Multimodal Enhancements to Public-Private Partnerships

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I dedicate this dissertation to my family and friends.

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 increased property values or 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. One such mechanism is value capture, where a part of the created property value that results from a P3 investment can be captured in the form of revenue. The problem, however, is that the impact of a multimodal P3 project on property values is not completely clear.

Given the possible benefits of a value capture strategy, the purpose of this research is to quantify how a multimodal P3 project influences property values; conceptually, such a model could be used in a value capture mechanism. Fulfilling this goal requires satisfying five

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 examine how agencies include multimodal components in P3s (necessary because there may be ways to achieve multimodal P3s beyond the value capture strategy noted here); (3) to develop a way to quantify jobs-housing balance that is sensitive to transportation investments across multiple modes (necessary because jobs-housing balance is one societal impact of interest to decision makers); (4) 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 (5) to quantify the impact of multimodal P3s on property values. The research that satisfies these five objectives uses real data sets from P3s in Virginia, Florida, Colorado, and Rhode Island. Most data elements are available in the public domain (only property value data had to be requested from the county government), and no data elements were fabricated. Thus, the methodology used herein should be replicable in other locations.

As an initial research effort to consider a value capture mechanism based on urban form impacts, this research suggests four key contributions: (1) lessons learned from practitioners' implementation of multimodal P3s; (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) a method to identify urban form and property value impacts of P3s. Ultimately the fourth contribution may inform guidelines for adopting value capture mechanisms in P3s.

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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 have included freeways where that allow for bus rapid transit (Ferrell et al., 2011), park-and-ride lots that allow 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, which is 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 dissertation 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. The Virginia experience shows this to be the case. For example, of the 17 P3 projects that are at the planning or construction stage in Virginia, 12 are focused on either general purpose lanes or High-Occupancy-Toll (HOT) lanes.

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 property value 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. Landowners and developers benefit from this increased value. Using value capture mechanisms, a part of this 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 investment, which in turn makes a given location more accessible and increases property value. 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, 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 property values. For example, a P3 project in Atlanta, Georgia that considers multiple modes such as rail, bus, bike and pedestrian, and expects increased property values around/in the facility. The key concern is thus determining to what extent such multimodal aspects influence property assessments.

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 increased property values 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 quantify the extent to which multimodal P3 projects influence property values. 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, relate this multimodality to a social goal in which there is interest such as jobs-housing balance, and verify that lessons from previous experiences with multimodal P3s have not been overlooked.

Accordingly, this research has seven 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.)

- Examine how U.S. transportation agencies incorporate multimodal components into P3 projects (or understand barriers to such multimodal components).

- 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 jobs-housing balance.

- Determine how changing the degree of multimodality for a multimodal P3 changes jobs-housing balance.

- Develop a model to quantify the impact of multimodal P3s on property values.

While the third, fifth, sixth, and seventh objectives are the chief goals of this research, three preceding 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 second objective was developed in explicit support of the problem statement offered by the Transportation Planning Research Advisory Committee (2012). The fourth 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; Welch and McLaughlin, 2014; Cameron, 2014).

1.6 Dissertation Layout

This dissertation consists of seven chapters, including the general introduction presented in Chapter 1 and general conclusion (in Chapter 7). Because each chapter (from Chapter 2 to 6) aims to be directly submitted to the journal publication, each chapter has its own title and separate contexts (e.g., introduction, methodology, main body, conclusion and references).

All major objectives of this research mentioned above are separately responded by different five chapters. That is, the first objective is addressed in Chapter 2, the second objective is in Chapter 3, the third and fifth objectives are in Chapter 4, the fourth and sixth objectives are in Chapter 5, and the seventh objective is in Chapter 6.

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CHAPTER II LESSONS LEARNED FROM THE RISE, FALL, AND RISE OF TOLL ROADS IN THE UNITED STATES AND VIRGINIA

2.1 Introduction

During the past three decades, "toll roads"—i.e., roads funded by some type of toll (also referred to as a user fee) attributed to using a given facility—have gained renewed interest at the national level for two distinct reasons.

1. *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).

2. *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).

