cases these geographic data contained land use classifications as attribute data. In others, land use data is available as tables, separate from the geographic files, which include tax lot identifiers. In the later case, the attribute tables were joined to the geographic data. A region-wide feature class of tax lots was then created by merging the feature classes covering various subsets of the study region. In some areas tax lots were merged only for municipalities on the waterfront. The resulting feature class is composed of over 1.5 million individual features. A new field in this feature class holds the sum of office, retail, and factory areas, which were available for all New York City tax lots.

A comprehensive land use classification for tax lots was developed to combine the classification systems used by the different jurisdictions within the study area. To this end, a relationship table containing the comprehensive classification was created in the geodatabase and classes within it were aggregated in a new field containing “mega-classes” corresponding to existing parking, other commercial uses, vacant, and residential land. Land use classes which explicitly specify public or private ownership were identified, and a field added to the relationship table specifying ownership type by land.
use classification where possible. This table is then linked to the region-wide tax lots feature class.

The source data for tax lots within New York City already contains a field specifying their public/private ownership status. These values and the land use classification-derived ownership information are combined in a new field. A field was added to the tax lot feature class to accommodate a projection of change in office space within tax lots as a result of new development.

Transit node feature classes from multiple transit systems within the study area were attributed with “type” and “operator” fields classifying them by mode and operating agency respectively. These were merged into a comprehensive feature class containing transit nodes of all modes for the entire region. Transit routes were similarly attributed and combined. Schedule and ridership data are available in table format from some transit system operators in the study region. These were restructured through table operations in Microsoft Excel so that ridership and schedules could be linked to transit nodes, and the tables stored in the geodatabase.

A feature class of census block groups covering the study area includes attributes for population, housing units, median household income and vehicles per occupied housing unit from the 2000 census. Additional fields contain space for housing units and population change, and the ratios of population to commuters, population to Manhattan-bound commuters and population to housing units. The latter can be used to estimate new commuter numbers based on change in population or housing units (assuming the applicable ratios remain constant).
Counts of commuter flows between census tracts thirty-six counties across the three-state New York metropolitan region can be derived from Census Transportation Planning Package data CDs. Features in the resulting table represent pairings of origin and destination census tracts, visualized as lines connecting the centroids of the two tracts. Matrix operations were performed using MATLAB scripts to aggregate commuters by origin tract, destination tract, and destination county. The resulting tables are joined to a feature class of census tracts, giving them attributes corresponding to incoming commuters, outgoing commuters, and Manhattan-bound commuters. Tract totals for each attribute are allocated among block groups according to the portion of the tract population within each block group, and written to the block groups feature class.

5.4 Model development

A set of geoprocessing models automates the evaluation and comparison of chosen locations as origin and destination sites for ferry service within the study region. The models combine data from the geodatabase described above through spatial and tabular operations to provide information about sites. Model users control several parameters, which incorporate their preferences and domain knowledge in the models’ functionality. “Sub-models” derive information pertaining to individual criteria themes and may be run independently, or in combination as complete origin and destination site evaluations. Two additional models combine information derived about sites with user-defined criteria weights to compare origin or destination sites using multicriteria decision rules.

The following sub-section describes the various sub-models, indicating their purpose within the overall analysis, the user options they offer, the key processes they
implement, and the output they generate. This is followed by a description of model
development and the user interface of the models.

5.4.1 Geoprocessing models for site evaluation and comparison

A dedicated geoprocessing model, called Modeshed Creation, creates catchments, or
modesheds, delineating the area accessible from a site by driving, cycling, and walking;
and an area within which to identify access roads. Modeshed Creation uses the Service
Area Layer functionality within the ArcGIS Network Analyst extension, which identifies
all segments of a street network reachable from a location before a chosen cost value is
accumulated. Cost values are stored as attribute values of street segment features. Once
the street segments within the specified maximum accumulated cost are identified, a
polygon is created in working memory covering the area within an offset of a specified
distance on either side of the segments. This polygon represents the area accessible from
the chosen location along the street network within the chosen cost (or impedance) value.
The maximum accumulated cost value corresponds with Liu and Zhu’s (2004) $d_2$, the
network distance between boarding and alighting points on a network. A maximum
allowable valued is specified corresponding to Liu and Zhu’s $d_3$, the straight line distance
between the alighting point and the actual destination location (which may not be on the
network). The offset value used to define the polygon in relation to the network
segments corresponds to $d_1$, the straight line distance between actual origins and boarding
points.

Modeshed Creation takes a transit hub location and calculates network distance
using the three mode-specific street networks in the supporting geodatabase. Model users
can enter parameter values specifying a maximum cost and unit of impedance for each mode, and within which to search for access roads. Driving and access road search cost can be specified in minutes, miles, or kilometers; biking and walking cost can be specified in miles, meters, or kilometers. Service Area Layer polygons are generated for each, and these are saved to a geodatabase of model output data. The polygons, representing the driveshed, bikeshed, walkshed, and access roadshed of the site are used by the other sub-models to identify the population with access to the site by each mode; the transit connections, land uses, and workplaces within walking distance of a site; and its access roads. They are also used for mapping.

The *Origin Demographic Analysis* sub-model characterizes the population with access to a site by each mode. This sub-model takes the three modesheds of a site created by *Modeshed Creation*, and the census data contained in the geodatabase. The model clips the census spatial units to the boundaries of the three modesheds, calculates the proportion of area within divided units to their original areas, and calculates new values for population, housing, and commuters based on the proportional area after clipping. These estimates are based on assumptions that population and housing units are uniformly distributed across block groups, and commuter counts at the tract level are distributed among block groups in proportion to block group population. The calculated estimates of population, housing units, outgoing commuters and Manhattan-bound commuters are summed, and population-weighted averages of median household income and vehicle ownership rates are calculated for each modeshed. The model returns summary tables and feature classes representing block groups for each modeshed with the calculated values as attributes. A *Destination Demographic Analysis* sub-model
implements the same processes for the walkshed only, to characterize the population
affected by potential development.

Two sub-models summarize land use characteristics at origin and destination
sites: Origin Land Use Analysis and Destination Land Use Analysis. Both models clip
the region-wide tax lots feature class from the supporting geodatabase to the walking
catchment of a site. Both dissolve the boundaries of tax lots by ownership type and broad
land use class (residential, commercial, and vacant). Origin Land Use Analysis also
selects those tax lots classified as parking, dissolves their boundaries and outputs a
feature class representing existing parking areas. Destination Land Use Analysis sums
the office, factory and retail space within New York City tax lots, multiplied by the
proportion of tax lot area within the walking catchment to that of the entire lot. (The
resulting calculation of office, retail and factory space relies on the assumption that the
areas of these uses are uniformly distributed within tax lots.) Both models sum the
vacant, public and private land within the walkshed of a site. Origin Land Use Analysis
also sums existing parking, commercial and residential land. Destination Land Use
Analysis sums the factory, office and retail space. Summary tables are generated for all
these values and geographic feature classes of tax lots within walksheds are written to the
model output geodatabase.

A Destination Employment Analysis sub-model calculates the number of
incoming commuters associated with a destination site. The model clips the census tracts
feature class from the supporting geodatabase to the walkshed polygon of the site, and
multiplies the number of commuters by the ratio of census tract areas within the walkshed
to their original areas. (According to the underlying assumption is that commuting
destinations within a tract are uniformly distributed across the tract’s footprint.) The estimated total number of commuters within the walkshed of the site is output in table form.

*Mode Change Opportunity Analysis* summarizes the opportunities for commuters to change transit modes within walking distance of a potential site. This sub-model sums the number of transit connections within the walkshed of a site by type (bus, commuter rail, subway), and generates a feature class of those connection points and a summary table listing their names and the lines they serve in the model output geodatabase.

An *Access Road Analysis* sub-model summarizes the road access at a site. It clips the drivable streets feature class from the supporting geodatabase to the boundary of the access roadshed for the site of interest. It then aggregates the resulting road segments by ACC class, and sums the length of the segments of class 5 or below (those of greater than “residential” geographic significance).

Two *Site Description Summary* sub-models, an origin and a destination summary, combine the information about a site generated by the other sub-models in preparation for report generation and multicriteria evaluation. They join the summary tables generated by each sub-model to a point feature representing the site of interest, and write the resulting table to a geodatabase of site summary and comparison tables. The user can qualify the site’s name in the table and specify the name for the output file.

