Multimodal Enhancements to Public-Private Partnerships

Morgan State University
The Pennsylvania State University
University of Maryland
University of Virginia
Virginia Polytechnic Institute & State University
West Virginia University

The Pennsylvania State University
The Thomas D. Larson Pennsylvania Transportation Institute
Transportation Research Building ❖ University Park, PA 16802-4710
Phone: 814-865-1891 ❖ Fax: 814-863-3707
www.mautc.psu.edu

Research Report

Multimodal Enhancements to Public-Private Partnerships

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Dr. Changju Lee
Dr. John S. Miller

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16. Abstract

Public-Private Partnership (PPP or P3) projects have received attention as they can increase private sector participation in transportation projects. However, P3s are not a panacea. Worldwide, almost 40% of P3 projects initiated during the 1990s required that the contractual agreement be renegotiated, implying some type of project failure. Because some (not all) types of P3 projects require a toll, one viewpoint is that P3 projects can be proposed only if tolls will render them financially self-sustaining. For passenger transportation, this generally means encouraging modes that can be more easily tolled—usually auto travel—and not necessarily modes that are subsidized—such as transit travel. However, it has been argued that multimodal projects can yield societal benefits, such as better jobs-housing balance. The emphasis on modes which will generate user fees may naturally reduce the likelihood of a P3 investment that will enhance multiple transportation modes. However, if it were possible to translate the socially beneficial impacts of multimodal investments into revenue sources, it might be possible to increase private sector participation in multimodal P3 projects.

This research examined how a multimodal P3 project influences land development, specifically the relationship between jobs and housing. There are four objectives: (1) to identify lessons learned from previous use of toll facilities (necessary because Virginia stakeholders are concerned that insights from more distant eras may be overlooked); (2) to develop a way to quantify jobs-housing balance that is sensitive to transportation investments across multiple modes; (3) to develop a taxonomy for classifying the degree of multimodality for P3 projects (necessary because such projects are not completely "multimodal" nor completely "unimodal"); and (4) to explore how implementation of a multimodal P3 affects the degree of multimodality and jobs-housing balance. This research uses real data sets from P3s in Virginia, Florida, Colorado, and Rhode Island. While some data had to be requested from public agencies, the data elements required for the research contained herein are available in the public domain. No synthetic data were used, thus, the methodology used herein should be replicable in other locations.

As an initial research effort to consider land development impacts in multimodal P3s, this research suggests four key contributions: (1) lessons learned from the use of toll facilities in the U.S.; (2) a methodology to scale multimodality; (3) a way to relate jobs-housing balance (given observed travel patterns) to the aforementioned multimodality scale; and (4) empirical evidence of the multimodality and jobs-housing balance impacts by multimodal P3 projects. Ultimately these contributions may inform guidelines for increasing multimodal components in P3s.

17. Key Words Public-Private Partnership, Multimodality, Jobs-Housing Balance, Toll	**18. Distribution Statement**

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I INTRODUCTION

"Multimodal" transportation investments have colloquially referred to corridors or transfer points where more than one mode of transportation is considered. Examples of multimodal investments are freeways supporting auto travel and bus rapid transit (Ferrell et al., 2011), park-and-ride lots for passengers to transfer from auto to transit modes (Strate et al., 1997), and drayage facilities that enable containerized freight to be shipped from a seaport to inland locations by rail and truck (Harrison et al., 2007). "P3" is a common acronym that refers to a public-private partnership—loosely described as a contractual agreement between the public sector (e.g., a federal, state, or local agency) and the private sector in order to provide services or infrastructure in a cost-effective manner (Istrate and Puentes, 2011). This research concerns *multimodal P3* investments.

1.1 P3s: A Set of Diverse, Promising, Imperfect Alternatives

P3s are not stringently defined: for example, Federal Highway Administration (FHWA) (Office of Innovative Program Delivery [OIPD], undated a) has described P3s as "*contractual agreements formed between a public agency and a private sector entity that allow for greater private sector participation in the delivery and financing of transportation projects.*" Examples of projects that meet this definition include (1) a $336 million project that built a walkway and consolidated land owned by private rental car agencies (in 2008 or earlier dollars) (Bobba et al., 2010), (2) a $4.1 million (in roughly 1976 dollars) conversion of an eight-block two-way street into a pedestrian only mall (Brunet, 1986), and (3) a $350 million project that provided public parks, multi-use trails for bicycle and pedestrian, and light rail transit (AECOM and JJG, 2012). Laudan (2003) defines a P3 as "*a legally-binding contract between government and business for the provision of assets and the delivery of services that allocates responsibilities and business risks among the various partners.*" To be clear, while P3s can help finance a transportation project and allocate risk to the private sector, P3s are not synonymous with user fees: a P3 can exist on a facility that does not have a toll, fare, or occupancy charge—and of course such fees can exist for projects that are in no way a P3.

By 2011, P3s had been used at least once in 31 countries and had been used extensively in 9 countries (Kwak et al., 2009). An attractive feature of P3s is that they can bring private financing to projects that cannot be built if only public sector funds are available. In the United States, they have been used as a tool to increase private investment in city and regional privatization since 1950s. Currently, many states are active in the P3 market. A review of FHWA (OIPD, undated b) suggests that as of 2012, 33 states have adopted legislation enabling P3s. The Commonwealth of Virginia has experience with P3 projects; notably, the Public-Private Transportation Act of 1995 (PPTA) was enacted in order to supplement public funding with private sources of money and encourage creative, timely and less costly transportation projects.

Despite their attractiveness, two decades of history shows that P3s are not a panacea. Even though P3s are still growing in popularity for funding projects in North America, a remarkable number of P3 projects were renegotiated during the 1990s. Worldwide, almost 40% of P3 projects throughout the 1990s saw their contract reworked because of unexpected excess budget which generally implies a failure of project (Orr, 2006). For example, in 1988 Virginia became the first U.S. state to enact legislation allowing what are currently described as P3 projects (Transportation Research Board [TRB], 2013). That said, the Dulles Greenway project in the greater Washington, D.C. area, which extended the existing Dulles Toll road from Dulles International airport to Leesburg, suffered from disappointing financial results, attributable to initial daily traffic volumes of 8,000 vehicles rather than the 35,000 forecast (TRB, 2013). It has been considered that these issues can be overcome by imposing tolls just like the Dulles Greenway example. However, Reinhart (2011) writes that *"few of the PPP projects being built now or [which] are being proposed for PPP development can support themselves financially with tolls alone."* Such a statement suggests that financial resources from the public sector, or other revenues, are necessary in order to make at least some P3 projects successful. In this regard, Orski (2013) noted that *"a growing number of states are not waiting for the federal government to come to the rescue but are using their own resources to keep their transportation facilities in good working order."* This suggests that, for P3 projects were are not financially viable from tolls alone, transportation agencies may need to find alternative sources of revenues—or new funding approaches—besides user fees. An acute example is transportation megaprojects that are beyond the states' fiscal capacity (Orski, 2013).

1.2 Multimodal P3s May Offer Societal Benefits

Generally the private sector would not be expected to invest capital unless the project yields a sufficiently high return on investment. AECOM Consult, Inc. (2007b) pointed out that highway transportation projects in the United States are facing a fiscal challenge caused by the growing gap between the costs of providing and preserving the highway infrastructure and available highway funding. This pressure to fund projects whose revenue comes from user fees, however, means that most projects that rely on private sector involvement will lean away from a multimodal focus.

However, AECOM Consult, Inc. (2007a) has suggested that P3s with a multimodal component can yield both (1) greater societal benefits and (2) increased private sector participation. The multimodal component in P3 projects can include (1) multi-occupant-auto modes such as carpools and vanpools, (2) non-auto modes such as pedestrian, bicycle, and transit, and (3) land use practices that support other modes. Societal benefits can be defined as (in)direct benefits in the society which include user benefits (user convenience, comfort, safety, and enjoyment), reduction of vehicle travel (vehicle cost savings, energy conservation, roadway cost savings), economic development (increased property values, employment, outputs and incomes), and reduced environmental impacts (air pollution reductions and noise reductions). These benefits can affect one user, a specific group of users, or society through direct, indirect, or cumulative impacts. The multimodal component can improve access to increased economic development opportunities and more diverse revenues and financial markets for transportation investments (AECOM Consult, Inc., 2007b). For example, for a multimodal P3 project consisting of 14 sub projects, it was estimated that $3 billion was injected into the local economy from 2005 to 2013; further, every $1 invested in transit infrastructure translates into a $4 dollar return over a 20 year period, and 12,000 direct full-time jobs have been created since 2005 (Regional Transportation District, 2014).

In short, the explicit consideration of multimodal aspects can be a new approach to expedite P3 projects. Although inclusion of multimodal components will often seem infeasible because these components do not increase revenue from user fees or may have been underestimated of possible economic benefits, AECOM Consult, Inc. (2007b) suggests that if one includes ancillary societal impacts—notably "land development"—such multimodal components could become viable. Land development may be defined as the set of characteristics that define how existing land uses are altered; such characteristics include property values (e.g., assessed value of buildings and land uses), type of development (e.g., commercial versus agricultural), intensity (e.g., dwelling units per acre), and consumption (e.g., number of acres consumed). In addition, Virginia encourages the statewide long-range multimodal transportation plan by VTrans2035 (Office of Intermodal Planning and Investment, 2010). In spite of these strength and emphasis, there is little research dealing with multimodal aspects of P3 projects. Previous research handles only single mode or Single-Occupancy-Vehicle (SOV) P3 projects in only highway projects. With an understanding of how multiple modes can affect societal benefits, especially land development in this research, it might be possible to make P3 projects financially viable. As a result, at this point of time, many P3 projects are in planning and under procurement in the U.S., research for in-depth guideline regarding evaluating the land development impact of multiple modes in P3 projects are quite necessary in order to make P3s profitable and maximize the transportation infrastructure sustainability.

1.3 Mechanisms for Generating Revenues from P3 Projects

The emphasis on modes which will generate user fees may naturally reduce the likelihood of a P3 investment that will enhance multiple transportation modes. Because the ability to private involvement becomes a key consideration in project starts, the promotion of private sector involvement may distort public spending priorities (Thia and Ford, 2009). That is, the lack of economic incentives for the private sector adjusts them to pursue only profitable projects such as tolled highways or bridges. As pointed out by Forrer et al. (2002), "*it is sometimes argued that the only incentive motivating the private sector will be the tendency towards cost cutting rather than service enhancing activities*" (quoted from Thia and Ford, 2009). What hampers implementation of "multimodal" P3 projects is consequently their financial viability (also acknowledged from Cromwell et al., 2013). For example, a project will initially be proposed as a transit and highway project at the conceptual stage; however, as the project moves through negotiations, the non-highway components may be dropped in order to render the project financially viable.

Accordingly, it is appropriate to consider how revenues can be raised from P3 projects. The FHWA Office of Innovative Program Delivery generally characterizes revenues as either "road pricing" or "non-road pricing."

Road pricing is a traditional and commonly well-known tool to support P3 project. This involves charging fees for the use of a roadway facility. The revenue generated may be used to pay for highway operations and maintenance or as the primary source of repayment for long-term debt used to finance a toll facility itself. FHWA identifies two primary variants (OIPD, undated c):

- *Tolling:* the imposition of a per-use fee on motorists to utilize a highway. Historically, these fees have involved fixed, distance-based tolls that vary by vehicle type, but not by time of day. Their primary purpose has been to generate revenue.

- *Pricing:* the imposition of fees or tolls that vary by level of vehicle demand a highway facility. Also known as congestion pricing, value pricing, variable (dynamic) pricing, peak-period pricing, or market-based pricing – this manages demand by imposing a fee that varies by time of day, location, type of vehicle, number of occupants, or other factors. While pricing generates revenue, this strategy also seeks to manage congestion, environmental impacts, and other external costs occasioned by road users.

A variety of *non-road pricing* mechanisms are available to generate revenue for transportation projects. These include a broad assortment of fees or taxes levied on defined groups of beneficiaries expected to benefit from the provision of a particular transportation facility or resource. These non-road pricing mechanisms cover a vast landscape of strategies to help pay for non-tolled improvements or facilities such as transit. In a P3, non-road pricing strategies may involve the sharing of costs, revenues or financial risk between public and private partners or may impose fees or taxes on defined groups expected to benefit from the project. Non-road pricing revenue sources are those that fund transportation from all levels of government that do not involve road pricing revenue source. Apparently, a number of federal, state, local and private non-road pricing revenue sources exist. These sources cover a broad range of fees, taxes, and shared cost or revenue arrangements. Table I-1 describes details of non-road pricing revenue sources and tools.

TABLE I-1. Representative Examples of Non-road Pricing Revenue Sources and Tools[a]

Level	**Type**
Federal Non-Road Pricing	• Motor fuel tax (18.4 cents [gasoline], 24.4 cents [diesel] per gallon)
State Non-Road Pricing	• State motor fuel excise tax • State other taxes and fees on motor fuel purchase including environmental fees and inspection fees • State sales tax • Vehicle registration fees and taxes • Other sources: property tax, income tax, driver license fees, advertising, rental car taxes, state lottery/gaming proceeds, oil company taxes, vehicle excise taxes, vehicle weight fees, investment income, etc.
Local Non-Road Pricing	• Local option sales taxes • Vehicle registration fees • Income/payroll/employer taxes • Property taxes • Other sources: transit fares, advertising, naming rights, shared resources, transportation utility fees
Value Capture	• Special assessment • Tax increment financing • Development impact fees • Developer contributions
Transit-Oriented Development	• Joint development
Private Equity Capital	

[a] This table is created on the basis of information from OIPD (undated c)

Among non-road pricing revenue sources, value capture strategies can be used to help pay for non-tolled improvements such as transit by leveraging localized benefits ranging from increased property values to a broader tax base. The basic idea of value capture derives from the linkage of transportation networks and urban activity. A transportation improvement increases the ease of access to desirable destinations, such as jobs or schools. Locations that are more accessible tend to command higher prices for land, such as parcels near a highway interchange. Landowners and developers benefit from this increased value. Using value capture mechanisms, a part of this newly created land value can be captured in the form of revenue. The revenue generated can help finance the transportation improvement, or it can go toward further transportation investments elsewhere, which in turn make an affected location more accessible and, by extension, a more valuable piece of property. In this regard, value capture strategies may also be applied to toll roads to take advantage of the increased property values and other economic benefits produced by transportation improvements.