Privately built toll facilities are not new. Although 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 suggested the use of tolling has been cyclical. To the extent that history repeats itself (Crabtree, 1993), the conditions that have encouraged (or discouraged) the use of toll facilities can be identified and used to determine situations when future toll facilities might be more feasible than at present.

2.2 Purpose and Scope

This paper documents decisions for using or not using tolled facilities in the United States in three ways: (1) it identifies periods in U.S. history that can be defined by the popularity or unpopularity of tolled facilities; (2) it indicates the extent to which non-financial considerations have affected this popularity; and (3) it identifies conditions that can help predict when user fees will be viewed more favorably than public funds as a financing mechanism.

Five periods characterizing U.S. toll roads were identified: 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). Although a review of the national literature was germane, a Virginia-specific focus provided more than 400 years of examples that helped identify lessons that might be extended to other contexts.

2.3 Methods

Three tasks were undertaken to achieve the purpose of this paper:

1. *A literature review was conducted that focused on how facilities were financed during the period 1607-2013*. (This period reflects the availability of data for North America.) The literature search used the Transportation Research in Development (TRID) and WorldCat databases and included excerpts of transportation histories (Federal Highway Administration [FHWA], 1976; Deakin, 1989; Williamson, 2012). Several sources (e.g., Klein and Majwski, 2008) and older Virginia-specific documents provided by the state transportation historian suggested

periods with common approaches toward financing toll facilities. The complete literature review, including 126 references, is available from the authors.

2. *From the literature review, details relevant to financing of toll facilities were documented.* In many cases, the literature reviewed in Task 1 provided the necessary information; for example, Mohl (2002) showed that tolls alone could not support the national highway system. Additional research was required for other cases; for example, there was a question as to whether the period in which turnpikes were popular ended before 1860 or in 1900. A tabulation of Virginia enabling acts for turnpikes (Tompkins, 1928; Virginia Department of Highways, 1932) (Figure II-2) revealed the number of such acts dropped by almost two thirds for the period 1866-1900 relative to the period 1795-1861, suggesting that the Turnpike Era ended before the Civil War. Similar data were used to quantify the use of plank roads in Virginia, e.g., penalties established in 1705 for failing to maintain facilities (Hening, 1819) and the number of New Jersey turnpikes in the 1800s (Durrenberger, 1931). These data, coupled with the findings from Task 1, were used to delineate periods based on legislation and public opinion.

3. *Conditions indicating when tolled facilities may be preferable to non-tolled facilities were identified.* After factors common to all facilities were identified, common themes were sought in terms of technology, design, and public perception that appeared to explain why tolling was or was not used. Contrasts between tolling and non-tolling approaches within the same time period were considered. For example, the 1840s National Road (funded by taxes) and the Lancaster Turnpike (funded by tolls) were compared; as were the 1940s toll-free network with the Pennsylvania Turnpike and the Merritt Parkway.

2.4 A Chronology of U.S. Toll Facilities

The research 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). Table II-1 gives examples of turnpikes in Virginia during this early period.

TABLE II-1. Examples of Turnpikes in Virginia during the Turnpike Era

Name	Date Built	Date Tolls Ended	Sources
Little River Turnpike	1802-1811	1892	Kelly (2013); National Active and Retired Federal Employees Association (2013)
Northwestern Turnpike	1827	Circa 1900	VDOT (2006)
Valley Turnpike	1834	1918	National Park Service (2014)
Howardsville Turnpike	1846	1860s	Shepherd (1846)
Staunton-Parkersburg Turnpike	1838-1850	1890s	Staunton-Parkersburg Turnpike Alliance (undated)
Weston-Gauley Bridge Turnpike	1849	1917	Cruz (1998)

Note: The Northwestern, Staunton-Parkersburg, and Weston-Gauley Bridge turnpikes were located in the portion of Virginia that seceded from Virginia at the beginning of the U.S. Civil War; since 1863, when West Virginia was admitted to the Union, the turnpikes have been located in West Virginia.

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.