A *Full Origin Site Analysis* model implements a complete origin site analysis by combining the *Modeshed Creation, Origin Land Use Analysis, Origin Demographic Analysis, Mode Change Opportunity Analysis, Access Road Analysis, and Origin Site Summary* sub-models in a single tool, which allows the model users to enter the
parameters for, and creates the data products of, each sub-model. A Full Destination Site Analysis does the same for destination sites, combining Modeshed Creation, Destination Land Use Analysis, Destination Employment Analysis, Destination Demographic Analysis, Mode Change Opportunity Analysis, Access Road Analysis, and Destination Site Summary.

Finally, Origin Site Comparison and Destination Site Comparison sub-models implement a multi-attribute comparison of sites using factors derived and collected by the other sub-models. The site comparison models take a group of site summaries (generated by the Site Description Summary sub-models) and a set of criteria weights chosen by the model user. The user also specifies a name for the group of sites being compared, and a name for the output file.

The set of site descriptors, or factors, combined in multicriteria analysis through the Site Comparison sub-models are as follows:

Origin analysis site descriptors:

- Commuters leaving block groups from each modeshed
- Manhattan-bound commuters from each modeshed
- Housing units in each modeshed
- Car ownership rate in each modeshed
- Median household income in each modeshed
- Known existing parking in the walkshed
- Potential parking in the walkshed
- Area of land known to be publicly owned in the walkshed
- Area of land known or assumed to be privately owned in the walkshed
- Percentage of land in the walkshed known to be publicly owned
- Number of bus and commuter rail connections within walkshed
- Length of access roads within the access road search distance

Destination analysis site descriptors:
- Vacant land in the walkshed
- Area of land known to be publicly owned in the walkshed
- Length of access roads within the access road search distance
- Number of bus and subway connections within the walkshed
- Commuters entering the walkshed
- Area of known office, retail and factory space in the walkshed
- Number of housing units in the walkshed
- Median household income in walkshed

The model implements a series of table operations, which linearly standardize the raw values of the site descriptors to derive a set of descriptor scores as:

\[ X_i = \frac{x_i - \text{min}_i}{\text{max}_i - \text{min}_i} \]  

(2)

where

- \( X_i \) = the score for descriptor \( i \)
- \( x_i \) = the raw value for descriptor \( i \)

\( \text{min}_i \) = the minimum value of descriptor \( i \) for the set of sites, and

\( \text{max}_i \) = the maximum value of descriptor \( i \) for the set of sites

The standardized values are then combined with user-specified weights for each site descriptor using a weighted linear combination (WLC) decision rule. The resulting unidimensional value associated with each site, called the composite origin or destination score, is written to a new field in a table combining the site summaries for the entire
group. The raw values, factor scores, and composite scores in these tables may be used as attributes for mapping site evaluations and comparisons, and as a matrix of site evaluation factors.

5.4.2 Development Environment and User Interface

The site analysis models and sub-models were developed using ESRI’s Modelbuilder environment within its ArcGIS version 9.2 software. Modelbuilder is a high-level graphical programming environment, which allows a user to create custom tools from pre-existing and user-created geoprocessing tools. In the parlance of ArcGIS, a tool created within Modelbuilder is a model. Models may be accessed within ArcGIS in the same ways that users access its standard tools: through dialogue boxes and command line statements, as well as through the Modelbuilder environment itself.

Because models created within Modelbuilder can be added recursively within other models, the environment streamlines the development of related workflows, and facilitates a modular approach to the creation of complex geoprocessing routines.

User interfaces for site evaluation and comparison models provide an intuitive analysis environment for non-expert GIS users. Each of the sub-models, and the complete site evaluation models, are created as individual tools within a dedicated “toolbox”, which can be added to an instance of the ArcMap application. In addition, map templates for origin and destination site analyses facilitate customized map production for multiple sites.

The dialogue boxes for each tool request user-specifiable parameters and provide help documentation, employing domain ontology language instead of GIS terminology.
Each user-specifiable parameter is accompanied by simple documentation clarifying its role within the analysis and a default value, making its specification optional. Figure 4 shows the dialogue box interface for the *Modeshed Creation* sub-model.

![Figure 4. The dialogue box for the *Modeshed Creation* sub-model, showing documentation pertaining to a user-determined parameter.](image)

After running any of the models or sub-models in the site evaluation map templates, refreshing the map automatically updates map layers corresponding to the theme analyzed by the model, using theme-specific symbology. For example, running the *Origin Land Use* sub-model creates a feature class of tax lots by broad land use class (residential, commercial and vacant), as well as existing and potential parking areas within the walkshed of a site. Refreshing the map display then updates corresponding map layers, where land uses are colored in accordance with standard land use map
conventions, existing parking is cross-hatched, and potential parking hatched diagonally with yellow lines. Running Full Origin Site Analysis ends by joining newly-derived site descriptors to the site feature. Refreshing the map then displays the newly-created land use and transportation feature classes in the site’s walkshed and labels the site with a summary of its descriptors, as in Figure 5.

Figure 5. A map of land use and transportation descriptors for an origin site generated by the Full Origin Site Analysis model.

The use of Modelbuilder as a development environment automatically generates diagrammatic representations of the geoprocessing workflows underlying each model,
which are exposed when the models are run within the Modelbuilder environment (Figure 6). Running them in this manner provides a second-level “GIS professional” interface to the models, in which their functionality is graphically communicated, and they are “opened.” The internal logic of the model can then be both read and edited by experienced ArcGIS users unskilled in text-based programming languages. Through the Modelbuilder environment interface the GIS professional can re-use the functionality of the models and alter the display properties of model-derived data to create new map templates. Model workflows can also be communicated to interested non-GIS domain experts through their graphical representations.

Figure 6. A ModelBuilder-generated representation of the geoprocessing workflow implemented in the creation of a walkshed.
5.5 Derivation of criteria weights and site ranking

The database and models detailed above are used to describe and rank eighty-five sites in the study area according to two sets of criteria weights. First, a set of weights was determined through a voting process involving stakeholder representatives of NYMTC’s member organizations. Second, members of the interdisciplinary FPLAS research team used the Analytical Hierarchy Process to arrive at their own set of weights. In the latter process, team members independently filled in a square matrix using pair-wise comparison to quantify the relative importance of each site descriptor derived by the site evaluation models. Team members were asked to utilize their own training as well as experience from the FPLAS project and previous research in determining the precedence of descriptors. The relative weights for each site descriptor determined by each team member were then averaged to arrive at a collaborative weighting scheme. The two derived weight vectors are listed in Tables 1 and 2.
<table>
<thead>
<tr>
<th>Origin Site Descriptor</th>
<th>Stakeholder vote-determined Weight</th>
<th>Research team AHP-determined weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commuters leaving walkshed</td>
<td>4.17</td>
<td>4.38</td>
</tr>
<tr>
<td>Manhattan-bound commuters within walkshed</td>
<td>4.17</td>
<td>6.22</td>
</tr>
<tr>
<td>Housing units in walkshed</td>
<td>2.78</td>
<td>3.27</td>
</tr>
<tr>
<td>Median household income in walkshed</td>
<td>2.78</td>
<td>4.39</td>
</tr>
<tr>
<td>Vehicle ownership rate in walkshed</td>
<td>2.78</td>
<td>1.91</td>
</tr>
<tr>
<td>Commuters leaving bikeshed</td>
<td>4.17</td>
<td>3.48</td>
</tr>
<tr>
<td>Manhattan-bound commuters within bikeshed</td>
<td>4.17</td>
<td>5.49</td>
</tr>
<tr>
<td>Housing units in bikeshed</td>
<td>2.78</td>
<td>2.99</td>
</tr>
<tr>
<td>Median household income in bikeshed</td>
<td>2.78</td>
<td>4.31</td>
</tr>
<tr>
<td>Vehicle ownership rate in bikeshed</td>
<td>2.78</td>
<td>1.91</td>
</tr>
<tr>
<td>Commuters leaving driveshed</td>
<td>4.17</td>
<td>4.49</td>
</tr>
<tr>
<td>Manhattan-bound commuters within driveshed</td>
<td>4.17</td>
<td>7.93</td>
</tr>
<tr>
<td>Housing units in driveshed</td>
<td>2.78</td>
<td>4.75</td>
</tr>
<tr>
<td>Median household income in driveshed</td>
<td>2.78</td>
<td>5.83</td>
</tr>
<tr>
<td>Vehicle ownership rate in driveshed</td>
<td>2.78</td>
<td>6.22</td>
</tr>
<tr>
<td>Existing parking within walkshed (m²)</td>
<td>4.17</td>
<td>6.01</td>
</tr>
<tr>
<td>Potential parking within walkshed (m²)</td>
<td>4.17</td>
<td>5.26</td>
</tr>
<tr>
<td>Total length of access roads in search distance (m)</td>
<td>4.17</td>
<td>4.54</td>
</tr>
<tr>
<td>Number of bus stops within walkshed</td>
<td>12.50</td>
<td>3.33</td>
</tr>
<tr>
<td>Number of commuter rail connections within walkshed</td>
<td>12.50</td>
<td>3.38</td>
</tr>
<tr>
<td>Non-public land ownership area in walkshed (m²)</td>
<td>4.17</td>
<td>2.58</td>
</tr>
<tr>
<td>Public land ownership area in walkshed (m²)</td>
<td>4.17</td>
<td>4.85</td>
</tr>
<tr>
<td>Percent of land in walkshed known to be publicly owned</td>
<td>4.17</td>
<td>2.51</td>
</tr>
</tbody>
</table>
Table 2. Destination Site Descriptor Weight Vectors