1.4 Problem Statement

Thia and Ford (2009) have suggested that, when P3s are used, there is a positive correlation between higher levels of collaboration of the private and public sectors, and higher levels of economic benefits to the community. For this reason, being able to articulate how a P3 project may increase land development, eventually for the purposes of value capture, is a way to inform private sector involvement in multimodal P3 projects.

The problem, however, is that the impact of a P3 on land development is not completely clear. Two factors can contribute to this uncertainty.

- *The toll.* It may be the case that P3 facilities have a different impact on land development than non-P3 facilities. For example, if a P3 facility imposes a toll, the facility may have a different impact on land development than a facility which does not impose a toll, since the toll may make certain areas more accessible—but only for certain types of users who are willing to pay a toll.

- *The degree of multimodality.* The extent to which a P3 project supports multiple modes may influence its impact on land development. That is, the key concern is determining to what extent such multimodal aspects influence land development.

Accordingly, there may be a practical benefit to analyzing how multimodal P3s influence land development. The practical value of analyzing land development impacts would be twofold: (1) to generate stakeholder support and (2) to show how changed urban forms could eventually help generate both public and private revenues. From the public's perspective, the land development estimated for the future would be captured as special types of fees or taxes. On the private sector's side, the rights for developing lands including air rights can be transferred to the private so that they might lease them out to enhance their revenues.

1.5 Purpose and Scope

The primary purpose of this research is to identify the extent to which multimodal P3 projects influence land development in terms of urban form. This purpose has greater utility, however, if a rationale for being interested in multimodal P3 projects is first established—that is, clarify what is a multimodal P3 project, determine a reliable way of measuring multimodality, and then relate this multimodality to a social goal in which there is interest such as jobs-housing balance.

Accordingly, this research has five major objectives:

- Identify lessons learned from the use of toll facilities in the U.S. (Toll facilities are not necessarily P3 facilities, but because some toll facilities involved substantial private sector risk, insights gained may relate to current P3 projects.)
- Develop and interpret a new dissimilarity indicator to scale jobs-housing balance for P3 projects, where this indicator can be calibrated to observed trip length distribution frequencies.
- Develop a taxonomy for classifying the degree of multimodality for a given project.
- Explore how implementation of a multimodal P3 affects the degree of multimodality and jobs-housing balance.
- Determine how changing the degree of multimodality for a multimodal P3 changes jobs-housing balance.

While the fourth and fifth objectives are the chief goals of this research, other objectives address areas of interest expressed by others. The first objective addresses an interest of the P3 office for a history of P3 facilities in the U.S. and Virginia (Cromwell et al., 2013). The third objective arose as a possible area of interest for the P3 office given that P3s may offer a new wave of large-scale transportation investments not seen since the construction of the interstate system (e.g., Cromwell et al., 2013).

1.6 Report Layout

This report consists of four chapters, including the introduction presented in Chapter 1 and conclusions and recommendations in Chapter 4. Because Chapter 2 and 3 discuss different topics relating to major objectives of this research, each chapter present its objectives, main body, results, and discussion. The first objective is addressed in Chapter 2, and the second, third, fourth and fifth objectives are in Chapter 3.

CHAPTER II A BRIEF OVERVIEW OF TOLL ROADS IN THE U.S. AND VIRGINIA

2.1 Chapter Objectives

During the past three decades, “toll roads”—that is, roads funded by some type of toll or user fee specifically attributed to using a given facility—have gained renewed interest at the national level, for two distinct reasons.

- *To build (or maintain) roads more quickly than would have been the case if toll roads had not been used.* States have recently used tolls to fund new facilities. For example, Virginia’s Public-Private Transportation Act of 1995 increased the feasibility of pursuing public-private partnership (P3) projects. A longer viewpoint shows that acquiring funds for maintenance is not a trivial matter, given that facilities built during the peak construction years of the Interstate System have been approaching the end of their design life (Gomez-Ibanez et al., 1991). This concern about maintenance is not new: the 95th U.S. Congress (1977-1979) permitted federal 4R (resurfacing, restoration, rehabilitation, and reconstruction) funds to be used on certain toll segments of the Interstate System (Schneider, 1985), and states without toll roads during the 1970s, such as Arizona and Wisconsin, considered converting interstate highways to toll roads in order to pay for maintenance (Virginia Department of Transportation [VDOT], 2006).

- *To influence travel behavior. As early as the mid-20th century, this possibility had been noted.* Zettel and Carll (1964), and Vickrey (1967) suggested that tolls can help reduce congestion during peak periods; thus tolls provide a societal benefit. Tolling can also cause a shift to other modes that may be beneficial for the public; for example, Pessaro and Songchitruksa (2014) reported that the implementation of tolls in Seattle was associated with a 14% increase in transit ridership—and this increase was larger than what had resulted from a previous improvement to transit service. Longer term behaviors—in terms of where to locate businesses and homes—may also be affected by tolls as noted by the Urban Land Institute (2013): when revenues from tolls exceed costs, those revenues may be applied to subsidize public transportation, thereby encouraging denser development within existing urban locations. Further, electronic toll collection has eliminated some delays previously associated with tollbooths (Washington State Transportation Commission, 2005).

However, privately built toll facilities are not a new development—while terms such as congestion pricing and P3 have become more common than they were two decades ago, a review of how roads have been funded since the colonial period suggests tolling is not a new concept. To the extent that history is repetitive, it may be feasible to identifying outcomes of past events, learn lessons, and then mitigate negative impacts of such events in the future. In this regard, this chapter has two objectives: (1) to provide a history of toll roads with Virginia examples and (2) to identify conditions that have been conducive to the use of toll facilities.

2.2 A History of Toll Roads in the United States

The chapter identified five periods associated with U.S. toll roads: Colonial/Early Federal Period (1607-1775), Turnpike Era (circa 1792-1845), Anti-Toll Sentiment Era (1879-1939), Post-World War II Era (1939-1963), and Renewed Interest in Tolling Period (circa 1976-present).

2.4.1 Colonial/Early Federal Period (1607-1775)

Until the end of the 18th century—and in Virginia, until the 1932 Byrd Road Act (O'Leary, 1998)—roads in the North American colonies were built and maintained mainly by towns and counties, a precedent set by the English (Pennsylvania's Historical Marker Program [PHMP], 2011). Although the British Parliament established the first organized postal system in the United States in 1711, the construction of post roads, such as the long distance Boston Post Road, was managed at the town and county level (Marriott, 2010).

The first highway legislation in North America was passed in Virginia in 1632; it put church parishes in charge of road construction and maintenance. Additional legislation in 1657, 1661, and 1663 transferred this responsibility to the county courts, which in turn appointed an individual to oversee highway work. All males over the age of 16, whether free or a slave, were required to work for a specific number of days per year; such individuals were known as "titheables" and were initially supervised by the vestry of the parish. (Pawlett, 1977). This concept of annually requiring road work without payment continued for more than two centuries, becoming known as a "labor tax" or "statute labor" (Wallenstein, 2004). Its use was not restricted to Virginia; for example, in 1683, maintenance of the Pennsylvania sections of the King's Highway (which ran from Charleston, South Carolina, to Boston, Massachusetts [Schools, 2012]), was achieved by requiring residents to work on the construction of roads and bridges or to pay a fee (PHMP, 2011). Although other definitions of *titheables* exist (e.g., Alcock [1999] included non-white females), both Pawlett (1977) and later case law ("Virginia reports," 1902) suggested that for road building purposes, titheables were strictly male.

Although England had permitted tolls, they were generally not accepted in the colonies (FHWA, 1976). Rather, during the Colonial/Early Federal Period, transportation facilities were viewed as a public good in terms of enabling defense. In 1691, the first road in the Virginia Colony was constructed by the government, connecting the frontier forts (Pawlett, 1977) located along what is today known as roughly the I-95 corridor; during this time, the colony's population increased 14-fold from 5,000 in the 1630s to 70,000 by 1700 (Virginia Department of Transportation [VDOT], 2006). Marriott (2010) illustrated the importance of defense: the (roughly) 9-mile Indian portage road that linked two key waterways, i.e., Lake Erie (thereby connecting to the Great Lakes) and Lake Chautauqua (thereby eventually connecting to the Ohio and Mississippi rivers), was widened by the French military in 1749 in part to help them claim ownership of land in the Ohio Valley.

Transportation facilities were also viewed as a public good in terms of improving freight during this period. For example, following its Virginia introduction in 1612, annual tobacco exports grew to 250 tons in less than 20 years; expansion of tobacco fields meant more tobacco needed to be shipped (VDOT, 2006). A 1705 revision to the law (initially titled "An act for making, clearing, and repairing the highways, and for clearing the rivers and creeks") specifically listed tobacco as a reason for the law, established a 30 foot wide clear zone, required the removal of trees within 48 hours (if cut by a landowner adjacent to the facility), and established fines for noncompliance with these standards (Hening, 1819). For example, a fine of five shillings was levied if a titheable (e.g., a male age 16 or older) was called by a surveyor to perform maintenance but failed to do so; this fine was doubled for a landowner who did not remove a cut tree within 48 hours (Hening, 1819). Throughout the colonies, mail freight was an explicit component of the rationale for publicly funded infrastructure: Straubenmuller (1905) wrote that when the Dutch controlled New Amsterdam (e.g., prior to it becoming New York City in 1665), three post roads (leading to the Brooklyn Ferry, the Harlem River, and Albany) were established, with the Albany Post Road being officially designated by the New York legislature in 1703 as Queen Anne's Highway (Marriott, 2010).

Unlike roadways, ferries were directly funded with tolls (Office of Highway Policy Information [OHPI], 2013). In some portions of the colonies, such as the area of Virginia that was east of the fall line (roughly the I-95 corridor between Alexandria, Richmond, and Petersburg), waterways were more important than the roadway system. Until the 1780s, hundreds of private ferries—canoes, rowboats, and flat-bottomed barges capable of carrying a wagon or cattle—navigated the rivers where feasible. For example, the Dutch post road from New Amsterdam to Albany actually used a ferry during the summer months (Straubenmuller, 1905). Although operation required a permit from the county court, private ferries were allowed to collect fixed fees as compensation for their services. Fees varied by location; the Pennsylvania ferry acts of 1683, 1690, and 1693 described the fixed rate of "two pence a head for carrying over every person, and with a horse, four pence," whereas the New Jersey ferry legislation of 1716 indicated specific toll rates only for a "single person" or for "horse and man" (Dunbar, 1915).

To be clear, although transportation was viewed as a public good, it became evident as the Colonial/Early Federal Period drew to a close that public monies were not sufficient for needed infrastructure investment. In order to help open western areas to new markets, the young American republic launched a road building campaign in the 1790s (PHMP, 2011). Needs were not limited to new construction: funds to repair existing facilities also exceeded what the public sector could provide (Klein, 1990). In his *Notes on the State of Virginia* in 1785, Thomas Jefferson pointed out that although bridges should be built "at the expense of the whole county," it was possible, in cases where counties could not pay the costs of construction, for funds to be sought from the state—in which case tolls might be pursued:

> If the stream be such as to require a bridge of regular workmanship, the county employs workmen to build it at the expense of the whole county. If it be too great for the county, application is made to the General Assembly, who authorizes individuals to build it and to take a fixed toll from all passengers, or gives sanction to such other propositions as to them appear reasonable (cited in VDOT, 2006).

2.4.2 Turnpike Era (Circa 1792-1845)

After the Revolutionary War (1775-1783), trade and, as a consequence, highway traffic increased, leading the federal government to consider how road construction could support commerce and the development of cities (OHPI, 2013). However, there was limited constitutional support and precedent for funding roadways at the national level—and state governments were already in debt, partly because of their efforts to help construct major private roads (Hoyt, 1966). An alternative approach was to attract private capital through the construction of turnpikes, with Thomas Jefferson observing that "toll financing provided a means of building highway facilities for which there was a need but which were too complex and costly to be constructed by the counties alone" (cited in VDOT, 2006). Documents from the Office of Road Inquiry—e.g., Crump (1895) and Stone (1894)—indicated that the word "turnpike" arose from medieval use in England: a traveler on a toll facility would first encounter a "pike" across the road, and after the traveler paid the toll, the "pike was turned," allowing the traveler to proceed.

The first toll road in what is now the United States was probably authorized by the Virginia legislature in 1772: the Howardsville Turnpike in Augusta County running south and west from Jennings Gap to Warm Springs (VDOT, 2002) across the Blue Ridge Mountains. Other authorizations soon followed. In 1785, the legislature designated a committee to allow toll gates on the Georgetown Road and on several roads leading west from Alexandria on the Potomac River (Mullen and Barse, 2012). In 1792, the Lancaster Turnpike—the earliest private turnpike in the United States —was permitted by the board of commissioners in Pennsylvania and was publicly supported through the state's purchase of stock in the turnpike (Klein and Majewski, 2008). Virginia had some examples of turnpikes during this early period: for example, Little River Turnpike (Kelly, 2013; National Active and Retired Federal Employees Association, 2013), Valley Turnpike (National Park Service, 2014), and Howardsville Turnpike (Shepherd, 1846).

Originally, the U.S. turnpike laws were modeled on the English system (Hadley, 1903) such that once the construction debt had been repaid, tolls would cease and the public sector would take over the facility (Hunter, 1961). In practice, however, this change of ownership from the private to the public sector did not occur in New England and Virginia (Liebertz, 2010); the turnpikes remained private even after the debt was repaid.

FHWA (1976) pointed out that the initial turnpike companies focused on the areas of greatest demand, such as what is now U.S. Route 1 along the eastern seaboard. That said, the number of turnpike companies grew from 69 (in 1800) to almost 1,600 (by the end of 1845), with more than one-half of the turnpikes concentrated in the Middle Atlantic states of Pennsylvania and New Jersey and almost one-seventh in Ohio (Klein and Fielding, 1992). In New York, in which almost 30% of the turnpikes shown in Figure II-1 were located, turnpikes developed without state subsidies because many of the turnpike roads were controlled by large landowners who sometimes were more interested in selling land than in providing transportation.