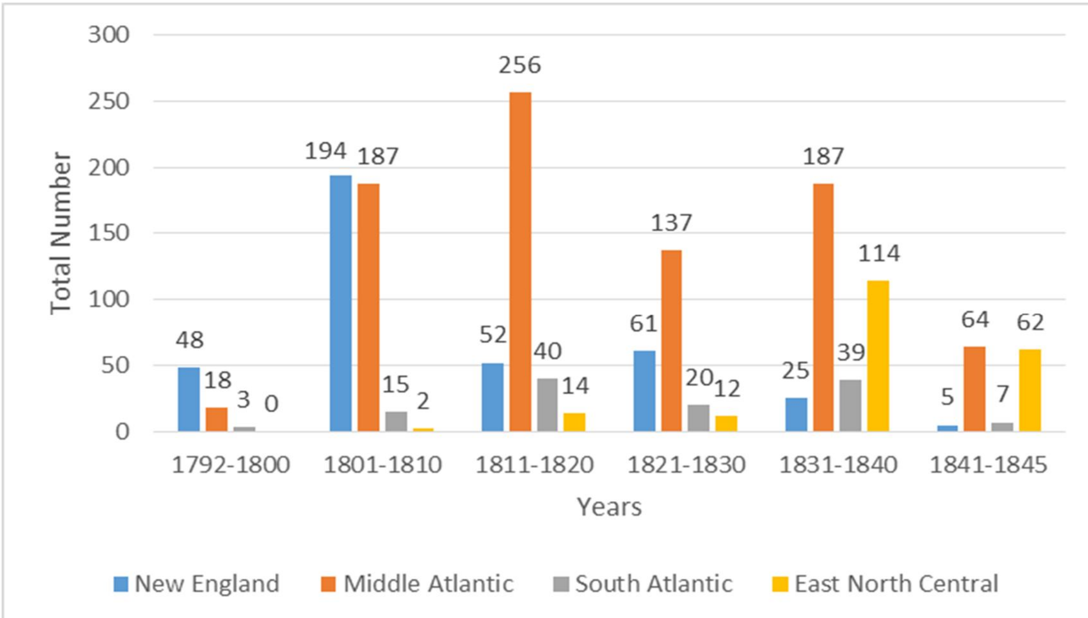

FIGURE II-1. Turnpike corporations by region in the Turnpike Era

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 as shown in Figure II-2) was roughly one-third of the rate (3.4 per year) before the Civil War.