<table>
<thead>
<tr>
<th>Destination Site Descriptor</th>
<th>Stakeholder vote-determined Weight</th>
<th>Research team AHP-determined weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commuters entering walkshed</td>
<td>20.00</td>
<td>19.76</td>
</tr>
<tr>
<td>Office, retail and industrial space within walkshed (ft2)</td>
<td>32.00</td>
<td>15.34</td>
</tr>
<tr>
<td>Number of bus stops within walkshed</td>
<td>16.00</td>
<td>15.23</td>
</tr>
<tr>
<td>Number of subway stops within walkshed</td>
<td>16.00</td>
<td>17.34</td>
</tr>
<tr>
<td>Housing units in walkshed</td>
<td>8.00</td>
<td>3.13</td>
</tr>
<tr>
<td>Median household income in walkshed</td>
<td>8.00</td>
<td>3.37</td>
</tr>
<tr>
<td>Total length of access roads in search distance (m)</td>
<td>0.00</td>
<td>4.16</td>
</tr>
<tr>
<td>Public land ownership area in walkshed (m2)</td>
<td>0.00</td>
<td>8.19</td>
</tr>
<tr>
<td>Vacant land area in walkshed (m2)</td>
<td>0.00</td>
<td>4.55</td>
</tr>
</tbody>
</table>

In addition, three testing weights sets were used to create alternate rankings of origin sites in order to test the effect of changing criteria weights on site rankings. A Transit Weight to Parking weight vector begins with the AHP-determined weights and re-assigns the mode-change opportunity weights to existing and potential parking. This vector implements an alternate view of origin site viability, in which ferry services are seen to compete with other modes, rendering mode-change opportunities within the walkshed of a site undesirable, and giving parking area greater importance. A Parking Weight to Car Ownership vector begins with the AHP weights and transfers existing and potential parking weights to vehicle ownership in the walk- and bikesheds. This vector intentionally contradicts both the logic of the analysis, by assigning greater importance to driving in the bikeshed and walkshed, and the widely accepted importance of parking as an origin site criterion. Finally an Equal Weights vector allocates one hundred possible
weight units equally among the twenty-three descriptors. The testing weight vectors are listed together with the AHP weight vector in Table 3. Shaded cells in the table indicate descriptor weights which differ from corresponding weights in the AHP vector.
Table 3. Origin Site Analysis Testing Weight Vectors

<table>
<thead>
<tr>
<th>Origin Site Descriptor</th>
<th>Research team AHP-determined weight</th>
<th>Transit Weight to Parking (test weight)</th>
<th>Parking Weight to Car Ownership (test weight)</th>
<th>Equal Weights (test weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commuters leaving walkshed</td>
<td>4.38</td>
<td>4.38</td>
<td>4.38</td>
<td>4.35</td>
</tr>
<tr>
<td>Manhattan-bound commuters within walkshed</td>
<td>6.22</td>
<td>6.22</td>
<td>6.22</td>
<td>4.35</td>
</tr>
<tr>
<td>Housing units in walkshed</td>
<td>3.27</td>
<td>3.27</td>
<td>3.27</td>
<td>4.35</td>
</tr>
<tr>
<td>Median household income in walkshed</td>
<td>4.39</td>
<td>4.39</td>
<td>4.39</td>
<td>4.35</td>
</tr>
<tr>
<td>Vehicle ownership rate in walkshed</td>
<td>1.91</td>
<td>1.91</td>
<td>7.91</td>
<td>4.35</td>
</tr>
<tr>
<td>Commuters leaving bikeshed</td>
<td>3.48</td>
<td>3.48</td>
<td>3.48</td>
<td>4.35</td>
</tr>
<tr>
<td>Manhattan-bound commuters within bikeshed</td>
<td>5.49</td>
<td>5.49</td>
<td>5.49</td>
<td>4.35</td>
</tr>
<tr>
<td>Housing units in bikeshed</td>
<td>2.99</td>
<td>2.99</td>
<td>2.99</td>
<td>4.35</td>
</tr>
<tr>
<td>Median household income in bikeshed</td>
<td>4.31</td>
<td>4.31</td>
<td>4.31</td>
<td>4.35</td>
</tr>
<tr>
<td>Vehicle ownership rate in bikeshed</td>
<td>1.9</td>
<td>1.9</td>
<td>7.17</td>
<td>4.35</td>
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<tr>
<td>Commuters leaving driveshed</td>
<td>4.49</td>
<td>4.49</td>
<td>4.49</td>
<td>4.35</td>
</tr>
<tr>
<td>Manhattan-bound commuters within driveshed</td>
<td>7.93</td>
<td>7.93</td>
<td>7.93</td>
<td>4.35</td>
</tr>
<tr>
<td>Housing units in driveshed</td>
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<td>4.75</td>
<td>4.75</td>
<td>4.35</td>
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<tr>
<td>Median household income in driveshed</td>
<td>5.83</td>
<td>5.83</td>
<td>5.83</td>
<td>4.35</td>
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<tr>
<td>Vehicle ownership rate in driveshed</td>
<td>6.22</td>
<td>6.22</td>
<td>6.22</td>
<td>4.35</td>
</tr>
<tr>
<td>Existing parking within walkshed (m²)</td>
<td>6.01</td>
<td>9.37</td>
<td>0.00</td>
<td>4.35</td>
</tr>
<tr>
<td>Potential parking within walkshed (m²)</td>
<td>5.26</td>
<td>8.62</td>
<td>0.00</td>
<td>4.35</td>
</tr>
<tr>
<td>Total length of access roads in search distance (m)</td>
<td>4.54</td>
<td>4.54</td>
<td>4.54</td>
<td>4.35</td>
</tr>
<tr>
<td>Number of bus stops within walkshed</td>
<td>3.33</td>
<td>0.00</td>
<td>3.33</td>
<td>4.35</td>
</tr>
<tr>
<td>Number of commuter rail connections within walkshed</td>
<td>3.38</td>
<td>0.00</td>
<td>3.38</td>
<td>4.35</td>
</tr>
<tr>
<td>Non-public land ownership area in walkshed (m²)</td>
<td>2.58</td>
<td>2.58</td>
<td>2.58</td>
<td>4.35</td>
</tr>
<tr>
<td>Public land ownership area in walkshed (m²)</td>
<td>4.85</td>
<td>4.85</td>
<td>4.85</td>
<td>4.35</td>
</tr>
<tr>
<td>Percent of land in walkshed known to be publicly owned</td>
<td>2.51</td>
<td>2.51</td>
<td>2.51</td>
<td>4.35</td>
</tr>
</tbody>
</table>
Site summaries for the eighty-five sites were generated using the *Full Origin* and *Full Destination Site Analysis* models. In order to model the low reliance on automobiles characteristic of New York City residents, and the increasing importance of that mode with distance from the city, a “graduated driveshed” is used in origin site evaluations. Maximum accumulated cost is set at zero driving minutes for the calculation of drivesheds at sites within Manhattan, and increased by five minutes for every increment of five miles distance from Manhattan. Default values are used for all other model parameters, as listed in Table 4. The sites were ranked using the *Site Comparison* sub-models and the five weight vectors described above.

**Table 4. Model Parameter Default Values**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walkshed maximum accumulated cost</td>
<td>0.5 miles</td>
</tr>
<tr>
<td>Bikeshed maximum accumulated cost</td>
<td>3 miles</td>
</tr>
<tr>
<td>Access roadshed maximum accumulated cost</td>
<td>200 meters</td>
</tr>
</tbody>
</table>

The results of site analyses and rankings (using stakeholder weights) are reported in tables, maps, and graphs. Origin and Destination ranking tables include the standardized scores of each site for each descriptor, and its composite score. Two versions of the ranking tables are generated: one ordered by composite score across the study area, and one by composite score within county groups. Maps were generated symbolizing sites with icons sized proportionally to their composite origin and destination scores. Site report tables for the top twelve origin and destination sites, include the raw values of each of their descriptors. Finally, graphs of standardized site descriptor scores visualize the trade-off between factors for the top scoring sites.
Chapter 6: Presentation of Results

This chapter lays forth the results of the analysis described above. It is divided into two sections: the presentation of two short lists of sites, using the two primary weight vectors described in Chapter 5, and a comparison of site rankings generated by the FPLAS team’s AHP-derived weight vector and the three testing weight vectors.