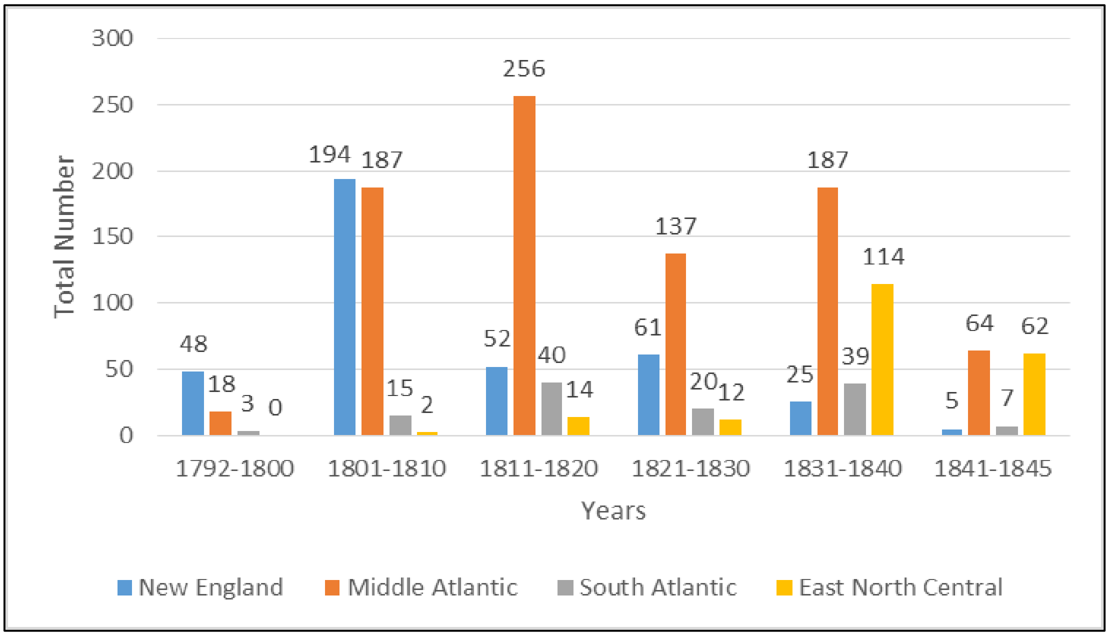

FIGURE II-1. Turnpike corporations by region in the Turnpike Era

Note: *New England* is defined as the five states of Connecticut, Massachusetts, New Hampshire, Rhode Island, and Vermont; *Middle Atlantic* is New Jersey, New York, and Pennsylvania; *South Atlantic* is Maryland and Virginia; and *East North Central* is Ohio. Drawn from data provided by Klein and Fielding (1992) with geographical categories based on the U.S. Census Bureau (2014).

Most turnpikes, except those in Pennsylvania, Virginia, and Ohio that were partially subsidized by state governments, were operated as private companies, with investors owning stock and receiving dividends. Yet "the turnpikes did not make money" (Kirkland, 1948, as cited in Klein and Majewski, 2008). This is noteworthy, given that road construction costs averaged $1,500 to $2,000 per mile (Klein and Majewski, 2008), which in today's dollars would approach $50,000 per mile (Sahr, 2014). It may be the case that a motivation for such turnpikes was the indirect benefits to farmers, land owners, and merchants resulting from the increased movement of goods. Some states were also strategic in their support of turnpikes in light of these benefits. Maryland chartered several turnpike incorporations in the 1820s to connect Baltimore with the Cumberland Road (the National Road) then being built by the federal government, with the idea that these turnpikes would make it possible to take advantage of the federal investment when the Cumberland Road reached the Ohio River (FHWA, 1976).

Liebertz (2010) stated that "turnpikes were not a technological innovation, but a legislative authorization to construct roadways and collect a toll." Turnpike corporations enjoyed a more stable revenue stream than their public counterparts—which directly affected maintenance. The private Pittsburgh Turnpike and a public alternative route, the trans-Appalachian section of the National Road (from Cumberland, Maryland, to Wheeling, West Virginia), may be considered examples. According to the comparison by Klein and Majewski (2008), even though per-mile costs for the latter ($13,455) were triple those of the former ($4,805), the Pittsburgh Turnpike continued to be profitable and well maintained, although the National Road, which relied on unstable government revenues for maintenance, deteriorated.

The Turnpike Era drew to a close for two reasons. First, and most important, modal competition—primarily the 31,000 miles of railroad in place by 1860 following the first-ever charter for a commercial railroad (the Baltimore and Ohio Railroad in 1827)—took passenger and freight traffic. Whereas early U.S railroads in the 1830s were operated by horse power (with speeds of 8 to10 mph), by 1840, steam engines were in use (with speeds of 16 to 20 mph) (Chatburn, 1923). FHWA (1976) noted that railroads enjoyed a tremendous advantage relative to roads not only because of higher speeds but also because freight was being moved relatively cheaply. For example, the completion of the Pennsylvania Railroad to Pittsburgh in 1854 was accompanied by the bankruptcy of Pennsylvania's western wagon road (FHWA, 1976). In specific east-west markets where canals were constructed, notably western New York to the Great Lakes (because of the 1825 Erie Canal) and Philadelphia-Pittsburgh (because of Pennsylvania's 1831 "river-canal" system), canals took freight, but not necessarily passenger, traffic from the turnpikes, which also decreased earnings (FHWA, 1976). For example, the Erie Canal reduced freight travel on New York's Albany & Schenectady Turnpike, Mohawk Turnpike, and Seneca Turnpike (Baer et al., 1992), eventually ending New York's toll road expansion (Larkin, undated). In fact, by the 1840s, few turnpikes had generated consistent profits: most did not pay taxes, and of a sample of 37 turnpikes that were operational in Virginia at some point during the years 1816 through 1848, only 10 ever paid a dividend. Even in those instances, the average rate of return was lower than what could be expected for other types of investments, leading Hunter (1957) to note that most buyers of the stock "were aware that the return would be either slight or absent altogether."

Second, events during the U.S. Civil War (hereinafter Civil War) damaged some facilities in the South; the literature gives descriptions of damage to bridges and/or roads in Louisiana (Smith et al., 2012), Mississippi (Harrison, 2014), Tennessee (Smith, 2013), and Virginia (VDOT, 2006). Hostile actions were a clear contributor, as described, for example, by Smith (2013); however, it is also likely that even if the destruction had not been deliberate, the movement of troops and heavy supplies alone would have damaged these facilities. For most turnpikes, toll revenues were insufficient to repair this damage, leading to a cessation of maintenance and travelers refusing to pay further tolls. As a result of this loss of profitability, shorter toll roads became feeder lines for railroads (Pawlett, 1977). One mechanism for this conversion was a turnpike enactment that transferred ownership to state or local government (Hoyt, 1966). As an example, some sections of the Lancaster (Pennsylvania) Turnpike (once considered to be the best road in the United States) were returned to public control around 1880, with the private entity being dissolved in 1902 (Hulbert, 1904). In other instances, turnpike corporations simply ceased operation and abandoned their facility (Williamson, 2012).

There is some question as to whether the Turnpike Era should be defined as closing in 1861. For example, in Virginia, turnpikes were legally permitted by enabling acts, i.e., legislation allowing the construction of a particular turnpike. Although turnpikes were constructed as late as 1900, based on tabulations using a Virginia data set (Tompkins, 1928; Virginia Department of Highways, 1932), most enabling acts for turnpikes occurred before the Civil War. Of the 272 such enabling acts passed from 1795 to 1900, only 40 were passed from 1867 and 1900 and none was passed from 1862 to 1866. The rate of enabling acts for such turnpikes after the Civil War (1.2 per year) was roughly one-third of the rate (3.4 per year) before the Civil War.

2.4.3 Anti-Toll Sentiment Era (1879-1939)

As the Turnpike Era drew to a close, abandoned turnpikes became public feeders for railroads (Daley, 1999; Majewski et al., 1993). Since many such converted roads had no toll, they rapidly deteriorated; rutting was evident where the wheels had traveled. Plank roads—so named for roads constructed from wooden planks—were an inexpensive, appealing alternative (Norris and Ireland, 2006), although it was difficult to keep these roads in good condition. In a relatively short period known as the Plank Road Boom, more than 1,000 corporations constructed more than 10,000 miles of plank roads across the United States during the 19th century, as shown in Figure II-2 (Klein and Majewski, 2008). In Virginia, enabling acts suggest that 19 plank roads were constructed during the period 1850 through 1858 (Tompkins, 1928; Virginia Department of Highways, 1932). Thus it is possible that although many turnpikes had been abandoned by the late 1870s, the improvement of plank roads may have stimulated public interest in better transportation.

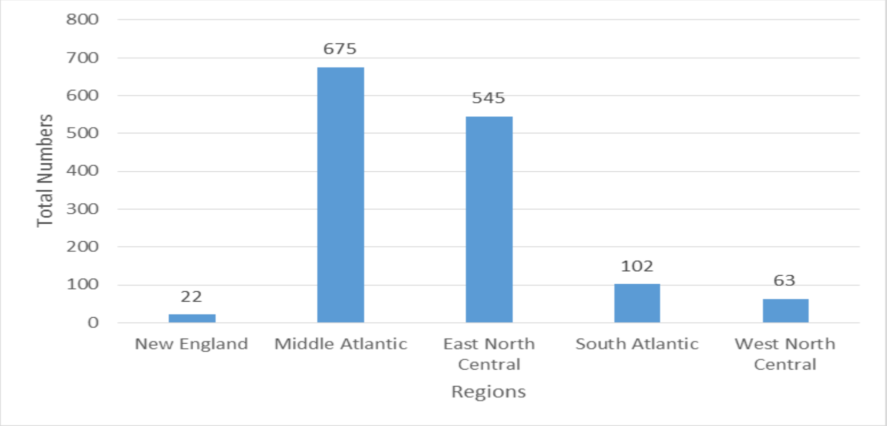

FIGURE II-2. Plank roads by regions in the Anti-Toll Sentiment Era (circa 1844-1858)

Note: *New England* is defined as the states of Connecticut, Massachusetts, and Vermont; *Middle Atlantic* is defined as New Jersey, New York, and Pennsylvania; *East North Central* is defined as Ohio, Wisconsin, Michigan, and Illinois; *South Atlantic* is defined as North Carolina, Maryland, Georgia, and Virginia; and *West North Central* is defined as Missouri and Iowa. Drawn mostly from data provided by Klein and Fielding (1992) with additional Virginia information from Tompkins (1928), Virginia Department of Highways (1932), and Barlow (2014). Geographical classification is from the U.S. Census Bureau (2014). Years are approximate because they vary by state (e.g., Ohio data are through 1851, and Maryland data are through 1857 (Klein and Fielding, 1992); Virginia data include plank roads through 1858 (Barlow, 2014).

To be clear, poor roadway conditions contributed to the demand for better facilities. Better facilities were found in cities or in short segments connecting one town to another, but the majority of roads in the countryside were unpaved. Even in 1904, more than 90% of the roads were unpaved or ungraded (Lee, 2012) such that most goods and people moved by railroad (Deakin, 1989). However, the invention of two additional modes—the bicycle and the automobile—also generated demand for improvements. Rough unpaved facilities were viewed as an obstacle by users of bicycles, which were first manufactured in the United States in 1878 and which included pneumatic tires starting in 1888 (Mozer, 2014). This inexpensive mode had popular appeal: Garrison and Deakin (1992) pointed out that “bicycles were the first mode to make personal transportation widely available,” which influenced public opinion. For example, in 1891, the growth of bicyclists led to the establishment of the Good Roads Association in Missouri, and similar organizations were soon established in other states to generate sentiment favorable to more and better road building (Keane and Bruder, 2003). Following the Duryea brothers 1895 creation of the first gasoline powered auto company in the United States, the Ford Motor Company produced 1,695 cars in 1904 and 14,887 in 1907—an almost 10-fold increase in just 3 years (VDOT, 2006). Both modes required a harder and smoother surface, which contributed to the growth of America's road network (Klein and Majewski, 2008).

One manifestation of the demand for better facilities was the emergence of the Good Roads Movement. This movement was characterized by a series of laws, public policies, and local interest in higher quality facilities; as pointed out by Merchant (2013), it encouraged governments to "pave more roads to accommodate the newly-invented bicycle." Although the initial good road laws were adopted by North Carolina in 1879 and Iowa in 1883, the Good Roads Movement grew rapidly in the 1890s. Examples of this growth include the circulation of *Good Roads* magazine by the League of American Wheelmen in 1892 (Quinn, 1968); the creation of federal highway departments such as the Office of Road Inquiry in 1893 and the Office of Public Roads in 1905 (OHPI, 2013); and state-specific groups such as the Virginia Good Road Association established in 1894 by the Young Business Men's League of Roanoke (VDOT, 2006). These facilities offered public benefits for freight also: the U.S. Department of Agriculture had established the Office of Road Inquiry because poor roads prevented farmers from transporting their products to railroad terminals or nearby towns in a timely fashion (Williamson, 2012).

The Good Roads Movement gained momentum as freight demand grew (resulting from the U.S. involvement in World War I) and as passenger demand grew (after the war). Initially, freight volumes grew exponentially as a result of Europe's extensive purchases of U.S. supplies, with the trucking industry growing rapidly as the nation's railroads were overburdened. During the early war years of 1914 and 1915, the nation's roads deteriorated as a result of heavy truck use (Williamson, 2012). After the end of World War I, the ability to own an automobile spread to the middle class (OHPI, 2013); annual sales more than tripled from 1.6 million (in 1921) to 5.3 million (in 1929), and more than one-half of American households owned an automobile by that time (Weingroff, 2014b).

During the Anti-Toll Sentiment Era, private ownership of facilities was discouraged. The 1906 opinion of a New York county board of supervisors showed well the common sentiment for toll road companies at that time:

> The ownership and operation of this road by a private corporation is contrary to public sentiment in this county, and the cause of good roads, which has received so much attention in this state in recent years, requires that this antiquated system should be abolished. . . . That public opinion throughout the state is strongly in favor of the abolition of toll roads is indicated by the fact that since the passage of the act of 1899, which permits counties to acquire these roads, the boards of supervisors of most of the counties where such roads have existed have availed themselves of its provisions and practically abolished the toll road (cited in Klein and Majewski, 2008).

This sentiment was also evident at the federal level. The federal government barred the use of tolls on highways for which federal monies were spent to (re)construct facilities as described in the Federal-Aid Road Act of 1916 and the Federal-Aid Road Act of 1921. Even though exceptions such as toll bridges and tunnels existed, this ban on tolls remained in effect some 70 years. In that context, the Interstate System as it is known today (e.g., as authorized by the Federal-Aid Highway Act of 1956) was to be constructed as a toll-free network of transcontinental roads, which consisted of approximately 47,000 miles of the roughly 1 million miles of the federal-aid highway system (Williamson, 2012).