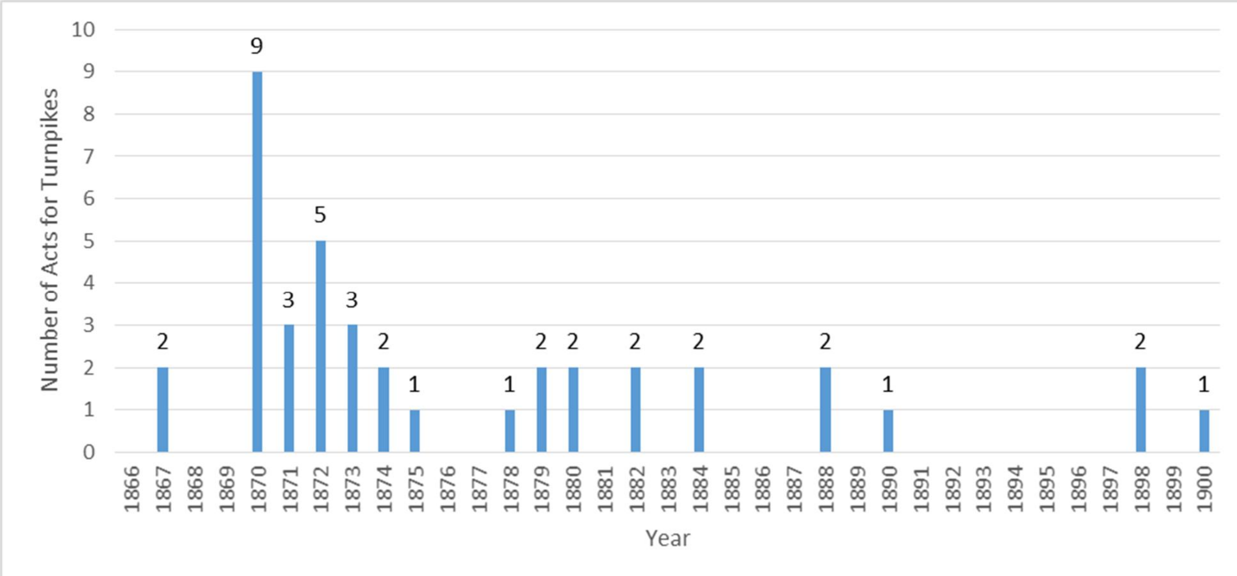

FIGURE II-2. Number of turnpike enabling acts passed in Virginia by year after the Civil War

Note: Figure II-2 is created based on an index of Virginia turnpikes (Virginia Department of Highways, 1932) and an accompanying map (Tompkins, 1928).

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-3 (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.

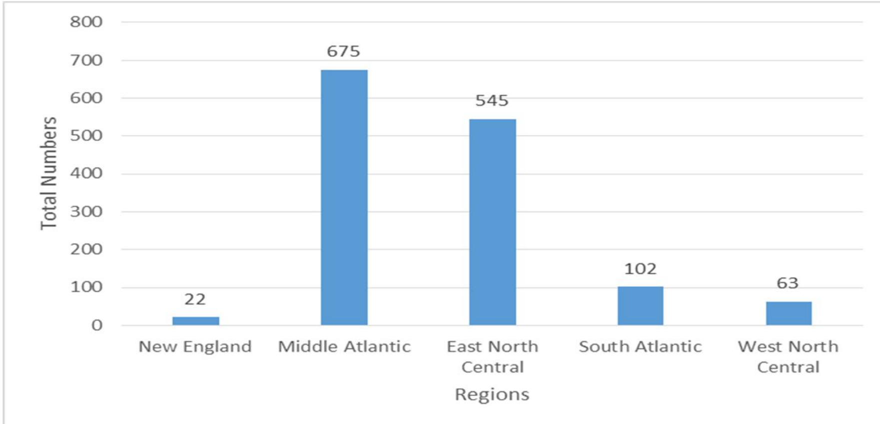

FIGURE II-3. Plank roads by regions in the Anti-Toll Sentiment Era (circa 1844-1858)

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-2 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-2. 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). As indicated in Table II-3, 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).

TABLE II-3. Examples of Successful Turnpikes in the Post-World War II Era

Turnpike	**Details**	**Date Opened**
Pennsylvania	• Before WWII: $500,000 loss (1.04 million vehicles paying $1.78 million in tolls) • After WWII: net operating revenue of $5.6 million per year in 1948 and $15.1 million per year in 1953 (resulting in the extension of 100 miles east to Philadelphia and 60 miles west to the Ohio state line)	1940
Maine	Surplus on a toll of about 1.5¢ per mile in 1947 and net operating revenue of $1.3 million per year in 1953 (the 47-mile road from U.S. Route 1 between Kittery and South Portland and thereafter a northern extension to Augusta)	1947
New Hampshire	• 20¢ for a passenger car on New Hampshire's 15-mile portion of U.S. Route 1 • Net operating revenue of $0.4 million per year in 1953	1950
New Jersey	Net operating revenue of $18.2 million per year in 1953 (117-mile principal artery between the George Washington Bridge and the Delaware River)	1952

Note: Table II-3 was created based on a review of material in ENR (1945, as cited in FHWA, 1976); BPR (1955); and Jacobs Engineering Group (2009).

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-4 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-4. 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-5). 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-5. 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, DC, 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-6 (Williamson, 2012).

TABLE II-6. 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-6 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 Lessons Learned from the Chronology

Figure II-4 describes the timeline for developing toll roads across the five aforementioned historical periods. This figure reflects factors common to tolled and non-tolled facilities and then gives conditions conducive to toll facilities. From these, conditions were identified that potentially influence the viability of a given toll facility in the future.