6.1 Short list sites

Tables 5 and 6 list the top twelve origin sites as ranked by the *Origin Site Comparison* sub-model, using the weight vectors assigned by the FPLAS research team through the Analytical Hierarchy Process (Table 5), and the stakeholder voting process (Table 6).

<table>
<thead>
<tr>
<th>Site</th>
<th>In Use</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trump City (New York)</td>
<td>no</td>
<td>42.73</td>
</tr>
<tr>
<td>Fordham Landing (Bronx)</td>
<td>no</td>
<td>41.09</td>
</tr>
<tr>
<td>Fulton Ferry Landing (Kings)</td>
<td>yes</td>
<td>34.97</td>
</tr>
<tr>
<td>Marina Del Ray (Bronx)</td>
<td>no</td>
<td>34.79</td>
</tr>
<tr>
<td>East 34th St. (New York)</td>
<td>yes</td>
<td>34.56</td>
</tr>
<tr>
<td>Fire Island (Suffolk)</td>
<td>yes</td>
<td>34.34</td>
</tr>
<tr>
<td>Cresthaven Marina (Queens)</td>
<td>no</td>
<td>34.00</td>
</tr>
<tr>
<td>Beechhurst Res. Park (Queens)</td>
<td>no</td>
<td>33.98</td>
</tr>
<tr>
<td>Atlantic Ave., Piers 6,7 (Kings)</td>
<td>yes</td>
<td>33.37</td>
</tr>
<tr>
<td>Port Richmond (Richmond)</td>
<td>no</td>
<td>32.72</td>
</tr>
<tr>
<td>Port Chester (Westchester)</td>
<td>no</td>
<td>32.61</td>
</tr>
<tr>
<td>Fort Tilden/Riis Landing (Queens)</td>
<td>no</td>
<td>31.30</td>
</tr>
</tbody>
</table>

Table 5. Top Twelve Origin Sites: FPLAS Team AHP Weights

<table>
<thead>
<tr>
<th>Site</th>
<th>In Use</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fordham Landing (Bronx)</td>
<td>no</td>
<td>45.64</td>
</tr>
<tr>
<td>Trump City (New York)</td>
<td>no</td>
<td>44.75</td>
</tr>
<tr>
<td>East 34th St. (New York)</td>
<td>yes</td>
<td>39.63</td>
</tr>
<tr>
<td>Port Chester (Westchester)</td>
<td>no</td>
<td>37.61</td>
</tr>
<tr>
<td>Port Richmond (Richmond)</td>
<td>no</td>
<td>34.87</td>
</tr>
<tr>
<td>Peekskill (Westchester)</td>
<td>no</td>
<td>33.90</td>
</tr>
<tr>
<td>Marina Del Ray (Bronx)</td>
<td>no</td>
<td>33.67</td>
</tr>
<tr>
<td>Beechhurst Res. Park (Queens)</td>
<td>no</td>
<td>33.24</td>
</tr>
<tr>
<td>Ossining (Westchester)</td>
<td>yes</td>
<td>32.95</td>
</tr>
<tr>
<td>Yonkers (Westchester)</td>
<td>yes</td>
<td>32.85</td>
</tr>
<tr>
<td>E. 63rd St. (New York)</td>
<td>no</td>
<td>31.90</td>
</tr>
<tr>
<td>Atlantic Ave., Piers 6,7 (Kings)</td>
<td>yes</td>
<td>30.63</td>
</tr>
</tbody>
</table>

Table 6. Top Twelve Origin Sites: Stakeholder Elected Weights

Figure 7 maps both rankings, where sites are symbolized in sizes proportional to their composite scores.
Figure 7. Maps of origin ranking results, where sites are symbolized in proportion to their composite scores under the FPLAS research team’s collaborative AHP-derived weight vector (left), and the stakeholder-elected weight vector (right).
Tables 7 and 8, and Figure 8, present the results of destination site rankings using the AHP and stakeholder-elected weights respectively.

**Table 7. Top Twelve Destination Sites: FPLAS Team AHP Weights**

<table>
<thead>
<tr>
<th>Site</th>
<th>In Use</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery (Slip 6) (New York)</td>
<td>yes</td>
<td>60.03</td>
</tr>
<tr>
<td>Pier 11 (New York)</td>
<td>yes</td>
<td>49.99</td>
</tr>
<tr>
<td>South Street Seaport (New York)</td>
<td>yes</td>
<td>39.26</td>
</tr>
<tr>
<td>Battery Park City/World Financial Center (New York)</td>
<td>yes</td>
<td>37.06</td>
</tr>
<tr>
<td>East River Landing (New York)</td>
<td>no</td>
<td>27.32</td>
</tr>
<tr>
<td>Trump City (New York)</td>
<td>no</td>
<td>25.31</td>
</tr>
<tr>
<td>East 34th St. (New York)</td>
<td>yes</td>
<td>23.12</td>
</tr>
<tr>
<td>E. 63rd St. (New York)</td>
<td>no</td>
<td>19.48</td>
</tr>
<tr>
<td>Port Richmond (Richmond)</td>
<td>no</td>
<td>19.16</td>
</tr>
<tr>
<td>Arverne (Queens)</td>
<td>no</td>
<td>18.97</td>
</tr>
<tr>
<td>Pier 40 (Hudson R.) (New York)</td>
<td>no</td>
<td>18.51</td>
</tr>
<tr>
<td>Piers 36 &amp; 42 (New York)</td>
<td>no</td>
<td>18.48</td>
</tr>
</tbody>
</table>

**Table 8. Top Twelve Destination Sites: Stakeholder Elected Weights**

<table>
<thead>
<tr>
<th>Site</th>
<th>In Use</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pier 11 (New York)</td>
<td>yes</td>
<td>68.40</td>
</tr>
<tr>
<td>Battery (Slip 6) (New York)</td>
<td>yes</td>
<td>68.22</td>
</tr>
<tr>
<td>South Street Seaport (New York)</td>
<td>yes</td>
<td>51.70</td>
</tr>
<tr>
<td>Battery Park City/World Financial Center (New York)</td>
<td>yes</td>
<td>47.74</td>
</tr>
<tr>
<td>East River Landing (New York)</td>
<td>no</td>
<td>40.14</td>
</tr>
<tr>
<td>E. 63rd St. (New York)</td>
<td>no</td>
<td>29.00</td>
</tr>
<tr>
<td>Trump City (New York)</td>
<td>no</td>
<td>27.66</td>
</tr>
<tr>
<td>East 34th St. (New York)</td>
<td>yes</td>
<td>26.46</td>
</tr>
<tr>
<td>Pier 40 (Hudson R.) (New York)</td>
<td>no</td>
<td>23.40</td>
</tr>
<tr>
<td>Port Richmond (Richmond)</td>
<td>no</td>
<td>18.50</td>
</tr>
<tr>
<td>Beechhurst Res. Park (Queens)</td>
<td>yes</td>
<td>17.58</td>
</tr>
</tbody>
</table>

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Figure 8. Maps of destination ranking results, where sites are symbolized in proportion to their composite scores under the FPLAS research team’s collaborative AHP-derived weight vector (left), and the stakeholder-elected weight vector (right).
Figures 9 through 13 visualize the standardized scores on each descriptor contributing to composite site ranking scores, under the stakeholder-elected weight vector, for the top twelve origin and destination sites.

Figure 9. Standardized scores on walkshed demographic descriptors for the top twelve stakeholder-ranked origin sites, and the average scores for all eighty-five sites. The walkshed demographic profiles appear to describe two types of sites within the top twelve: those in Manhattan, where high population densities lead to high commuter and housing numbers; and those in the surrounding counties, where lower density results in lower commuter and housing numbers, but high values on other descriptors compensate.
Figure 10. Standardized scores on bikeshed demographic descriptors for the top twelve stakeholder-ranked origin sites, and the average scores for all eighty-five sites. Manhattan sites score highly again on commuter and housing numbers as a result of higher density development.
Figure 11. Standardized scores on driveshed demographic descriptors for the top twelve stakeholder-ranked origin sites, and the average scores for all eighty-five sites. Manhattan sites receive zeros for these descriptors because they are evaluated without considering automobile access, as described in Chapter 5. Lines representing scores for all Manhattan sites are therefore overlaid on the zero line in the graph.
Figure 12. Standardized scores on land use and mode-change descriptors for the top twelve stakeholder-ranked origin sites, and the average scores for all eighty-five sites. A division is seen between those sites with access to one commuter rail station, and those without commuter rail station access.
Figure 13. Standardized descriptor scores for the top twelve stakeholder-ranked destination sites, and the average scores for all eighty-five sites. Lower Manhattan sites, which top the list, stand out in the graph for their relatively high numbers of incoming commuters and office/retail/factory space.