Up to four factors appear to explain at least some of the public opposition toward tolls during this era.

1. *Although projected revenues exceeded projected costs for some individual segments, it was not the case that all proposed toll facilities were economically viable.* Although President Franklin Roosevelt had considered a system of tolls to finance anticipated future construction, a subsequent 1938 feasibility study of six national toll routes (three running north-south and three running east-west) (as reported by Weingroff [2013] and Mohl [2002]) concluded that "the construction of direct toll highways cannot be relied upon as a sound solution of the problem of providing adequate facilities for . . . necessary highway transportation of the United States or to solve any considerable part of this problem" (Bureau of Public Roads [BPR], 1939). This BPR study (1939) showed that of a total of 14,336 miles that comprised these national routes, by 1960 toll revenues would exceed costs for just 172 miles—about 1% of the network. Further, a review of list of the 75 segments that would comprise such a toll network (BPR, 1939) showed that the median ratio of revenue to 1960 costs would be about 41%.

2. *"Concerns about potential abuses" may have contributed to federal opposition to toll facilities* (Deakin, 1989). Given that Semmens (1987) suggested that intercity facilities (with fewer or no parallel routes) are more susceptible to excessive pricing because of a monopoly (than urban streets with multiple alternatives), such concern would seem warranted.

3. *Because automobiles could travel faster than nonmotorized transportation, the comparative delay from stopping to give a toll collector a fee may have been larger (Klein and Majewski, 2008).*

4. *It is possible that no technology (whether wooden or paved) was immune to the market forces that affected the viability of toll facilities.* The Plank Road boom in the mid-1850s ended rather suddenly because the plank roads, although faring better than gravel roads in poor weather, lasted only 5 years (Majewski et al., 1991). Their replacement after 4 years was reported ("Macadamized vs. plank roads," 1856).

The federal government actively supported road construction during this period through financing and technical assistance. As an example of the latter, the Office of Public Road Inquiries developed an inventory of all roads in the United States outside cities and used lectures, publications, and consultations to assist in road improvement (FHWA, 1976). As an example of the former, the Federal-Aid Highway Act of 1916 offered matching funds for postal routes in states that had established professionally staffed highway departments (Lee, 2012). After World War I, demand for "a nationwide interconnecting system of highways" increased (a contributing factor being the need for defense) (OHPI, 2013). Further, the Federal-Aid Road Act of 1921 provided financial assistance for states connecting metropolitan areas (Slattery et al., 1992).

That said, it would be an oversimplification to state that tolled facilities did not exist during this period. Table II-1 lists six facilities that operated during the 1920s in Virginia. Further, Congress awarded 75 "franchises" for bridges; this number does not include awards made by the states (FHWA, 1976). There were other exceptions to the federal ban on toll road financing for the federal-aid highway system, notably the Pennsylvania Turnpike and Merritt Parkway. The Pennsylvania Turnpike was a modern high-speed heavy-duty interstate highway, supported by public bonds, that used an abandoned rail right of way; it was a success as soon as it opened in 1940 (Fisher et al., 2007). The Merritt Parkway, a 37-mile modern landscaped parkway that opened in 1938, connected Westchester County's Hutchinson River Parkway in New York State to the Housatonic River (FHWA, 1976). For an extension to Hartford, the Connecticut legislature decided in 1939 to impose a toll, and thereafter the parkway was profitable for the state, earning $320,664 (with a net operating revenue of $280,000) within 6 months. Another proposed toll facility was rejected because of a legal challenge: Westchester County also tried to impose a toll on the Hutchinson River Parkway in order to overcome heavy debt, but the New York Court of Appeals forced the county to stop collecting the toll and refund what had already been collected. The court held that although built entirely with county funds, the Hutchinson River Parkway had been used as an artery of the state highway system on which the collection of tolls was prohibited (Engineering News-Record [ENR], 1940, as cited in FHWA, 1976).

TABLE II-1. Examples of Toll Facilities in Virginia during the 1920s

Name	Date Built	Date Tolls Ended	Source
Boulevard Bridge (Route 161)	1925	Tolls are still used	Hester (2010)
South Norfolk Jordan Bridge (Route 337)	1928	Tolls are still used	VDOT (2014), South Norfolk Jordan Bridge (2013)
James River Bridge	1928	1975	Kozel (2004)
Northwestern Turnpike	1831	Circa 1900	Miller (2011), Tompkins (1928)
Southwestern Turnpike	1846	1871	

Note: As of 1863, the Northwestern turnpike was located in West Virginia. The Northwestern and Southwestern turnpikes were first identified on a map (Tompkins, 1928) and then dates were confirmed from Miller (2011).

2.4.4 Post-World War II Era (1939-1963)

The large construction activity for what is known today as the U.S. primary highway system—for which construction had begun in 1921—came to an end with the U.S. entry into World War II in 1941. Although the 1920s had seen the designation of a 168,902-mile network as the federal-aid system (Weingroff, 1996), funds for this system dropped in the early 1940s, supporting the (re)-construction of 12,936 miles (in 1941), 10,178 miles (in 1942), and 8,445 miles (in 1943) (Weingroff, 2014b). Reduced federal-aid funds were invested mainly to construct new roads for national defense and to mitigate traffic congestion generated by war activities.

After World War II, the public's willingness to pay for better service increased interest in advanced highway systems. Automobile travel was growing as a result of suburbanization, automobile ownership, and the use of the automobile for social and recreational trips. Although prohibitions on using federal dollars for toll facilities continued, several states—Florida, Illinois, Maine, Maryland, and New York—created independent authorities to sell bonds and construct new state-of-the-art highways (ENR, 1941, as cited in FHWA, 1976). In addition, the success of the Pennsylvania, Maine, New Hampshire, and New Jersey turnpikes showed that the public was willing to pay for modern and well-maintained highways.

Despite the popularity of these turnpikes, objections to federal support of tolled facilities remained, primarily because access points had to be spaced far apart to reduce the cost of toll collection. Therefore, local traffic would not benefit from these facilities. Further, if trucks were prohibited on toll facilities, states would have to provide parallel free highways. In another feasibility study requested by the 83rd Congress (1953-1954), BPR (1955) recognized that local traffic would not benefit from toll facilities and thus strongly supported the continued prohibition of using federal funds for such facilities, even though about 6,900 miles of heavily travelled roads would be feasible from BPR's feasibility study. Most of these roads—6,700 miles—were on the "National System of Interstate Highways," which had been designated, but not funded, by the Federal-Aid Highway Act of 1944 (FHWA, 1976).

Thus, the 84th Congress (1955-1957) offered no federal support for new toll road construction but instead created a highway trust fund supported by dedicated fuel taxes. For the most part, the Federal-Aid Highway Act of 1956 did not allow tolls on public highways. However, in response to demand for better systems, by 1954 toll road authorities existed in at least 15 states: Connecticut, Indiana, Illinois, Ohio, Kansas, Kentucky, Florida, Georgia, Louisiana, Massachusetts, Michigan, North Carolina, Rhode Island, Texas, and Virginia. Contrary to the corporations of the Turnpike Era, these authorities used a variety of financing mechanisms: bonds backed by the state's full faith and credit, bonds secured only by tolls, motor fuel credits, bonds backed by highway funds, and direct subsidies from state and local government (Deakin, 1989). By the end of 1954, 1,382 miles of toll roads with estimated costs of $2.3 billion were under construction by these authorities, and they were making plans or studies for 3,314 additional miles ($3.75 billion). As of January 1955, 1,239 miles of toll roads ($1.55 billion) had already been completed by these authorities. During this period, the turnpike authorities had invested three times more funding in regional highways than state highway departments had invested (FHWA, 1976). Visual inspection of the 1947 map of the Public Road Administration's National System of Interstate Highways (FHWA, 1976) shows that these routes often, but not always, followed the proposed interstate routes: routes in Maine (from Portland to the New Hampshire border) and Oklahoma (from Tulsa to Oklahoma City) are clearly evident on the map; however, the map shows the Denver route as passing north to Cheyenne rather than northwest to Boulder. Table II-2 provides examples of toll roads during this era.

Although the use of federal funds was generally not allowed for toll roads, exceptions existed. The Federal-Aid Highway Act of 1956 provided for a coast-to-coast highway system, connecting important cities and industrial centers. Although the system was tax-supported, Congress authorized the use of federal funds for approach roads connecting toll roads to the free portions of the Interstate System (Fisher et al., 2007). Further, the act allowed existing tolled expressways to be included in the Interstate System when the toll roads followed interstate routes, met interstate standards, and were accompanied by parallel free roads. However, this permit was conditioned on the state's agreement to convert the toll section to a free section after bonds had been repaid (Kirk, 2013). By 1957, the Interstate System included more than 2,000 miles of toll roads (Kirk, 2013), but by 1963, when the last toll roads already planned prior to the establishment of the federal-aid system were completed, few new tolled facilities were being considered (Fisher et al., 2007).

During this period—and consistent with the Anti-Toll Sentiment Era—the public policy generally favored toll bridges to a greater extent than toll roads. As an illustration, the Virginia State Highway Commission established a 20-year plan for upgrading all road systems and sought to replace most of the state's remaining ferries. For example, during Fiscal Year 1946 and Fiscal Year 1947, the commission decided to construct toll bridges to replace ferry crossings on the York River at Yorktown and the Rappahannock River at Grey's Point and to acquire from private owners the ferries that carried vehicles across Hampton Roads between the Norfolk and Lower Peninsula area. By separate legislation, the Virginia General Assembly created a special authority to replace the Chesapeake Bay ferries with a 17.6-mile toll bridge-tunnel facility (VDOT, 2006). An example from Pennsylvania shows a favorable state government view of toll bridges. In 1943, Pennsylvania decided to purchase the privately owned intrastate toll bridges in the state and had authorized the issuance of $10 million in bonds for that purpose (Pennsylvania State Archives, 2014).

TABLE II-2. Selective Toll Roads from the 1940s through the 1960s

State	Road Description	Date Built	Source
Colorado	17-mile Denver–Boulder Turnpike	1952	Danish (2011)
New York	426-mile New York Thruway (New York City–Buffalo)	1956	Eastern Roads (2014)
Oklahoma	88-mile Turner Turnpike (Oklahoma City–Tulsa)	1953	Oklahoma Historical Society (1953)
Virginia	Chesapeake Bay Bridge-Tunnel (Route 13)	1962	Morrison (2014)
	George P. Coleman Bridge (Route 17)	1952	Historic American Engineering Record (1993)
	Governor Harry W. Nice Memorial Bridge	1940	Maryland Transportation Authority (2014)
	Hampton Roads Bridge-Tunnel (I-64)	1957	Kozel (2007)
	Norfolk–Virginia Beach Expressway (Old Route 44, now I-264)	1967	VDOT (2010)
	Richmond-Petersburg Turnpike (I-95)	1953-1958	Samuel (1997)
West Virginia	2-lane toll road (Charleston–Princeton)	1954	Hohmann (1999)

2.4.5 Renewed Interest in Tolling Period (circa 1976–Present)

Although restrictions regarding the assessment of tolls on federally funded projects remain, five key changes in the political, economic, and land use environment since the late 1970s have led to renewed interest in tolling and changes to Virginia and federal policy.

1. *Budgetary pressures increased.* The roads built during the 1960s—the peak construction years of the Interstate System—were approaching the end of their design life (Gomez-Ibanez et al., 1991). The funding gap was exacerbated by a sharp increase in highway construction costs coupled with a reduction in fuel tax receipts because of increased vehicle fuel efficiency (Deakin, 1989).

2. *Opposition to taxes made it preferable to defer construction—even if this meant forgoing new construction projects because of increased maintenance needs.* As an example, excluding its urban system, Virginia maintains the nation's third-largest highway system, with approximately 58,371 centerline miles of interstate, primary, and secondary roads as of 2012 (VDOT, 2012). Prior to the passage of new state transportation funding legislation

in 2013, Chase (2011) reported that only 19% of Virginia's future transportation dollars would be available for future construction in Virginia; the remainder would be needed to maintain the existing system. In fact, the state showed greater interest in devolving certain state maintenance responsibilities for secondary roads to counties (Chase, 2011).

3. *Urban congestion (affecting commuter and daily trips) became a greater concern than congestion in rural areas (affecting longer distance trips).* According to surveys from several toll states, these states preferred tolls over other possible options for facility rehabilitation and upgrading (Wuestefeld, 1988, as cited in Deakin, 1989). Even states without toll roads, such as Arizona and Wisconsin, tried to assess the possibility of building new toll roads or converting interstate highways to toll roads in order to pay for maintenance (Schneider, 1985). Although there was still public opposition to tolls, by the mid-1980s, the American Association of State Highway and Transportation Officials had decided to support states' use of tolls on new roads and existing roads without loss of federal aid (Deakin, 1989). Unlike the interest in turnpikes after World War II, in the 1980s the interest in the construction of toll roads was mainly concentrated in new rights of way in urban and suburban areas (see Table II-3). Virginia's growth exemplified this need for metropolitan infrastructure: by the 1970s, more than two-thirds of the state's 4.6 million people were in and around cities (VDOT, 2006). According to Deakin (1989), fast-developing suburban areas needed more roads because existing roads were heavily congested; however, public funding for new roads was not sufficient to support these demands immediately (Deakin, 1989).

4. *Starting in the 1980s, tolls appeared to be a reasonable way to manage—rather than add to—highway congestion.* In the 1960s, Zettel and Carll (1964), and Vickrey (1967) had suggested that tolls during peak hours could reduce demand; the commensurate decrease in travel costs (in terms of delay) would increase societal welfare. The idea of congestion pricing was related to the feasibility of electronic toll collection: because vehicles no longer needed to stop at a tollbooth, tolls became a way of reducing—not increasing—congestion (Washington State Transportation Commission, 2006). Many motorists with Smart Tag or E-ZPass transponders could travel throughout eastern states such as Maryland, New Jersey, New York, Pennsylvania, and Virginia without having to stop to pay tolls (Crabtree et al., 2008). However, tolls did not always influence behavior in the manner expected. For example, Burris et al. (2004) showed that in one location, variable tolls had a lesser impact on individuals' time of departure than other literature had shown. That said, a review of Parsons Brinckerhoff et al. (2009b) indicated that tolls have been considered as a mechanism that could possibly influence a variety of behaviors such as shifting the hour of the commute trip, choosing transit or carpooling, or changing the location and type of land development.