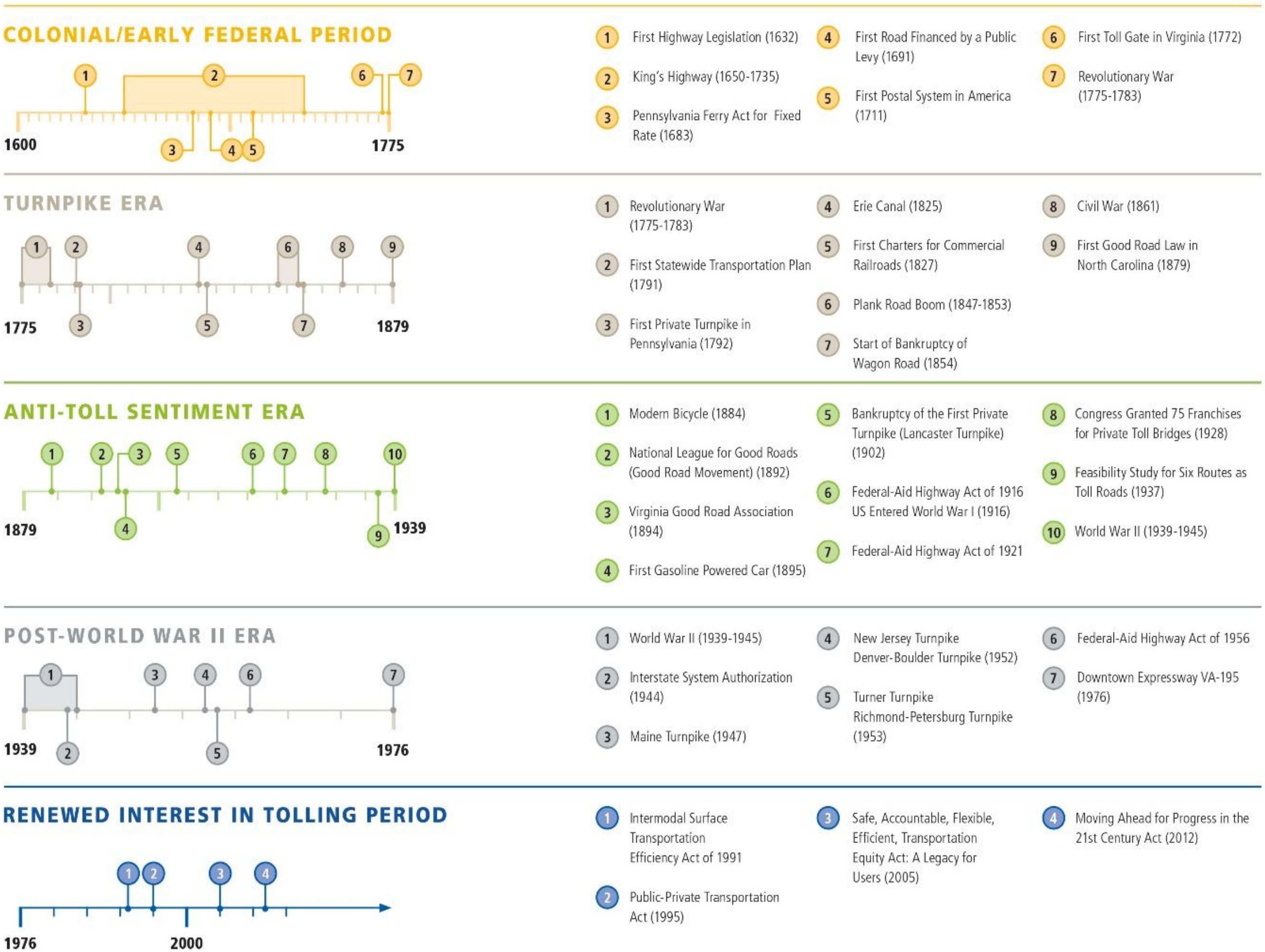

FIGURE II-4. Timeline for U.S. toll road development

2.5.1 Factors Common to Toll and Non-Toll Facilities

The two types of facilities have several factors in common.