A sample site report containing the raw values on all descriptors for a single site is included as Appendix B.

6.2 Comparison of short lists using alternate weight vectors

The top twelve origin sites, as ranked by the AHP-determined weight vector and the three test weight vectors are listed in Table 9.
Table 9. Comparison of Top Twelve Origin Sites for Four Weight Vectors

<table>
<thead>
<tr>
<th>Expert AHP</th>
<th>Transit Wt to Parking</th>
<th>Parking Wt to Car Ownership</th>
<th>Equal Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trump City (New York)</td>
<td>Trump City (New York)</td>
<td>Fire Island (Suffolk)</td>
<td>Trump City (New York)</td>
</tr>
<tr>
<td>Fordam Landing (Bronx)</td>
<td>Fordam Landing (Bronx)</td>
<td>Marina Del Ray (Bronx)</td>
<td>East 34th St. (New York)</td>
</tr>
<tr>
<td>Fulton Ferry Landing (Kings)</td>
<td>Fulton Ferry Landing (Kings)</td>
<td>Cresthaven Marina (Queens)</td>
<td>E. 63rd St. (New York)</td>
</tr>
<tr>
<td>Marina Del Ray (Bronx)</td>
<td>Fire Island (Suffolk)</td>
<td>Beechhurst Res. Park (Queens)</td>
<td>Fordham Landing (Bronx)</td>
</tr>
<tr>
<td>East 34th St. (New York)</td>
<td>Cresthaven Marina (Queens)</td>
<td>Port Chester (Westchester)</td>
<td>South Street Seaport (New York)</td>
</tr>
<tr>
<td>Fire Island (Suffolk)</td>
<td>Huenoton Avenue (Richmond)</td>
<td>Fort Tilden/Riis Landing (Queens)</td>
<td>Pier 84 (W. 44th St.) (New York)</td>
</tr>
<tr>
<td>Cresthaven Marina (Queens)</td>
<td>East 34th St. (New York)</td>
<td>Trump City (New York)</td>
<td>Piers 36 &amp; 42 (New York)</td>
</tr>
<tr>
<td>Beechhurst Res. Park (Queens)</td>
<td>Port Richmond (Richmond)</td>
<td>Rye/Rye Playland (Westchester)</td>
<td>Fulton Ferry Landing (Kings)</td>
</tr>
<tr>
<td>Atlantic Ave., Piers 6,7 (Kings)</td>
<td>Marina Del Ray (Bronx)</td>
<td>Great Kills Harbor (Richmond)</td>
<td>Pier 40 (Hudson R.) (New York)</td>
</tr>
<tr>
<td>Port Richmond (Richmond)</td>
<td>Atlantic Ave., Piers 6,7 (Kings)</td>
<td>Captains Quarters (Richmond)</td>
<td>Battery Park City/World Financial Center (New York)</td>
</tr>
<tr>
<td>Port Chester (Westchester)</td>
<td>Kent Terminal (Kings)</td>
<td>Huenoton Avenue (Richmond)</td>
<td>Pier 63 (W. 23rd St.) (New York)</td>
</tr>
<tr>
<td>Fort Tilden/Riis Landing (Queens)</td>
<td>Beechhurst Res. Park (Queens)</td>
<td>Ossining (Westchester)</td>
<td>Battery (Slip 6) (New York)</td>
</tr>
</tbody>
</table>

In all, twenty-six sites are represented in the four top-twelve lists. Of these, only Trump City appears on all four. Seven sites are represented on three lists; five appear on two lists, and thirteen on only one.

All seven sites which appear on three different lists are on the AHP and Transit Weight to Parking lists. Four out of five sites appearing on two lists are on the AHP list. None of those appear on the Equal Weights list. Ten sites on the AHP list also appear on the Transit Weight to Parking list. Seven AHP list sites appear on the Parking Weight to Car Ownership list, and only four on the Equal Weights list. On the other hand, eight of the thirteen sites which appear only once are on the Equal Weights list. Four are on the Parking Weight to Car Ownership list.
The AHP list is thus most similar to the other lists, while the Equal Weight list is the least similar. The Transit Weight to Parking and Parking Weight to Car Ownership lists fall in between, in descending order of similarity to the other lists.

All top twelve Equal Weight sites are in New York City, and all but two are in Manhattan. By contrast, eight Parking Weight to Car Ownership sites are in NYC, but only one is in Manhattan. Ten AHP sites are in NYC as well, two of which are in Manhattan. Eleven Transit Weight to Parking sites are in NYC: two, again, in Manhattan.

In general, there is little agreement in site rank between lists, with the exception of Trump City, which ranks first on three of them. In some cases, sites rank highly on one or more list and not at all on at least one other list (for example Fire Island, Marina Del Ray, E. 34th Street, and E. 63rd Street). This is most often true for sites which appear on the Equal Weights list and not on others, or vice versa. The greatest difference in site ranking for those sites which appear on more than one list is eight places, for Beechhurst Res. Park in Queens: fourth on the Parking Weight to Car Ownership list, twelfth on Transit Weight to Parking. Several sites move by five or more places between lists. Table 10 lists all sites appearing in any of the top twelve lists with their average rank, rank variance, and frequency of appearance.
Table 10. Frequency, Average Rank, and Rank Variance

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Frequency</th>
<th>Average Rank</th>
<th>Rank Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic Ave., Piers 6,7 (Kings)</td>
<td>2</td>
<td>9.50</td>
<td>0.5</td>
</tr>
<tr>
<td>Battery (Slip 6) (New York)</td>
<td>1</td>
<td>12.00</td>
<td>n/a</td>
</tr>
<tr>
<td>Battery Park City/World Financial Center (New York)</td>
<td>1</td>
<td>10.00</td>
<td>n/a</td>
</tr>
<tr>
<td>Beechhurst Res. Park (Queens)</td>
<td>3</td>
<td>8.00</td>
<td>16</td>
</tr>
<tr>
<td>Captains Quarters (Richmond)</td>
<td>1</td>
<td>10.00</td>
<td>n/a</td>
</tr>
<tr>
<td>Cresthaven Marina (Queens)</td>
<td>3</td>
<td>5.00</td>
<td>4</td>
</tr>
<tr>
<td>E. 63rd St. (New York)</td>
<td>1</td>
<td>3.00</td>
<td>n/a</td>
</tr>
<tr>
<td>East 34th St. (New York)</td>
<td>3</td>
<td>4.67</td>
<td>6.33</td>
</tr>
<tr>
<td>Fire Island (Suffolk)</td>
<td>3</td>
<td>3.67</td>
<td>6.33</td>
</tr>
<tr>
<td>Fordam Landing (Bronx)</td>
<td>3</td>
<td>3.00</td>
<td>3</td>
</tr>
<tr>
<td>Fort Tilden/Riis Landing (Queens)</td>
<td>2</td>
<td>9.00</td>
<td>18</td>
</tr>
<tr>
<td>Fulton Ferry Landing (Kings)</td>
<td>3</td>
<td>4.67</td>
<td>8.33</td>
</tr>
<tr>
<td>Great Kills Harbor (Richmond)</td>
<td>1</td>
<td>9.00</td>
<td>n/a</td>
</tr>
<tr>
<td>Huguenot Avenue (Richmond)</td>
<td>2</td>
<td>8.50</td>
<td>12.5</td>
</tr>
<tr>
<td>Kent Terminal (Kings)</td>
<td>1</td>
<td>11.00</td>
<td>n/a</td>
</tr>
<tr>
<td>Marina Del Ray (Bronx)</td>
<td>3</td>
<td>5.00</td>
<td>13</td>
</tr>
<tr>
<td>Ossining (Westchester)</td>
<td>1</td>
<td>12.00</td>
<td>n/a</td>
</tr>
<tr>
<td>Pier 40 (Hudson R.) (New York)</td>
<td>1</td>
<td>9.00</td>
<td>n/a</td>
</tr>
<tr>
<td>Pier 63 (W. 23rd St.) (New York)</td>
<td>1</td>
<td>11.00</td>
<td>n/a</td>
</tr>
<tr>
<td>Pier 84 (W. 44th St.) (New York)</td>
<td>1</td>
<td>4.00</td>
<td>n/a</td>
</tr>
<tr>
<td>Piers 36 &amp; 42 (New York)</td>
<td>1</td>
<td>7.00</td>
<td>n/a</td>
</tr>
<tr>
<td>Port Chester (Westchester)</td>
<td>2</td>
<td>8.00</td>
<td>18</td>
</tr>
<tr>
<td>Port Richmond (Richmond)</td>
<td>2</td>
<td>9.00</td>
<td>2</td>
</tr>
<tr>
<td>Rye/Rye Playland (Westchester)</td>
<td>1</td>
<td>8.00</td>
<td>n/a</td>
</tr>
<tr>
<td>South Street Seaport (New York)</td>
<td>1</td>
<td>6.00</td>
<td>n/a</td>
</tr>
<tr>
<td>Trump City (New York)</td>
<td>4</td>
<td>2.50</td>
<td>9</td>
</tr>
</tbody>
</table>
Chapter 7: Conclusions, Evaluation, and Future Work