TABLE II-3. Examples of Urban and Suburban Toll Roads in the 1970s and 1980s

State (City)	Road Description	Opening Year	Source
Illinois (Chicago)	17-mile North-South Tollway	1990	Enstad (1990)
Texas (Houston)	22-mile Hardy Toll Road	1987	Schott (2009)
	88-mile Sam Houston Tollway	1990	
Virginia (Richmond)	The Downtown Expressway VA-195	1976	Joint Legislative Audit and Review Commission (2000), Bruno (2011)
	The Powhite Parkway Extension VA-76	1988	

Virginia (near Washington, DC)[a]	12-mile Dulles Toll Road	1984	Metropolitan Washington Airports Authority (MWAA) (2014a)
	17-mile extension (the Dulles Greenway)	1995	Michael Baker Jr., Inc. and ATCS, P.L.C. (2009)

[a] Route 267 (VDOT, 2003) is composed of two different toll facilities: an eastern segment (the Dulles Toll Road that opened in 1984) and a western segment (the Dulles Greenway that opened in 1995) (Michael Baker Jr., Inc. and ATCS, P.L.C., 2009). These are parallel to the Dulles International Airport Access Road that serves airport traffic only; it opened in 1962 and was extended to I-66 in 1983 (MWAA, 2014b).

5. *Toll roads could be constructed in a shorter period of time than roads that received federal aid, as some federal planning and environmental review standards would not apply.* Sandlin (1989) notes that for projects not using federal funds, some environmental standards—and the "elaborate planning and approval process" of USDOT are not applicable; in fact, an FHWA official quoted therein compared building a road without federal funds to building a shopping center. As a consequence, toll projects in Illinois, Texas, and Colorado were shifted from federal-aid funding to toll funding because the latter has fewer environmental requirements (Deakin, 1989). Further, Schneider (1985) indicated that toll roads had better pavement quality (e.g., an average of 17% better than that of non-tolled interstate segments), which reduced costs for highway uses by about 5%. Munroe et al. (2006) noted that toll roads had improved fuel efficiency and lower travel time and crash rates compared to non-tolled facilities.

Several states approved toll facilities in this period, with the private sector taking additional financial risk. For example, in 1992, the Toll Road Corporation of Virginia built a 15-mile private toll road between Dulles Airport and Leesburg, Virginia, which extended the state-owned Dulles Toll Road between the airport and Washington, D.C., built in 1984 (Miller, 2000). Legislation, such as the Virginia Highway Corporation Act of 1988 and the Public-Private Transportation Act of 1995, enabled private entities to assume longer term risk and potential profit from highway construction activities (Farley and Norboge, 2014). In 1989, the California legislature approved private financing and construction of as many as four general transportation facilities during the 1990s. These new facilities provided connections between existing highways (e.g., a new San Francisco Bay bridge and an existing 30-mile Los Angeles freeway). During this period, Colorado, Illinois, and Missouri started to allow the construction of private toll roads. For example, the Front Range Toll Road Company in Colorado proposed building and operating a 210-mile toll highway between Pueblo and Fort Collins (Gomez-Ibanez et al., 1991).

Compared to previous federal surface transportation reauthorizations, the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) permitted tolling to a much greater degree on federal-aid facilities, allowing new toll road construction (except on interstates); conversion (if rebuilt) of bridges and tunnels to tolled facilities including interstates (FHWA, 1992; Weiner, 1992); and, notably, a congestion pricing pilot program allowing up to three toll projects on the Interstate System (U.S. Department of Transportation, 1991). The Safe, Accountable, Flexible, Efficient, Transportation Equity Act: A Legacy for Users (SAFETEA-LU), signed into law in 2005, afforded states more flexibility in adopting tolling to control congestion and fund road infrastructure improvements, as shown in Table II-4 (Williamson, 2012).

TABLE II-4. Tolling Programs Made Available to States by SAFETEA-LU

Program	Description
New Interstate System Construction Toll Pilot Program	• Applies to interstate highways, bridges, or tunnels for the purpose of constructing interstate highway • Limited to 3 projects in total; prohibits a participating state from entering into an agreement with a private person that would prevent the state from improving adjacent public roads to accommodate diverted traffic
Interstate System Reconstruction and Rehabilitation Toll Pilot Program	• Established in the Transportation Equity Act for the 21st Century (TEA-21) in 1998 • Allows up to 3 interstate tolling projects for the purpose of reconstructing or rehabilitating interstate highway corridors that could not be adequately maintained or improved without the collection of tolls
Value Pricing Pilot Program	• Authorized under the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) • Supports the costs of implementing up to 15 variable pricing pilot programs nationwide to manage congestion and benefit air quality, energy use, and efficiency
New Express Lanes Demonstration Program	• Allows a total of 15 demonstration projects to permit tolling to manage high levels of congestion, reduce emissions in a nonattainment or maintenance area, or finance added interstate lanes for the purpose of reducing congestion • Eligible toll facilities include existing toll facilities, existing high-occupancy vehicle (HOV) facilities, and a newly created toll lane • Variable pricing according to time of day or level of traffic for HOV facilities • Automatic toll collection required

Note: Table II-4 was created based on a review of material in Office of Legislation and Intergovernmental Affairs (2005).

In 2012, President Barack Obama signed the Moving Ahead for Progress in the 21st Century Act (MAP-21). MAP-2 1 relaxed the general tolling prohibition on interstate highways (Kirk, 2013; Ungemah, 2012) and incorporated more flexibility for tolling:

> Tolling of newly constructed lanes added to existing toll-free Interstate highways is now permitted . . . so long as the facility has the same number of toll-free lanes after construction as it did before (excluding HOV lanes and auxiliary lanes). (This authority was previously available under the Express Lanes Demonstration Program). Tolling for initial construction of highways, bridges, and tunnels on the Interstate System is now permitted. . . . Prior to MAP-21, such authority was limited to non-Interstate facilities. . . . This change effectively mainstreams the Interstate System Construction Toll Pilot Program (FHWA, 2012).

2.5 Conditions Conducive to the Use of Toll Roads in the U.S.

Three observations can be tentatively identified from this history.

- Historically, tolled facilities have shown an ability to exceed and not meet maintenance standards. As an example of the latter, privately-owned turnpikes decreased in the mid nineteenth century due to poor maintenance, which resulted from of course the Civil War but also from competition with the railroad. As an example of the former, higher quality roads, such as the success of the Pennsylvania Turnpike in the late 1940s, showed the benefits of innovation.

- Consideration of externalities has influenced both non-tolled and tolled facilities. As an example of the former, consider the Good Roads Movement: interest in accommodating new types of vehicles with pneumatic tires (an increasingly large class of users) and the economic benefits of improved trade contributed to the development of a federal policy of financing facilities. As an example of the latter, the Turnpike era showed that turnpikes provided better road facilities to nearby merchants, farmers, land owners, and ordinary residents; consequently, this facilitated more movements and trades among them.

- There is a tradeoff between construction cost and service life. The advantages of plank roads – good quality and low construction costs as feeder roads – brought a boom period (when over 1,000 such roads were built), but lasted only a few years because of its nature of material.

The above observations apply to both non-tolled and tolled facilities. Thus what are some conditions that have led to the use of toll roads versus roads that do not require a user fee?

Conditions that favor a toll appear to be: (1) an ability to extract fees from a specific market segment; (2) the availability of a more reliable funding stream than a more general tax base (e.g., the prevalence of the Pittsburgh Turnpike relative to the National Road); (3) an ability to exploit new design approaches (e.g., the Pennsylvania Turnpike's higher speeds); and (4) technology that could collect fees from users without additional negative impacts such as stopping.

Conditions that appear to favor non-toll roads and/or a subsidy from entities other than the direct users appear to be (1) a recognition of the external impacts of roadways as being more important than the direct costs paid by users (hence the creation of the Office of Road Inquiry to accommodate farmers' need to market their goods); (2) the relative reliability of tax revenues; (3) a need to accommodate an entire class of users who benefit from consistent design standards (e.g., vehicles with pneumatic, not wooden, tires who could use an entire network of roadways); and (4) technology that could collect taxes without adverse consequences.

While past conditions cannot predict future results, over the long term, determination of whether a given toll facility will be viable may depend on factors that extend well beyond the scope of the facility. These are (1) whether its external impacts are greater than what its revenue impacts; (2) the relative stability of its funding stream; (3) whether the facility benefits from design consistency or design innovation; and (4) the impacts for collecting related revenue.

2.6 Application of Lessons Learned to Determine Feasibility in New Situations

The five-period history of toll roads in the United States revealed conditions that can help in the assessment of the feasibility of a tolled facility. Although there is no guarantee that the future will replicate the past, consideration of these conditions may help determine feasibility in new situations. For example, in determining whether a toll road in a particular location is likely to be successful, the reliability of user tolls vs. the reliability of revenues (from taxes) is one condition that can influence this success. Reliability can be generalized beyond revenue to other aspects of construction, such as the duration of the environmental review process, time required to garner public acceptance, and amount of review required for alternative designs. That is, as noted by Sandlin (1989), toll roads can be constructed in a shorter period of time than non-tolled roads because of the additional flexibility of the review process when certain federal requirements do not apply. Thus, whether tolled facilities receive more, less, or the same scrutiny as non-tolled facilities may affect a project's financial viability, as is the case with reliability of revenue.

CHAPTER III RELATING THE DEGREE OF MULTIMODALITY TO JOBS-HOUSING BALANCE

3.1 Chapter Objectives

This research focuses on land development impacts of multimodal P3s. Because P3s may affect jobs-housing balance, some way of measuring jobs-housing balance is needed—and ideally this measurement approach will be consistent with travel demand modeling practice. Also, clearly some P3 projects may appear to be more "multimodal" than others, however, the definition of 'multimodal' varies (e.g., Litman, 2014; Chen et al., 2011). While diversity of different modes is the main determinant of whether a project is multimodal in nature, a firm definition was not found by the authors. Because we wish to relate multimodality to jobs-housing balance, an index that scale the degree of multimodality is necessary. This chapter has thus four objectives—(1) develop an index for scaling jobs-housing balance (section 3.2.1), (2) use another index to define degree of multimodality (section 3.2.2), (3) apply the proposed indices with actual multimodal P3 projects (sections 3.3 and 3.4), and (4) identify the relationship between the degree of multimodality and jobs-housing balance (section 3.5).

3.2 Index Development

3.2.1 Jobs-Housing Balance Index

A few ways have been proposed in measuring jobs-housing balance. A direct ratio is the simplest way to measure jobs-housing balance. A rich body of literature has employed a ratio of jobs to housing (e.g., Giuliano, 1991; California Planning Roundtable, 2008). Since a simple ratio analysis in a particular area is difficult to "*capture either multidimensional opportunities for potential spatial interaction or people's differential accessibilities to employment within a realistic commuting framework that includes consideration of a range of possible home/work location options*" (Horner and Marion, 2009), the linear dissimilarity index was employed to resolve this issue. This dissimilarity index computes the proportion of employment and population within sub-areas relative to total areal employment and population, thereby suggesting the percentage of an area's population (or employment) that should be moved to employment (or residential) site for acquiring the identical distribution; the index can easily be computed and has been used in Virginia (Miller, 2010; 2011). Despite the ease of its interpretation, as Charron (2007) and Horner and Marion (2009) indicated, this index possibly gives an unreasonable result, because of not capturing potential spatial interactions among population groups which inherently occurs in many locations where residence is located in the proximity of employment. One alternative approach is the exponential dissimilarity index (Equation 1), which can explain the inherent impact of adjacent jobs-rich and population-rich zones (Horner and Marion, 2009).

$$Exponential\ Dissimilarity\ Index = 0.5\sum_{i=1}^{n}\left|\frac{\sum_{j=1}^{m} g_j exp(-\beta d_{ij})}{\sum_{i=1}^{n}\sum_{j=1}^{m} g_j exp(-\beta d_{ij})} - \frac{\sum_{j=1}^{m} h_j exp(-\beta d_{ij})}{\sum_{i=1}^{n}\sum_{j=1}^{m} h_j exp(-\beta d_{ij})}\right| \tag{1}$$

where,

g_i, g_j = worker in zone i, j

h_i, h_j = job in zone i, j
β = parameter of exponential function
d_{ij} = travel impedance between zone i and j

The exponential dissimilarity index appears appropriate for inter-urban analyses, that is, for looking at spatial interactions at a more macroscopic scale, such as for an entire state where. This index presumes that the level of potential interaction from each zone would follow the exponential distribution, and at the state level, the authors are not aware of any reason to dispute this assumption. However, in this research, the authors sought to apply an index at a smaller scale—basically that of a project within a single urban region. In general, spatial interactions at that scale are not necessarily believed to follow the exponential distribution but rather the gamma distribution. For example, research funded by the National Cooperative Highway Research Program (NCHRP) indicates that the gamma distribution can help one replicate the observed trip length distribution (NCHRP, 1998; 2012). Thus, before using the exponential dissimilarity index, one should at least test whether the resultant trip length frequency distribution follows an exponential distribution.

In this regard, six multimodal P3 project sites (Table III-1) were selected to determine the observed trip length distribution. An impact boundary was established as 13 miles away from the project, based on the average commute distance in the U.S. from previous studies (Federal Highway Administration, 2014a; Kneebone and Holmes, 2015). The 2014 Public Use Microdata Sample (PUMS) from the American Community Survey (ACS) was used to have the observed travel time for journey to work among Public Use Microdata Area (PUMA)-level zone pairs. 48,673 observations (out of 650,793 observations) were selected with all feasible transportation modes in six sites.

TABLE III-1. Details of Six Sites

State	Site Name[a]	Number of Selected PUMAs	Number of Selected Observations
Colorado	Denver Union Station	14	8,323
	US 36 Express Lanes	22	15,060
Florida	I-595 Express Corridor	16	7,808
	Miami Intermodal Center	3	1,722
Rhode Island	InterLink	19	7,799
Virginia	I-495 Express Lanes	13	7,961

[a] Site names used in Table III-1 are those used by agencies and information therein is current as of the time the research was conducted.

The one-sample Kolmogorov-Smirnov test was performed to determine if the exponential or gamma distributions were a reasonable fit for these data. The one-sample Kolmogorov-Smirnov test is a useful nonparametric method to determine whether a sample distribution differs statistically from theoretical expectations (Lehmann, 2006). Conducting this test with the gamma distribution shows high *p-value* (0.3138) which can't reject the null hypothesis that the observed and gamma distributions are identical (assuming a standard 95% confidence level), while a test with the exponential distribution has low *p-value* (2.2e-16) which demonstrates that the observed and exponential distributions are different.

Given that the exponential dissimilarity index is derived from the concept of accessibility, a new dissimilarity index based on the gamma distribution can be obtained with a procedure similar to that of Horner and Marion (2009). Consequently, a new dissimilarity index, "gamma dissimilarity index", is proposed as shown in Equation (2). Note that as a travel impedance term, the composite impedance function is applied to reflect the multimodal components. The average actual travel time for each mode is used in this research instead of the direct travel cost, travel time or straight-line distance which were assumed in previous studies.

$$Gamma\ Dissimilarity\ Index = 0.5\sum_{i=1}^{n}\left|\frac{\sum_{j=1}^{m} w_j({c_{ij}}^{\alpha-1}e^{-\beta d_{ij}})}{\sum_{i=1}^{n}\sum_{j=1}^{m} w_j({c_{ij}}^{\alpha-1}e^{-\beta d_{ij}})} - \frac{\sum_{j=1}^{m} h_j({c_{ij}}^{\alpha-1}e^{-\beta d_{ij}})}{\sum_{i=1}^{n}\sum_{j=1}^{m} h_j({c_{ij}}^{\alpha-1}e^{-\beta d_{ij}})}\right| \quad (2)$$

where,

w_i, w_j = employment in zone i, j
h_i, h_j = population in zone i, j
α = shape parameter
β = rate parameter
c_{ij} = composite impedance function between zone i and j

This index is a better fit for the observed data. Further, this index theoretically expresses the previous exponential dissimilarity index and linear dissimilarity index. First, if $\alpha = 1$ in the shape-rate parametrization of gamma distribution, this gamma dissimilarity index is then converted to the exponential dissimilarity index. Second, if two conditions are met: (1) parameter β goes sufficiently enough (no potential influence between zones) and (2) intrazonal travel impedance generates practically no difficulty, the gamma dissimilarity index collapses to the linear dissimilarity index. In practice, however, there will be some difficulty of intrazonal and interzonal travel; thus, the assumptions for linear dissimilarity index are less realistic.

3.2.2 Multimodality Index

When practitioners or researchers refer to a project as multimodal, there may be a degree of judgement rather than a firm definition for this classification. To reflect this, an index measuring the degree of multimodality was newly created. The scale ranges from zero to one, based on the concept of "species diversity" in ecology (Agrawal and Gopal, 2013; Nicholas and Anne, 2013). This multidimensional indicator considers not just the number of modes served, but the probability of multiple modes being operated as a function of (1) each mode's standardized composite share and (2) each mode's construction or operation/maintenance costs, given the inherent uncertainty for estimating actual percentages of modes in operation (see Equation 3).

$$Multimodality\ Index = w_1\left[1-\sum_{i=1}^{l}\left(a\sum_{j=1}^{k}(p_i \cdot MS_{ij})\right)^2\right] + w_2\left[1-\sum_{i=1}^{l}\left(\frac{MC_i}{TC}\right)^2\right] \quad (3)$$

where,

MS_{ij} = mode share information of mode i from source j
p_i = parameter estimates for mode i

($p_i = \frac{w_i}{mw_i+n}$ when sources for mode i include only the home-based work trip,

$p_i = \frac{1}{mw_i+n}$ when sources for mode i include all trip purposes)

w_i = proportion of home-based work trips, by mode i for all trip purposes

MC_i = specific construction and maintenance cost for mode i

TC = total construction and maintenance cost for a given project

k = number of mode share sources

l = number of modes in given sources

a = adjustment parameter

w_1, w_2 = combining weights

m = number of sources that have only home-based work trip

n = number of sources that have all trip purposes

Because mode share information is rarely complete, the concept of composite mode share is incorporated with multiple sources. Another advantage of this indicator is that the normalization of each dimension is not necessary because of the same scale (percentage). Note that the variables MC_i and TC can be replaced, if desired, by other attributes which denote the relative investment in a given mode i; in practice, because data are available for MC_i and TC, they have been used in this research.

3.3 Calibration of Parameters

While shape and rate parameters in gamma dissimilarity index can be calibrated by Maximum Likelihood Estimation (MLE) using statistical software packages, three parameters (p_i, w_1, w_2) in multimodality index need to be calibrated with new approaches. First, for the parameter p_i, this research applied the relative ratio of bias for each of data sources. That is, the American Community Survey (ACS) is the survey data of home-based work trips, while others include all trip purposes. With this difference, parameter p_i is calculated by the ratio of the annual number of trips by transportation mode and trip purpose from the National Household Travel Survey in 2009 as shown in Table III-2 (Santos et al., 2011). One of the advantages of this index is that parameter p_i is automatically calculated without additional computations.

TABLE III-2. Annual Number (in Millions) of Person Trips by Mode of Transportation and Trip Purpose

Trip Purpose	Passenger Car	Transit	Walk	Other
To/From Work	55,969	2,247	1,854	1,144 (7.0%)
Work-Related Business	10,525	264	684	469 (2.9%)
Family/Personal Errands	146,158	2,344	15,174	2,859 (17.4%)
School or Church	26,654	829	3,542	6,651 (40.5%)
Social and Recreational	82,887	1,426	18,833	4,576 (27.9%)
Other	4,925	409	874	725 (4.4%)
Total	327,118	7,520	40,962	16,424 (100%)

Other parameters, weights (w_1, w_2), are calibrated by Principal Component Analysis (PCA) which can reduce a set of features to a smaller number of representative variables. PCA can select a low-dimensional representation that collectively explain most of the variability in a given original data set (Venables and Ripley, 2002). In a theory, PCA is therefore to find these representative dimensions which are a linear combination of the features. The first principal component ($z_{i1} = \emptyset_{11}x_{i1} + \emptyset_{21}x_{i2} + \cdots + \emptyset_{p1}x_{ip}$) of sample features ($x_{i1}, x_{i2}, \dots, x_{ip}$) from a $n \times p$ data set X can be computed as an optimization problem as shown in Equation (4) (Manly, 1994; James et al., 2014). Note that the multimodality index has only two variables, the first principal component loading vector is only necessary for this research.

$$\underset{\emptyset_{11},\dots,\emptyset_{p1}}{maximize} \left\{ \frac{1}{n} \sum_{i=1}^{n} \left(\sum_{j=1}^{p} \emptyset_{j1} x_{ij} \right)^{2} \right\} \text{ subject to } \sum_{j=1}^{p} \emptyset_{j1}^{2} = 1 \tag{4}$$

where,

$\emptyset_{11}, \dots, \emptyset_{p1}$ = loadings (elements of first principal component loading vector $\emptyset_1$)
x_{ij} = features

Although there are arguments for applying PCA with scaling or without scaling, scaling was applied for the results presented here in order to prevent the bias of loading on the principal components in this research, considering that two variables have different means and variances.

3.4 Data Sources and Application Sites

3.4.1 Basic Data Sources

To analyze jobs-housing balance impacts and multimodality of multimodal P3s, multiple data sets are required. Table III-3 illustrates the data types and sources for each index.

TABLE III-3. Summary of Basic Data Sources

Index	Component	Data Type	Data Source
Jobs-housing balance	Shape and rate parameters	Travel time to work by mode	Public Use Microdata Sample
	Impact boundary	Spatial information (GIS shapefile)	Public Use Microdata Area
	Population	Total population 16 years and over	American Community Survey
	Employment	Employed civilian population 16 years and over, workers 16 years and over (who did not work at home)	American Community Survey
Multimodality	Mode share	Annual Average Daily Traffic (AADT)	Detector count database
		Continuous traffic counts obtained from permanent count stations	
		Means of transportation to work	American Community Survey
		Forecasted traffic volumes or trips by mode (travel demand forecasting)	Draft or Final Environmental Impact Statement (EIS), Traffic and Revenue Study, Unsolicited Proposal, or Proposal in response to a Request for Proposals (RPF)
		Stated preference survey for travel mode	
	Construction or operation/ maintenance cost	Annual or whole costs	

In terms of the multimodality index, four distinct sources are used to determine the composite mode share: (1) the “AADT” (the acronym used by various state databases and which denotes the average annual daily traffic; an AADT could either be a true AADT based on solely on a continuous count station or it could be a temporary count that has been expanded to estimate the AADT); (2) Census data for the journey to work trip, (3) forecasts from urban travel demand models, and (4) the results of stated preference surveys or in some cases daily traffic data from continuous count stations.

Also, information of construction or operation/maintenance costs are obtained from project-related documents, including environmental impact statements, traffic and revenue studies or proposals.

3.4.2 Selected Application Sites

Six multimodal P3 projects were chosen for the application, which are exactly same as those used in testing the gamma distribution previously. A 13-mile impact boundary was selected based on the average commute distance in the U.S. (Federal Highway Administration, 2014a; Kneebone and Holmes, 2015). Then, a 5-mile impact boundary was analyzed to see the changes by different impact boundaries. PUMA-level areas were selected when their centroids were located in 5-mile and 13-mile impact boundary, respectively. The analysis years were selected with 1-year before the construction and the most recent year after the construction. Table III-4 and Figure III-1 describe the analysis years and selected PUMAs in six sites.

TABLE III-4. Number of Selected PUMAs

State	**Site Name**	**Analysis Year**	**5-Mile Impact Boundary**	**13-Mile Impact Boundary**
			Number of PUMAs	
Colorado	Denver Union Station	2009	2	14
		2014	2	14
	US 36 Express Lanes	2011	4	13
		2014	4	13
Florida	I-595 Express Corridor	2010	3	14
		2014	5	16
	Miami Intermodal Center	2006	3	16
		2014	5	19
Rhode Island	InterLink	2006	N/A	3
		2014		3
Virginia	I-495 Express Lanes	2007	3	17
		2014	7	22

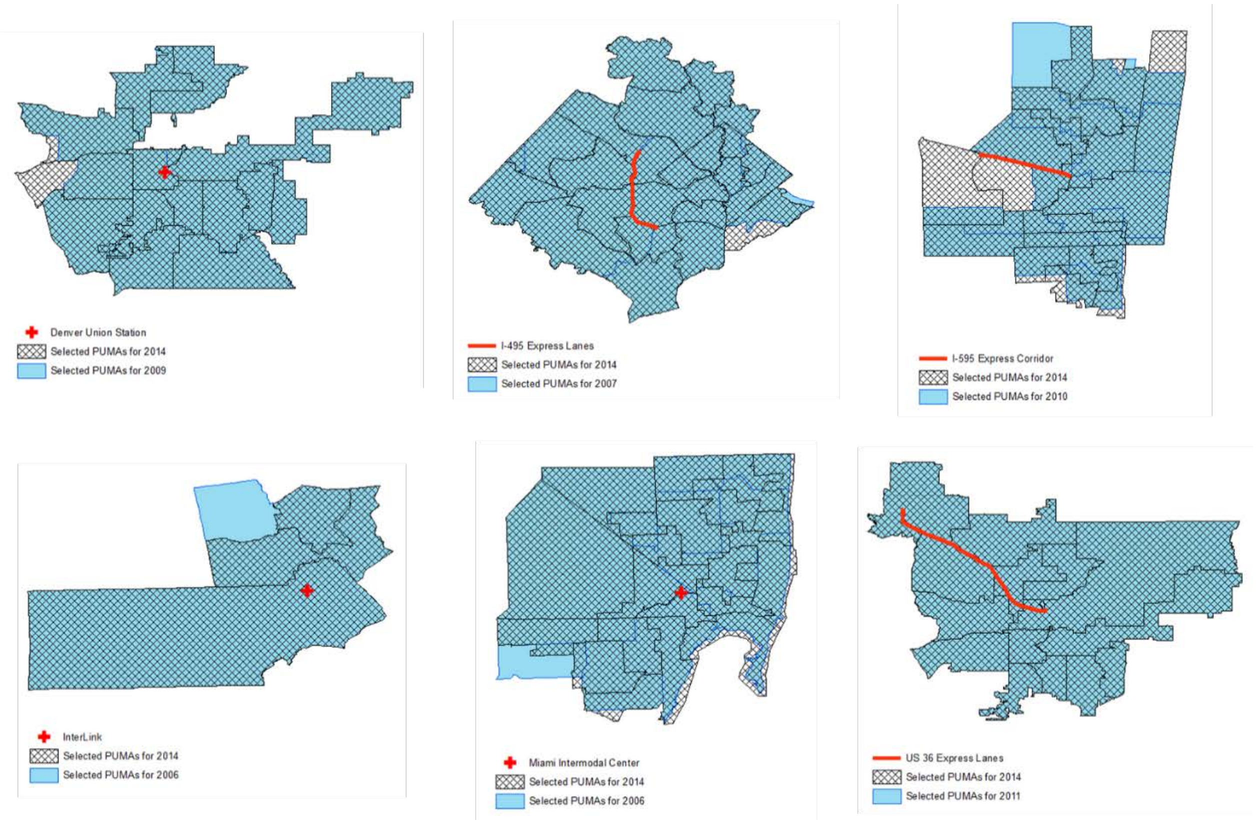

FIGURE III-1. Selected PUMAs in the 13- mile impact boundary of six sites

Note that six sites consist of three transportation centers and three transportation corridors (express lanes or corridors) to observe any meaningful results.

3.4.3 Collected Data for Multimodality Index

Because the multimodality index required a variety of data sources, all applicable data sets were sought but in some cases specific data sets were not available. Table III-5 shows the status of acquired data sets for multimodality index. Note that while some data had to be requested from public agencies, most data sets were in the public domain, such as the continuous traffic count data for the I-495 Express Lanes in Virginia.