This final chapter begins with a discussion of the results reported in the previous chapter, continues with an assessment of the appropriateness and efficacy of the methods used in this study, and concludes by outlining plans for the future use of the site evaluation and comparison models and suggesting possible directions for related future research.

7.1 Conclusions

In the results described above, the site evaluation and comparison models do a good job of replicating stakeholders’ and researchers’ understanding of the viability of sites, which were based on personal knowledge of the conditions at individual sites and the geographic characteristics of the region as a whole. Probably the most notable trend in the model outcomes reported in Chapter 6 is the predominance of New York City and Manhattan sites, which rank highly as both origins and destinations. At the origin end, this is most likely due to the influence of the city’s high density on population, housing and commuter numbers, which were weighted as important factors for origin viability. At the destination end, many characteristics of Manhattan sites, for example, high residential densities and rich public transportation connectivity favored them. In addition, a bias was introduced toward New York City sites by the fact that office, retail and factory space were highly ranked attributes of destination sites, particularly by the stakeholder voting process. As previously noted, these numbers were not available outside the city. Thus the importance of that criterion may have favored city sites.

Although the dominance of New York City and Manhattan sites within the highest-ranked sites appears first as a geographic bias of the model, it is exactly in line with the expert interview-based criteria for site evaluation. Indeed lower and midtown
Manhattan were seen by interviewees to typify a successful destination site, based on their knowledge of the region and the past performance of existing sites. Thus for a popular existing site like Pier 11 or Battery (Slip 6) to score highly as a destination site generates greater confidence in the rankings. Favorable destination rankings of those and other Manhattan sites are consistent with experts’ conceptions of the domain.

In the context of this support for the models’ ranking results, highly ranked sites without existing services merit further study. The Trump City site, for example, which does not have existing services tops the AHP ranked origin sites and appears second on the stakeholder ranked list. Fordham Landing in the Bronx, which also does not have existing service, is first on the stakeholder origin list and second on the AHP list. East River Landing, a previously-studied hypothetical site, scores very well on both destination lists. Whether newly established services at this site would harm the nearby South Street Seaport and Pier 11 sites, or ease over-use and potentially increase overall ridership is unanswerable by the site evaluation models in their current form. Its high score, though, suggests the need for a review of conditions at the other two sites.

The results of the analysis of site rankings generated by different weight vectors described in Chapter 6 suggests that weight vectors play a major role in determining the ranking of sites, but that the results of differently chosen weights are logical and correspond with domain knowledge. Great diversity is seen in the top-twelve site lists produced by the different origin site weight vectors, but it is explained by the definition of the vectors themselves. The AHP ranked list was similar to the Transit Weight to Parking list and the Parking Weight to Car Ownership list because the AHP weight vector was the basis for the other two vectors. The Equal Weight list was the least similar
to the other lists because the values of its weights differed the most. The *Transit Weight to Parking* list was more similar to the *AHP* list than was the *Parking Weight to Car Ownership* list. Both were based on the *AHP* weight vector, and created through the reassignment of two weight values. The *Parking Weight to Car Ownership* vector intentionally undermines the logic of the analysis: parking receives no weight, despite its having been an important criterion of origin sites throughout the FPLAS project. In addition, its weight is reassigned to car ownership in the walk- and bikesheds: areas which were defined by walking and biking rather than driving accessibility. By contrast the *Transit Weight to Parking* vector merely moves weight from one expert-valued criterion to another. The numerical value of changes to individual weights from the *AHP* weight vector is also greater in the case of the *Parking Weight to Car Ownership* vector. Unsurprisingly then, the site list produced by the *Transit Weight to Parking* vector is more similar to the *AHP* list than is that produced by the *Parking Weight to Car Ownership* vector.

The weight vectors also had significant, though logical, effects on the geographic results of site rankings. Compared to the *AHP* weights and results, moving weight from parking to car ownership moved sites from New York City to the surrounding counties. This again is unsurprising: more people own cars outside the city, where the transit system is less robust. Therefore emphasizing car ownership at origins emphasizes non-NYC origins (despite the bizarre logic of weighting car ownership in walksheds). The *Equal Weights* vector produced the most dramatic geographic results, assigning ten of twelve top ranks to Manhattan sites. The logical explanation for this result is that because of its high density and exhaustive street grid, Manhattan sites have larger
walksheds and more of *every* origin descriptor except car ownership per occupied housing unit and, in many cases, percentage of land in public ownership.

Finally, the site rankings privileged sites with existing services. This result too is logical, and contributes to confidence in the models’ site rankings. After all, sites that have proven viable *should* score well on measures of viability that are based on past experience. That they do suggests that those measures are adequately formalized in the model’s functioning. The result is of little use in the identification of promising new sites for development, however. Accordingly, the short list of sites passed along for detailed analysis in the following phase of the FPLAS project are highly ranked sites *without* existing services, along with one or two sites included by the research team to accommodate NYMTC’s regional equity goals.

### 7.2 Evaluation of Methodology

The construction of the geodatabase and site evaluation models was useful in the process of evaluating sites for potential investment in waterborne transportation infrastructure for the New York metropolitan region, and as noted above, the models performed well. Preliminary discussion with NYMTC’s GIS professionals suggests interest in the model for their future use and comfort with its COTS GIS-based logic and functionality. I was told by one professional within the organization that he “couldn’t wait to play with it” (NYMTC GIS Professional, personal communication 2008).

There is, of course, room to improve upon the model and its use in decisions of waterborne transit hub siting in the region. There are also limitations on the use of the
model associated with the choice of development environment and its current implementation.

As discussions within the FPLAS research team and with stakeholders suggested at various times during the implementation of the project, the larger study would have benefited from incorporating New Jersey sites in the long list of sites under evaluation. Individual ferry sites are linked with other sites through services, and the demand for use of any given site is determined largely by the destinations or origins with which it is paired. As mentioned in Chapter 4, in many cases destination sites in Manhattan are currently linked with sites in New Jersey, and serve many New Jersey residents. Building on this study to examine sites in New Jersey or Connecticut could be done with relatively minor preparation of the database for those areas, assuming the availability of data. No changes in site evaluation or comparison models would be necessary.

Stakeholders brought certain concerns about the analysis to the research team too late in the process for them to be incorporated in the model’s development. First, the effect of distance of origin sites from Manhattan (or other destinations) is not adequately accounted for in the site evaluation model. The cost of fuel is a significant one for ferry operators, and is obviously greater over longer distances. In addition, the existence of storage and maintenance facilities near origin sites becomes increasingly important with the distance of origins from destinations. These facilities obviate the need for “deadheading” boats between origins and storage locations before and after commuting times, which uses yet more fuel and pilot time.

One stakeholder mentioned the idea of incorporating limited drivesheds within Manhattan to model passengers’ potential use of taxis to access sites. This is easily
accomplished in the model’s current state. The expected result would be an increase in the scores of Manhattan sites as origins.

Another stakeholder wished for a more nuanced profile of the mode-change opportunities associated with destination sites, for example the proximity of individual mode-change opportunities and a representation of the destinations these opportunities open for users of the site. Both could be readily implemented in the model in its current configuration with minor adjustment to the supporting database.

Finally, a stakeholder commented on the age of the demographic data used in characterizing the population with access to sites. As noted in Chapter 4, the database incorporates commuter data from 2000 and population data from 2005. The stakeholder noted the construction of new housing development in proximity to at least one site since that time. Until 2010 census data becomes available this is a real limitation of the database. New residential development was flagged as an important factor for origin suite suitability early in the definition of site evaluation criteria. Unfortunately, data on recent and planned waterfront development for the study area were not available, or they would have been incorporated in the database. In the absence of these data, knowledge about changes in population and new development must be incorporated in parcel and census geography feature classes within the supporting database.

The use of ESRI’s ModelBuilder as a development environment for the site evaluation and comparison models was successful in that it facilitated a speedy and intuitive development process. In addition, it looks very likely that NYMTC GIS professionals will appreciate the choice of ModelBuilder and ArcGIS for their future use of the models, both for running new ferry site analyses, and potentially for their ability to
re-purpose model components to other tasks. The models’ use of existing ArcGIS routines and a graphical interface succeeded in making its functionality comprehensible to non-programmer GIS professionals.

On the other hand, the models are not very accessible to a more general audience through their current user interface. They do not achieve the flexibility of query and ease of visualizations which PSS developers advocate for technologies of planning practice. Nor are they supported by a framework which explicitly facilitates collaboration. These goals might be achieved in the future through integration of the models in a PSS software framework such as Community Viz.

Barriers to sharing are also created by the use of ArcGIS software components in the models and supporting database. The model functionality, and some of the database logic, relies on proprietary components of the ArcInfo version of ArcGIS, a relatively expensive commercial software license. For the immediate and future use of the models within NYMTC and the academic environment of its development, however, this is not a limiting factor.

7.3 Directions for future work building upon this research

Model results and products have been and will continue to be used in decision making processes as part of the Ferry Parking and Landside Access Study. Beyond the life of that project, it is projected that the model and database may be used by NYMTC and its member organizations in future analyses of potential ferry sites, potential hubs in other transit networks where land use and user demographics are key criteria, and possibly in
other tasks. For this purposes, the model and database will be packaged with documentation and delivered to NYMTC staff.

Applications of the models or their products may form part of presentations and discussion in public outreach meetings as part of the FPLAS project or future transportation planning processes in the region. To facilitate its use in public involvement contexts, a member of the FPLAS research team is currently adapting the model to run within the Community Viz PSS environment.

Specific future improvements to the site evaluation and comparison models could include extensions to their analytical capabilities on the one hand, and improvements to the user interface and flexibility on the other. The former include the addition of functionalities requested by stakeholders as described in the previous section, as well as a more complete analysis of demand which would consider sites as nodes on the multi-modal transportation network of the region. Such an approach would enable the testing of demand for potential linkages between ferry sites. On the other hand, more refined measures of accessibility could be built into the model, incorporating individual accessibility and time prism approaches as described in Liu and Zhu (2004).

Potential improvements to model usability and flexibility include the development of a more intuitive user interface, in the form of a toolbar and menu format for example. Automated report and graphics generation would make the model’s functionality more accessible to the casual GIS or PC user. Building greater flexibility into the model’s input and output functions would facilitate its portability for use as a tool independent of the supporting database developed for this study.
More broadly, the models presented here can be understood as types among those required for the development of a flexible modular package of analytical tools for SDSS. The information requirements, input and output formats, and basic functionality of the sub-models described are not unique to the current study, and the solutions presented could be re-used, emulated in other environments, or abstracted as part of a comprehensive description of such a modular analytical suite.

The ontology for land use- and user base-oriented transit hub siting presented in Chapter 5 was developed for application both in and beyond the current study. In its current general form the ontology can be used to structure the data requirements and processes of other studies of waterborne transit or commuter movement by other modes. It can also serve as a basis for the development of more specialized ontologies. Finally, this ontology can be used in conjunction with the ever-expanding collection of geographic ontologies for databases, processes, and services, to specify the development requirements for a specifically geographic ontology builder as advocated in Albrecht, Derman and Ramasubramanian (forthcoming). Such a tool would go a long way in facilitating spatial decision support projects in planning by helping GIS managers to efficiently bridge the technology-versus-domain knowledge gap.
### Appendix A