TABLE III-5. Status of Acquired Datasets

State	Site Name	Analysis Year	AADT	ACS	Forecasted Traffic Volumes or Trips	Continuous Traffic Counts or Survey	Financial Plan
Colorado	Denver Union Station	2009	√	√	-	-	-
		2014	√	√	-	-	√[a]
	US 36 Express Lanes	2011	√	√	Forecasted Traffic Volumes[b]	Continuous Traffic Count	-
		2014	√	√	Forecasted Traffic Volumes[bc]	Continuous Traffic Count	√[c]
Florida	I-595 Express Corridor	2010	√	√	-	Continuous Traffic Counts	-
		2014	√	√	-	Continuous Traffic Counts	√[d]

	Miami Intermodal Center	2006	√	√	-	Survey[e]	-
		2014	√	√	Forecasted Trips[f]	Survey[g]	√[f]
Rhode Island	InterLink	2006	√	√	-	Survey[h]	√[h]
		2014	√	√	Forecasted Trips[i]	Survey[h]	√[h]
Virginia	I-495 Express Lanes	2007	√	√	Forecasted Trips[j]	Continuous Traffic Counts	-
		2014	√	√	Forecasted Trips[j]	Continuous Traffic Counts	√[j]

[a] Colorado Department of Transportation (2008)
[b] 36 Commuting Solutions (2012)
[c] Colorado Department of Transportation (2009)
[d] Bowen Civil Engineering, Inc. (2006)
[e] Gosling (2014)
[f] Florida Department of Transportation (Undated)
[g] Adamson (2014)
[h] Landrum & Brown (2014)
[i] Devine and Pimental (2014)
[j] Fluor Daniel (2003)

Recall that the American Community Survey (ACS) is area-based survey information (e.g., how many people living in zone x use a given mode to go to work) and that AADT denotes corridor-level information (e.g., what volume is observed on link y, where this volume includes some people living in zone x but also people living in other zones.) To have some association between AADT and ACS information, it is necessary to establish an impact boundary. An impact boundary that is too small will likely underestimate the impact of the P3 project, but an impact boundary that is too large will likely overestimate the impact of the P3 project. (As an example of the latter, a 100 mile impact boundary would clearly capture other factors besides the P3 project.) For this research effort, impact boundaries of 5 miles and 13 miles, chosen in part based on the mean trip length, were used to extract mode shares and to later determine land use impacts.

3.5 Analysis Results and Discussion

3.5.1 Calibration Results

Each year's parameters—shape (α) and rate (β) in the gamma dissimilarity index and the combining weights (w_1 and w_2 for each data the mode shares and monetary investments, respectively) in the multimodality index—were calibrated by the MLE and PCA, respectively.

First, as shown in Table III-6, the shape and rate parameters were calibrated with the fitted gamma distribution for each year i, which were shown statistically significant in terms of replicating the observed data sets from the ACS by the one-sample Kolmogorov-Smirnov test. Only one case (I-495 in 2007 with 13-mile impact boundary) showed 0.04 for the *p-value*, but the fitted exponential distribution showed a lower *p-value* (<<0.01) in a 95% confidence level. That is, the exponential distribution is far different from observed distribution, while the gamma distribution generally replicates much better the observed distribution.

TABLE III-6. Calibration Results of Gamma Dissimilarity Index at Six Study Sites

State	Site Name	Analysis Year	5-Mile Impact Boundary			13-Mile Impact Boundary		
			Shape α	Rate β	*p-value*	Shape α	Rate β	*p-value*
Colorado	Denver Union	2009	2.64	0.09	0.97	2.49	0.08	0.67

	Station	2014	4.14	0.16	0.65	3.20	0.10	0.81
	US 36 Express Lanes	2011	3.08	0.14	0.93	3.60	0.13	0.74
		2014	3.03	0.11	0.82	2.92	0.10	0.88
Florida	I-595 Express Corridor	2010	2.43	0.09	0.66	1.86	0.05	0.60
		2014	2.25	0.08	0.75	2.27	0.06	0.61
	Miami Intermodal Center	2006	4.18	0.13	0.88	2.71	0.08	0.59
		2014	2.59	0.08	0.93	2.42	0.08	0.80
Rhode Island	InterLink	2006	N/A			3.53	0.17	0.98
		2014				1.99	0.07	0.55
Virginia	I-495 Express Lanes	2007	3.02	0.11	0.99	2.89	0.07	0.04
		2014	3.47	0.11	0.57	3.52	0.09	0.08

Second, correlation among the two data sets (mode share and investment) was determined before applying the PCA for the combining weights w_1 and w_2 in the multimodality index. The reason is that PCA does not necessarily work when the two variables are uncorrelated. The Pearson's correlation test showed a value of 0.59 for these two variables for the 5-mile impact boundary and a similar correlation of 0.57 for the 13-mile impact boundary. After conducting the PCA with scaling, mode share and financial ratio have same first principal component loadings (i.e., same combining weights of 0.5) for both the 5-mile impact boundary and the 13-mile impact boundary (see Table III-7). The adjustment parameter a prevents the sum of composite mode shares from exceeding 100% and for the application of Equation 3, the value of a is determined automatically according to the given project. 0.9871-1.0164

TABLE III-7. Principal Components and PVEs with Scaling

	5-Mile Impact Boundary		**13-Mile Impact Boundary**	
	First Component	Second Component	First Component	Second Component
Mode Share Loading	-0.71	-0.71	0.71	-0.71
Financial Ratio Loading	-0.71	0.71	0.71	0.71
Standard Deviation	1.26	0.64	1.25	0.66
Proportion of Variance Explained (PVE)	0.79	0.21	0.78	0.22
Cumulative PVE	0.79	1.00	0.78	1.00

Proportion of Variance Explained (PVE) expresses the proportion of variance which can be accounted for by each component. That is, the first component can explain 79% of variance, and the second component can explain 21% of variance in the 5-mile impact boundary. Therefore, the sum of PVEs for the two principal components (cumulative PVE) should be 1.0 as all the principal components account for 100% of variation in the original data set.

3.5.2 Results of Jobs-Housing Balance Index

The jobs-housing balance indices based on the 5-mile and 13-mile impact boundaries were computed by the proposed gamma dissimilarity index. Table III-8 summarizes the changed jobs-housing balance using each impact boundary. (Recall that because the gamma dissimilarity index considers intrazonal travel impedance to be nonzero and that interzonal interactions are possible, the results would be same as those of linear dissimilarity index if intrazonal travel had no impedance and interzonal travel had infinite impedance.)

TABLE III-8. Resultant Jobs-Housing Balance Index (Equation 2)

State	Site Name	Analysis Year	5-Mile Impact Boundary	13-Mile Impact Boundary
Colorado	Denver Union Station	2009	0.0016	0.0003
		2014	0.0011	0.0001
		Change	-0.0005(-32.5%)	-0.0002(-67.1%)
	US 36 Express Lanes	2011	0.0005	0.0005
		2014	0.0007	0.0001
		Change	0.0003(52.4%)	-0.0003(-67.8%)
Florida	I-595 Express Corridor	2010	0.0008	0.0028
		2014	0.0005	0.0025
		Change	-0.0004(-41.6%)	-0.0003(-9.9%)
	Miami Intermodal Center	2006	0.0019	0.0003
		2014	0.0005	0.0002
		Change	-0.0014(-73.0%)	-0.0001(-43.2%)
Rhode Island	InterLink	2006	N/A	0.0040
		2014		0.0015
		Change		-0.0025(-62.8%)
Virginia	I-495 Express Lanes	2007	0.0013	0.0025
		2014	0.0018	0.0024
		Change	0.0005(38.8%)	-0.0002(-7.2%)

Note that when the index has zero value, this means perfect jobs-housing balance. Table III-8 presents 11 cases where the index changed over time—5 cases with a 5-mile impact boundary and 6 cases with the 13-mile impact boundary. Two of these 11 cases showed an increased index, which means worsening jobs-housing balance: US 36 Express Lanes, CO and I-495 Express Lanes, VA, both with the 5-mile impact boundary. Interestingly, all sites (six cases) show better jobs-housing balance in the 13-mile impact boundary. This might be because the 13-mile impact boundary accurately represents the average commuting distance to work. Although the jobs-housing balance of US 36 Express Lanes became worse with the 5-mile impact boundary after its introduction, better jobs-housing balance was shown with the 13-mile impact boundary, which was the largest change (-67.8%) among six cases. On the other hand, Miami Intermodal Center, FL has the largest change (-73.0%) with the 5-mile impact boundary.

3.5.3 Results of Multimodality Index

The composite mode share, financial ratio and multimodality index (Equation 3) were calculated with all obtainable data sources. For unit compatibility, traffic counts whether from AADT, continuous detectors or forecasted counts were each converted to the number of persons based on the vehicle occupancy rate (Federal Highway Administration, 2014b; U.S. Department of Energy, 2015).

TABLE III-9. Summary of Mode Shares, Financial Ratios and Multimodality Index (Equation 3)

Site Name	Analysis Year	5-Mile Impact Boundary			13-Mile Impact Boundary		
		Composite Mode Share	Financial Ratio	Multimodality	Composite Mode Share	Financial Ratio	Multimodality
Denver Union Station, Colorado	2009	0.391	-	0.391	0.380	-	0.380
	2014	0.391	0.600	0.496	0.373	0.600	0.486
	Change	0.000 (0.0%)	-	0.104 (26.7%)	-0.008 (-2.0%)	-	0.106 (27.9%)
US 36 Express Lanes, Colorado	2011	0.296	-	0.296	0.266	-	0.266
	2014	0.298	0.355	0.326	0.336	0.355	0.346

	Change	0.002 (0.7%)	-	0.031 (10.4%)	0.071 (26.6%)	-	0.080 (30.2%)
I-595 Express Corridor, Florida	2010	0.317	-	0.317	0.317	-	0.317
	2014	0.375	0.433	0.404	0.376	0.433	0.404
	Change	0.058 (18.2%)	-	0.087 (27.4%)	0.059 (18.6%)	-	0.088 (27.7%)
Miami Intermodal Center, Florida	2006	0.370	-	0.370	0.343	-	0.343
	2014	0.692	0.643	0.667	0.692	0.643	0.668
	Change	0.322 (87.1%)	-	0.297 (80.5%)	0.350 (102.0%)	-	0.325 (94.7%)
InterLink, Rhode Island	2006	0.249	0.175	0.212	0.287	0.175	0.231
	2014	0.285	0.672	0.478	0.319	0.672	0.496
	Change	0.036 (14.4%)	-	0.266 (125.8%)	0.033 (11.4%)	-	0.265 (114.8%)
I-495 Express Lanes, Virginia	2007	0.200	-	0.200	0.208	-	0.208
	2014	0.320	0.264	0.292	0.329	0.264	0.297
	Change	0.120 (59.7%)	-	0.092 (45.8%)	0.122 (58.5%)	-	0.089 (42.9%)

On average, for the five multimodal P3 projects, the degree of multimodality increased by 52.7% (for the 5 mile impact boundary) and 56.4% (for the 13 mile impact boundary). These results suggest that it is possible for P3 projects to increase multimodality. The Miami Intermodal Center has the largest degree of multimodality (0.667, 0.668 respectively) for the 5-mile and 13-mile impact boundaries, while InterLink, RI increased the degree of multimodality more than the other four projects (125.8%, 114.8%, for the 5 and 13 mile impact boundaries, respectively) after construction.

Noticeably, three transportation centers—Denver Union Station, InterLink and Miami Intermodal Center— have larger degrees of multimodality than the three express lanes projects (I-495 Express Lanes, I-595 Express Corridor, and US 36 Express Lanes). As shown in Table III-10, regardless of the size of impact boundaries, transportation centers projects have larger changes (70.8% on average) compared to those of the express lanes projects (29.1% on average). Although express lanes projects aim to increase the use of multiple modes by making non-single occupant vehicle travel more attractive (e.g., no toll for carpoolers or the use of Bus Rapid Transit), transportation centers' better accessibility or convenience yields such centers a higher degree of multimodality.

TABLE III-10. Comparison of Transportation Center and Express Lanes

Site Name	**5-Mile Impact Boundary**			**13-Mile Impact Boundary**			**Average of Change**
	Before	After	Change	Before	After	Change	
Transportation Center	0.324	0.547	0.223(68.7%)	0.318	0.550	0.232(72.9%)	0.228(70.8%)
Express Lanes	0.271	0.341	0.070(25.7%)	0.263	0.349	0.086(32.5%)	0.078(29.1%)

3.5.4 Relationship between Jobs-Housing Balance and Multimodality

One research objective is to determine if there is a relationship between multimodality and jobs-housing balance. Table III-11 shows the change in degree of multimodality and jobs-housing balance for the 5-mile and 13-mile impact boundaries.

TABLE III-11. Summary of Change in the Multimodality and the Jobs-Housing Balance Indices

State	Site Name	5-Mile Impact Boundary		13-Mile Impact Boundary	
		Jobs-Housing Balance	Multimodality	Jobs-Housing Balance	Multimodality
Colorado	Denver Union Station	-0.0005	0.1044	-0.0002	0.1060
	US 36 Express Lanes	0.0003	0.0307	-0.0003	0.0801
Florida	I-595 Express Corridor	-0.0004	0.0869	-0.0003	0.0878
	Miami Intermodal Center	-0.0014	0.2975	-0.0001	0.3247
Rhode Island	InterLink	-	0.2665	-0.0025	0.2649
Virginia	I-495 Express Lanes	0.0005	0.0919	-0.0002	0.0891
Pearson's Correlation		-0.8658		-0.4389	
R-squared (adjusted R-squared)		0.7497 (0.6662)		0.0009(-0.0091)	

The Pearson's correlation test shows that the change in jobs-housing balance and multimodality has a large negative correlation with a 5-mile impact boundary, while that change has a relatively small negative correlation with a 13-mile impact boundary. (A negative relationship means the higher degree of multimodality brings better jobs-housing balance, where this indicator illustrates better accessibility or less travel impedance. In short, there is a positive correlation between improved jobs housing balance and increased multimodality, although this correlation is stronger for the 5-mile impact boundary than it is for the 13-mile impact boundary.)

Note also that at the five mile impact boundary the relationship is not sensitive to a single site; for instance, removal of the second and sixth site increases the strength of the correlation from -0.87 to -0.99. By contrast, at the 13 mile impact boundary, removal of the fifth site (Interlink) results in a positive correlation. Given that at the 13 mile boundary that all six sites showed that multimodality increased and that jobs-housing balance improved, the interpretation based on these data is that at the 13 mile impact boundary, with the removal of the Interlink site, lesser increases in jobs-housing balance are associated with larger increases in multimodality. On balance, it seems that the connection between degree of multimodality and jobs-housing balance is less as the impact boundary grows.

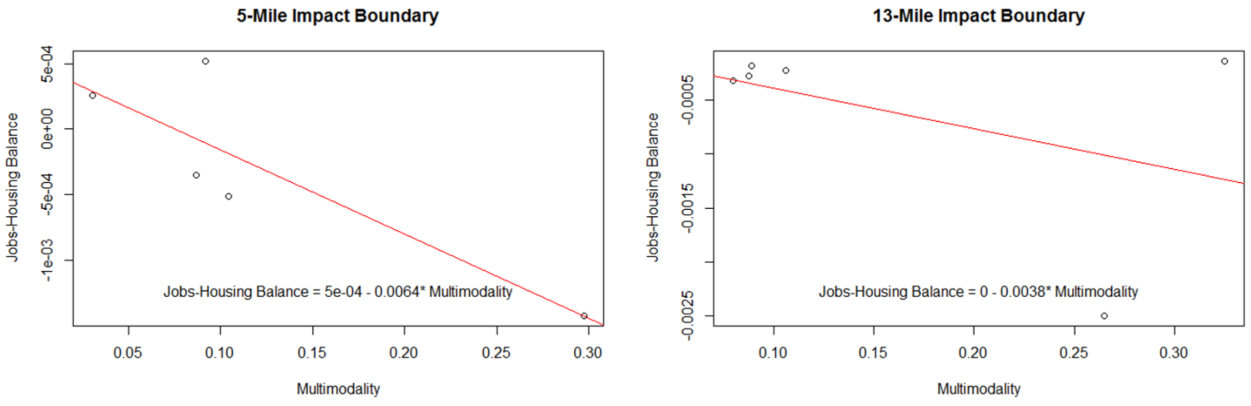

FIGURE III-2. Correlation plots between multimodality and jobs-housing balance

To be clear, the change in multimodality and jobs-housing balance with the 13-mile impact boundary has relatively small correlation. There are at least three potential contributing factors—two concerning the interaction between transportation and land use, and one concerning the manner in which this interaction is measured. One potential factor is that the time horizon for land use changes and transportation supply changes are different. That is, prior to construction, the spatial correlation between multimodality and jobs-housing balance was -0.65, which presumably would reflect a state of equilibrium. Following construction, the spatial correlation dropped to -0.49, which may reflect the fact that although the impedance indicators in Equation (2) would have changed, the population and employment values in each zone (e.g., h_i and w_i) might not have changed as a function of the new transportation supply. A second potential factor is that the project impact may lessen as one extends further from the project, given the difference in values for a 5-mile and 13-mile impact boundary. A third potential factor relates not to the observed phenomena but rather the indicator itself. The amount of scale space occupied by observed values of the multimodal indicator is different from the amount of scale space occupied by observed values of the jobs-housing balance indicator. That is, while both indicators range from 0 to 1, the observed values for the multimodal indicator range from 0.03 to about 0.68; for the jobs-housing balance, they range from 0.0001 to 0.0040—a tiny fraction of the available space. That is, the indicator may not fully reflect the degree of jobs-housing balance. This can be rectified to some degree by looking at correlations between percentage change in each indicator (and for the 13 mile boundary, the such correlation is -0.23), but the fact that largest jobs-housing balance indicators is 25 times the value of the smallest indicator will affect any analysis of the data.

3.6 Chapter Conclusions

This chapter concerns urban from impacts (in terms of jobs-housing balance) and degree of multimodality (for multimodal P3s). Because the proposed approaches are newly created, this chapter results in several meaningful contributions on multimodal transportation and P3-related fields.

First, a new gamma distribution-based dissimilarity index was developed to analyze the jobs-housing balance of which goodness of fit was statistically proven by six multimodal P3 site. Thanks to its use of multiple shape parameters, the gamma dissimilarity index is a more generalized form that can be transformed to the exponential dissimilarity index and linear dissimilarity index when certain conditions are met. Second, a new method to quantify the degree of multimodality was proposed, which can determine the extent to which projects are multimodal. Although two variables were considered, this index can incorporate additional variables by using PCA approach if necessary in the future. Third, six multimodal P3 projects were chosen to analyze the changes of jobs-housing balance and multimodality after projects were implemented. Six projects appeared to improve jobs-housing balance with the 13-mile impact boundary, and to increase the multimodality by 52.7% (5 miles) and 56.4% (13 miles). Fourth, a correlation between the multimodality and jobs-housing balance was observed, but the strength of this relationship reduced when the impact boundary was extended. (It is possible that within a smaller impact area, multimodal projects may contribute to better jobs-housing balance, but as noted in the discussion of further research [section 4.4], more experimentation with this impact boundary is appropriate.)

A possibility has been shown in this chapter that multimodal P3 projects could yield higher multimodality and better jobs-housing balance. Considering that jobs-housing balance represents one type of land development impact, the results of this chapter offers some evidence that supports a public benefit of enhancing multimodal components in P3 projects. If there is strong public support for this benefit, and if it is a feature that increases land values, then such positive land development impacts can possibly be captured as revenues through certain types of fees or taxes to increase financial viability in multimodal P3s.

CHAPTER IV CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

P3s have attracted renewed attention because of their ability to generate private financing for what had previously been, since the Second World War, largely "pay as you construct" projects. Conceptually, multimodal P3s may be beneficial for two additional reasons. First, if the inclusion of multimodal components can be monetized in the form of value capture, such additional revenue can potentially reduce the number of P3 projects that fail for budgetary reasons. Second, to the extent that multimodality is societally beneficial (e.g., some persons have equated multimodality with sustainability), finding a way to implement multimodal P3 projects is desirable.

Accordingly, this research consists of four major subtopics which in the aggregate provide some evidence for the second reason, and with further research could help address the first reason: that multimodal components may be used in a value capture mechanism to support implementation of multimodal P3s. Conclusions are italicized and supporting information is given in regular font.

- *Historically, two reasons for choosing a financing method have been (1) the stability of the revenue stream and (2) the positive impacts to society of the transportation investment.*

  The first topic, in Chapter 2, focused on the review regarding the uses of toll facilities in the U.S. with a specific focus on Virginia. Given that most P3 projects have used tolls as a revenue source, this observation of the national literature was germane. From the qualitative review, it was noted that tolls provided the relative stability of revenue streams from user fees. Additionally, an indirect benefit for localities was the increased movement of goods, and anticipation of such a benefit made, in many cases, the high road construction costs acceptable.

- *It is possible to quantify how a multimodal P3 project impacts jobs-housing balance.*

  The second topic, in Chapter 3, empirically explored the effects of changes in multimodal P3s on urban form (i.e., jobs-housing balance), resulting from new multimodal P3 facilities. From the investigation of six multimodal P3 projects in four states, multimodal P3 projects increased jobs-housing balance. To the extent that better jobs-housing balance improves accessibility multimodal P3 projects can be socially desirable.

- *It is possible to measure degree of multimodality, which provides more information than simply categorizing projects as "multimodal" or "unimodal."*

  The third topic, also in Chapter 3, quantified the degree of multimodality for six P3 projects. This scale varies from zero to 1.0 and is based on two key inputs: observed modal shares and observed modal investments. Given that transportation mode share data are often lacking, the scale appropriately considers other ways—in this case, capital and operating costs for specific modes—in order to determine degree of multimodality.

- *P3 projects have the potential to contribute to jobs-housing balance.*

  The fourth topic, also in Chapter 3, related the degree of multimodality to jobs-housing balance. Various sizes of the project impact boundary were considered, and based on the larger impact boundary, all P3 projects appeared to increase degree of multimodality and to improve jobs-housing balance. Further, a strong correlation (0.87) between jobs-housing balance and degree of multimodality was observed with a smaller impact boundary, although the use of the larger impact boundary reduced this correlation to 0.44. This finding supports the concept that more emphasis on multimodal components could have a positive impact on urban form. The conclusion states "potential" because, as shown in Chapter 3, the manner in which the impact boundary is established can affect one's evaluation of how the P3 affects jobs-housing balance.

4.2 Explanation of How the Research Scope Was Established

In a purely academic context, one might argue that only the second, third and fourth topics are critical such that the history topic is superfluous. However, the authorizing environment to pursue the fourth topic would not exist without a rationale that articulates why multimodal P3s merit detailed study. The first topic provides this rationale, albeit in an indirect manner. The first topic showed that while a stable revenue source is one reason for choosing a financing method (such as that provided by a P3), another reason for choosing a financing method—even if that method may not offer a monetary return on investment—has been that the transportation project could achieve some societal goal. Historically, this societal goal was greater trade that would result from improved transportation. However, another potential societal goal identified in the fourth bullet is improved jobs-housing balance. Whether this societal goal is sufficient to justify pursuit of a P3 is beyond the scope of this research. However, it has been the authors' strategy to align these subtopics to reach the goal of this research: an empirical analysis demonstrating how multimodal P3 projects influence one aspect of land development—so that such a result could eventually help support a value capture strategy. To do so, it was necessary to not only understand why private participation has historically been attractive but to also define this multimodality, define a social goal (jobs housing balance) and, in a defensible manner, seek to empirically relate the two.

Meyer and Miller (2013) have noted that the transportation planning process is "inherently political" rather than being solely being a technical exercise. A political process entails explicit consideration of stakeholders' values, and both of these vary with time and location. For example, in the 1890s, an emerging national consensus favored the promotion of bicycle travel through additional paved surfaces paid for by the public. In Virginia during the mid-to-late 1990s, a strong interest in greater private sector participation generally contributed to the passage and implementation of the Public-Private Transportation Act (PPTA). Stakeholders' values for each of these two examples differ: the first valued geometric improvements (as documented by the Good Roads Movement), and the second valued reduced reliance on government. If the authors had been trying to encourage multimodal P3s in the environment of the first example, then this research would have focused exclusively on how P3s can improve geometric design. If the authors had been trying to encourage multimodal P3s in the second example, this research would have focused more heavily on how such P3s could reduce government regulation and outlays. The stakeholder values in Virginia in 2015 are difficult to summarize, but three values that relate to stakeholders are, listed roughly in order of importance, (1) making P3s financially viable, (2) achieving multimodality in a cost effective manner without additional subsidies and, (3) improving jobs-housing balance—a social goal. This research has thus sought to show how multimodal P3s can support these three stakeholder values, while remaining within the constraints that most consumers of transportation—regardless of political values—tend to choose modes on the basis of cost and service.

4.3 Research Contributions

As one of the first research efforts that consider the multimodal aspect of P3s from both qualitative and quantitative approaches, this research offers five contributions to the topic of multimodal P3s:

- *An explanation of why tolls have been favored or not favored in the past*.

  The specific conditions that appear to have influenced the likelihood of tolls being used to support construction or maintenance activities was developed based on an extensive literature review (127 references) of how toll facilities have been used in the U.S. A review with examples more than 400 years focusing on toll facilities in the U.S. is not available in other contexts.

- *A performance measure for jobs-housing balance that is more consistent with urban travel demand modeling assumptions than previous indices*.

  A new gamma-based dissimilarity index was developed and statistically proven to better replicate observed trip length frequency distributions from six sites than other indices. This more generalized form can be collapsed to the more standard exponential dissimilarity index and linear dissimilarity index. The jobs-housing balance of six multimodal P3 projects were analyzed, which is not currently found in any other sources.

- *A methodology to quantify the degree of multimodality for P3 projects*.

  There is not literature that currently provides an indication of the extent to which these projects are multimodal.

- *The potential relationship between multimodality and jobs-housing balance*.

  The positive relationship between increased multimodality and better jobs-housing balance from Chapter 3 can be used to emphasize multimodality in transportation projects both in non-P3 projects and P3 projects. As noted in Chapter 3 and in section 4.3, the manner in which these are calculated and the size of the impact boundary will affect the relationship, but early results suggest a positive association.

- *Potential support eventually developing value capture strategies*.

  The analysis in Chapter 3 to identify land development impacts in terms of jobs-housing balance by multimodal P3s may be used as an element of guidelines where one might consider positive changes in urban form resulting from multimodal P3s. The examples of multimodal P3 projects supporting jobs-housing balance offers one starting point which could be extended by better understanding how P3s affect property values (as discussed in the first research need in section 4.4).

This research was demonstrated by promising examples of multimodal P3s in the U.S.; therefore, it may help planners enhance multimodal components for future P3 efforts. The interdisciplinary nature of this research suggests that the results may be of interest to practitioners from diverse fields such as urban planning, transportation planning, and transportation economics.

4.4 Future Research Directions

There are at least five directions for future research.

- *Quantifying how P3s affect property values*.

  Chapter 3 demonstrated that multimodal P3 projects could affect, in a positive manner, both jobs-housing balance and the degree of multimodality. If these are both desirable outcomes that are valued by the population, it is plausible that a multimodal P3 project could affect property values. A next step could be to develop a model that forecasts the extent to which a multimodal P3 project influences property values.

- *Site-specific motivations for pursuing a project as a P3 (or not as P3).*

  Now that this research provides a way to measure a project's degree of multimodality, it would be worthwhile to see if there is an association between this degree and the reasons for pursuing a project as a P3. For example, one might test if projects with a higher degree of multimodality also tend to have greater emphasis on expected land development impacts.

- *Evaluation of the multimodality indicator.*

  The multimodality indicator is based on the theory of replicated sampling probability. However, it would be interesting to compare the results of this indicator to the results of a survey of practitioners (as has been done in comparing level of service concepts). The comparison could suggest additional data sources for the indicator, such as net present value of project costs.

- *Evaluating the impacts of longer time horizons and different impact boundaries*.

  The time horizon for each project varied but were relatively short—generally under a decade—and thus longer time horizons are an area for further study. For example, one multimodal P3 project is arguably Charlottesville's pedestrian mall in Virginia, which reduced auto accessibility and increased pedestrian accessibility. At the time of this writing, the project has been in place for roughly 40 years, but positive land development impacts of that project were not necessarily been apparent until sometime had elapsed following the project's implementation. The results in section 3.5.4 where the linkage between jobs-housing balance and multimodality differed by the size of the impact boundary suggests that, as longer time horizons are explored, one should also test whether the correlation (between better balance and higher multimodality) decreases with an increasing impact boundary, which was the case with the data in Table III-11.

- *Calibration of the indices using more recent NHTS data.*

  Equation 3 in Chapter 3 demonstrated how the multimodal index used 2009 NHTS data for calculating a certain parameter. It is possible that the increase in shared vehicles or other transportation changes may affect this index; for example, there may be cases where the amount of on-demand carpooling changes from previous values. As the NHTS and other data sets are updated, it would be of interest to revisit how the indices are affected. While the multimodal index is the critical item, it is possible that if carsharing alters the travel impedance, that jobs-housing balance would also be affected.

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