**Table 11: Study Sites by Name, Number, County, and Usage Status**

<table>
<thead>
<tr>
<th>#</th>
<th>Site Name</th>
<th>County</th>
<th>In Use</th>
<th>#</th>
<th>Site Name</th>
<th>County</th>
<th>In Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Atlantic Ave., Piers 6,7</td>
<td>New York</td>
<td>Yes</td>
<td>44</td>
<td>Fort Slocum Road</td>
<td>Westchester</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>Battery (Slip 6)</td>
<td>New York</td>
<td>Yes</td>
<td>45</td>
<td>Fort Tilden/Riis Landing</td>
<td>Queens</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>Battery Park City/World F</td>
<td>New York</td>
<td>Yes</td>
<td>46</td>
<td>Freeport</td>
<td>Nassau</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>Brooklyn Army Terminal</td>
<td>Kings</td>
<td>Yes</td>
<td>47</td>
<td>Glen Cove, Fox Navigation</td>
<td>Nassau</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>East 34th St.</td>
<td>New York</td>
<td>Yes</td>
<td>48</td>
<td>Great Kills Harbor</td>
<td>Richmond</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>Fire Island</td>
<td>Suffolk</td>
<td>Yes</td>
<td>49</td>
<td>Harlem Piers</td>
<td>New York</td>
<td>No</td>
</tr>
<tr>
<td>7</td>
<td>Flushing Bay Marina (Shea Bridge)</td>
<td>Queens</td>
<td>Yes</td>
<td>50</td>
<td>Howland Hook</td>
<td>Richmond</td>
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<tr>
<td>8</td>
<td>Fulton Ferry Landing</td>
<td>Kings</td>
<td>Yes</td>
<td>51</td>
<td>Huguenot Avenue</td>
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<td>9</td>
<td>Governors Island</td>
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<td>Yes</td>
<td>52</td>
<td>Hunts Point</td>
<td>Bronx</td>
<td>No</td>
</tr>
<tr>
<td>10</td>
<td>Haverstraw</td>
<td>Rockland</td>
<td>Yes</td>
<td>53</td>
<td>Inwood Terminal</td>
<td>Nassau</td>
<td>No</td>
</tr>
<tr>
<td>11</td>
<td>Hunters Point</td>
<td>Queens</td>
<td>Yes</td>
<td>54</td>
<td>Kent Terminal, Brooklyn</td>
<td>Kings</td>
<td>No</td>
</tr>
<tr>
<td>12</td>
<td>Nyack</td>
<td>Rockland</td>
<td>Yes</td>
<td>55</td>
<td>LaGuardia Airport</td>
<td>Queens</td>
<td>No</td>
</tr>
<tr>
<td>13</td>
<td>Ossining</td>
<td>Westchester</td>
<td>Yes</td>
<td>56</td>
<td>Mamaroneck</td>
<td>Westchester</td>
<td>No</td>
</tr>
<tr>
<td>14</td>
<td>Pier 11</td>
<td>New York</td>
<td>Yes</td>
<td>57</td>
<td>Marina Del Ray, Bronx</td>
<td>Bronx</td>
<td>No</td>
</tr>
<tr>
<td>15</td>
<td>Pier 45 (Christopher St.)</td>
<td>New York</td>
<td>Yes</td>
<td>58</td>
<td>Mariners Harbor</td>
<td>Richmond</td>
<td>No</td>
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<tr>
<td>16</td>
<td>Pier 63 (W. 23rd St.)</td>
<td>New York</td>
<td>Yes</td>
<td>59</td>
<td>Oak Point Railyard</td>
<td>Bronx</td>
<td>No</td>
</tr>
<tr>
<td>17</td>
<td>Pier 84 (W. 44th St.)</td>
<td>New York</td>
<td>Yes</td>
<td>60</td>
<td>Orchard Beach</td>
<td>Bronx</td>
<td>No</td>
</tr>
<tr>
<td>18</td>
<td>Red Hook (Fairway)</td>
<td>Kings</td>
<td>Yes</td>
<td>61</td>
<td>Peekskill</td>
<td>Westchester</td>
<td>No</td>
</tr>
<tr>
<td>19</td>
<td>Schaefer Landing</td>
<td>Kings</td>
<td>Yes</td>
<td>62</td>
<td>Piers 36 &amp; 42</td>
<td>New York</td>
<td>No</td>
</tr>
<tr>
<td>20</td>
<td>South Street Seaport</td>
<td>New York</td>
<td>Yes</td>
<td>63</td>
<td>Pier 40 (Hudson R.)</td>
<td>New York</td>
<td>No</td>
</tr>
<tr>
<td>21</td>
<td>W. 38th (39/Midtown)</td>
<td>New York</td>
<td>Yes</td>
<td>64</td>
<td>Point Little Bay</td>
<td>Queens</td>
<td>No</td>
</tr>
<tr>
<td>22</td>
<td>Yankee Stadium</td>
<td>Bronx</td>
<td>Yes</td>
<td>65</td>
<td>Port Chester</td>
<td>Westchester</td>
<td>No</td>
</tr>
<tr>
<td>23</td>
<td>Yonkers</td>
<td>Westchester</td>
<td>Yes</td>
<td>66</td>
<td>Port Ivory</td>
<td>Richmon</td>
<td>No</td>
</tr>
<tr>
<td>24</td>
<td>44th Dr. Pier, Queens</td>
<td>Queens</td>
<td>No</td>
<td>67</td>
<td>Port Regalle</td>
<td>Richmond</td>
<td>No</td>
</tr>
<tr>
<td>25</td>
<td>65th St., Bay Ridge</td>
<td>Kings</td>
<td>No</td>
<td>68</td>
<td>Port Richmond</td>
<td>Richmond</td>
<td>No</td>
</tr>
<tr>
<td>26</td>
<td>90th Street</td>
<td>New York</td>
<td>No</td>
<td>69</td>
<td>Randall's Island</td>
<td>New York</td>
<td>No</td>
</tr>
<tr>
<td>27</td>
<td>Arverne, Queens</td>
<td>Queens</td>
<td>No</td>
<td>70</td>
<td>Red Hook Container Term.</td>
<td>Kings</td>
<td>No</td>
</tr>
<tr>
<td>28</td>
<td>Beechhurst Res. Park</td>
<td>Queens</td>
<td>No</td>
<td>71</td>
<td>Rockaway</td>
<td>Kings</td>
<td>No</td>
</tr>
<tr>
<td>29</td>
<td>Brooklyn Navy Yard</td>
<td>Kings</td>
<td>No</td>
<td>72</td>
<td>Roosevelt Island</td>
<td>New York</td>
<td>No</td>
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<tr>
<td>30</td>
<td>Bklyn PA Mar. Term. (1-5)</td>
<td>Kings</td>
<td>No</td>
<td>73</td>
<td>Rye/Rye Playland</td>
<td>Westchester</td>
<td>No</td>
</tr>
<tr>
<td>31</td>
<td>Canarsie Pier</td>
<td>Kings</td>
<td>No</td>
<td>74</td>
<td>Sheephead Bay</td>
<td>Kings</td>
<td>No</td>
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<tr>
<td>32</td>
<td>Captains Quarters, S.I</td>
<td>Richmond</td>
<td>No</td>
<td>75</td>
<td>Shore Towers (Pot Cove)</td>
<td>Queens</td>
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<tr>
<td>33</td>
<td>Captree State Park</td>
<td>Suffolk</td>
<td>No</td>
<td>76</td>
<td>Shorehaven</td>
<td>Bronx</td>
<td>No</td>
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<tr>
<td>34</td>
<td>Castle Hill</td>
<td>Bronx</td>
<td>No</td>
<td>77</td>
<td>Snug Harbor</td>
<td>Richmond</td>
<td>No</td>
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<tr>
<td>35</td>
<td>College Point Sites</td>
<td>Queens</td>
<td>No</td>
<td>78</td>
<td>South Bklyn Marine Termin</td>
<td>Kings</td>
<td>No</td>
</tr>
<tr>
<td>36</td>
<td>Co-op City</td>
<td>Bronx</td>
<td>No</td>
<td>79</td>
<td>Tarrytown</td>
<td>Westchester</td>
<td>No</td>
</tr>
<tr>
<td>37</td>
<td>Cresthaven Marina</td>
<td>Queens</td>
<td>No</td>
<td>80</td>
<td>Torpedo Pier/Ft. Wadsworth</td>
<td>Richmond</td>
<td>No</td>
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<tr>
<td>38</td>
<td>E. 63rd St., Manhattan</td>
<td>New York</td>
<td>No</td>
<td>81</td>
<td>Tottenville</td>
<td>Richmond</td>
<td>No</td>
</tr>
<tr>
<td>39</td>
<td>East River Landing</td>
<td>New York</td>
<td>No</td>
<td>82</td>
<td>Toys 'R' Us</td>
<td>Kings</td>
<td>No</td>
</tr>
<tr>
<td>40</td>
<td>Echo Bay</td>
<td>Westchester</td>
<td>No</td>
<td>83</td>
<td>Trump City</td>
<td>New York</td>
<td>No</td>
</tr>
<tr>
<td>41</td>
<td>Erie Basin</td>
<td>Kings</td>
<td>No</td>
<td>84</td>
<td>Watersedge Estates</td>
<td>Richmond</td>
<td>No</td>
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<tr>
<td>42</td>
<td>Ferry Point Park</td>
<td>Bronx</td>
<td>No</td>
<td>85</td>
<td>Williamsburg</td>
<td>Kings</td>
<td>No</td>
</tr>
<tr>
<td>43</td>
<td>Fordham Landing</td>
<td>Bronx</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>
Figure 14. Midtown and Lower Manhattan; East River, and Upper New York Bay Sites.
Figure 15. Upper Manhattan, Bronx, Northern Queens, Westchester, and Rockland County Sites.
Figure 16. Nassau, Suffolk, Southern Queens, South Brooklyn, and Richmond County Sites.
### Appendix B

#### Table 12. Sample Site Report for Fordham Landing (Site 43, Figure 17)

<table>
<thead>
<tr>
<th>Site Descriptor</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commuters leaving walkshed</td>
<td>4,205</td>
</tr>
<tr>
<td>Commuters entering walkshed</td>
<td>2,195</td>
</tr>
<tr>
<td>Number of Manhattan-bound commuters within walkshed</td>
<td>2,590</td>
</tr>
<tr>
<td>Housing units in walkshed</td>
<td>4,979</td>
</tr>
<tr>
<td>Average median household income in walkshed</td>
<td>$24,202</td>
</tr>
<tr>
<td>Vehicle ownership rate in walkshed (vehicles/occupied housing unit)</td>
<td>0.28</td>
</tr>
<tr>
<td>Commuters leaving bikeshed</td>
<td>232,925</td>
</tr>
<tr>
<td>Number of Manhattan-bound commuters within bikeshed</td>
<td>116,426</td>
</tr>
<tr>
<td>Housing units in bikeshed</td>
<td>277,148</td>
</tr>
<tr>
<td>Average median household income in bikeshed</td>
<td>$27,013</td>
</tr>
<tr>
<td>Vehicle ownership rate in bikeshed (vehicles/occupied housing unit)</td>
<td>0.34</td>
</tr>
<tr>
<td>Commuters leaving driveshed</td>
<td>276,760</td>
</tr>
<tr>
<td>Number of Manhattan-bound commuters within driveshed</td>
<td>144,959</td>
</tr>
<tr>
<td>Housing units in driveshed</td>
<td>343,395</td>
</tr>
<tr>
<td>Average median household income in driveshed</td>
<td>$26,580</td>
</tr>
<tr>
<td>Vehicle ownership rate in driveshed (vehicles/occupied housing unit)</td>
<td>0.34</td>
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<tr>
<td>Existing parking within walkshed (m²)</td>
<td>37,850</td>
</tr>
<tr>
<td>Potential parking within walkshed (m²)</td>
<td>32,347</td>
</tr>
<tr>
<td>Total length of access roads, class ACC 1-5 in search distance (m)</td>
<td>645</td>
</tr>
<tr>
<td>Number of bus stops within walkshed</td>
<td>10</td>
</tr>
<tr>
<td>Number of NYC subways stops within walkshed</td>
<td>1</td>
</tr>
<tr>
<td>Number of commuter rail connections within walkshed</td>
<td>1</td>
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<tr>
<td>Non-public land ownership area in walkshed (m²)</td>
<td>276,482</td>
</tr>
<tr>
<td>Public land ownership area in walkshed (m²)</td>
<td>104,067</td>
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<tr>
<td>Office, retail and industrial space in walkshed (ft²)</td>
<td>429,965</td>
</tr>
<tr>
<td>Percent of land in walkshed known to be vacant</td>
<td>17.40%</td>
</tr>
<tr>
<td>Percent of land in walkshed known to be publicly owned</td>
<td>27.30%</td>
</tr>
</tbody>
</table>
Notes

1) The Ferry Parking and Landside Access website is accessible from the main NYMTC website by clicking on “Programs and Projects” and then “Ferry Parking and Landside Access Study.”

References


Harris, B. 1994. The real issues concerning Lee's 'Requiem'. *Journal of the American Planning Association* 60 (1): 31-34.