1. *Instances can be identified where the quality of the user experience was better on tolled facilities than on non-tolled facilities and vice versa.* As an example of the latter, privately owned turnpikes decreased in the mid-19th century, attributable in part to damage from the Civil War but also from modal competition. As tolled facilities fell into disrepair, the user experience suffered such that the system of paved roads suitable for pneumatic tires that emerged in the early 20th century was clearly superior to the roads of the Turnpike Era. As an example of the former, although the concept of a limited access facility today is well understood, when the Pennsylvania Turnpike was introduced in the 1940s, its design concepts—medians, 12-foot lane widths, acceleration ramps for entry, and interchanges rather than at-grade intersections (Pennsylvania Turnpike Commission, 2015)—could be considered innovative at the time. Weingroff (2014a) provided a quotation from an engineer who contrasted the design of existing facilities where geometric standards (e.g., curvature, lane width, and so forth) could "fluctuate every few miles" with the more uniform design of the Pennsylvania Turnpike. In general (not just for the Pennsylvania Turnpike), Rose (1979) noted that in 1939 (when the turnpike's design would have been underway), "few states" permitted designers to prohibit immediate access points for a roadway.

2. *Consideration of societal impacts has influenced popular perception of both non-tolled and tolled facilities.* As an example of the former, the Good Roads Movement reflected an interest in accommodating users of 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 an early federal policy of financing facilities that would eventually comprise the U.S. system of highways. As an example of the latter, in the Turnpike Era, turnpikes provided better road facilities to those engaged in commerce (Klein and Majewski, 2008; Durrenberger, 1931). Majewski (2000) quoted Gordon, an individual from the Turnpike Era in 1832: “None have yielded profitable returns to the stockholders, but everyone feels that he has been repaid for his expenditures in the improved value of his lands, and the economy of business.” As another example of a considered societal impact, i.e., congestion reduction, peak period pricing (Washington State Transportation Commission, 2006) was a consideration for tolls during the Renewed Interest in Tolling Period. In short, externalities (e.g., positive or negative impacts that are not reflected in the price [Meyer and Miller, 2013]) matter, but their degree of influence has varied over time.

3. *In the past there has been a trade-off 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 more than 1,000 such roads were built), but this period appears to have been short lived when compared to the duration of each of the five historical periods noted herein. The aforementioned pre–Civil War article (“Macadamized vs. plank roads,” 1856) advised farmers to use macadamized roads, noting that the annual cost of repairs for plank roads was 30% of their construction cost. For longer service life, therefore, the use of wood for these feeder roads was to be avoided. More than a century later (although the topic was not plank roads), the Council on Virginia’s Future (2014), in its discussion of transportation performance, acknowledged the choice between reducing initial outlays and reducing design life. Using the example of a bridge, the

council stated that "there is a trade-off between cost and longevity," as a larger initial construction cost may result in a bridge that lasts longer.

4. *Coordination between public and private entities can increase the societal benefits of both tolled and non-tolled facilities, and the form of this coordination can vary.* This coordination can certainly refer to establishing an acceptable user fee. Toll roads were first introduced because state governments sought to satisfy demands for additional road construction without using public funds—and even then, public protections existed. As noted by FHWA (1976), the operating agreements typically called for tolls to be reduced if profits rose above roughly 15% annually. This coordination can also refer to route planning: the Federal-Aid Highway Act of 1921 encouraging states to connect metropolitan areas (Slattery et al., 1992) was a form of intergovernmental coordination. Maryland's decision to support private turnpikes in the 1820s meant the state was ready for commercial benefits once the National Road was extended to the Ohio River (FHWA, 1976). This coordination can also refer to performance monitoring. Many private turnpikes, such as those that competed with the Erie Canal or railroads, went bankrupt, resulting from a cycle of decreased revenues, lack of funds for maintenance, and poor service. Because private facilities have not been a panacea, monitoring has been used to ensure an appropriate level of service. Recent examples are the public sector establishing performance criteria to achieve a specific objective for a privately operated facility (FHWA, 2013); older examples are monitoring of financial performance (FHWA, 1976). It is not surprising, therefore, that the public-private agreements regarding these toll facilities can be quite detailed.

5. *Transportation activity and population are highly associated.* Although there is some uncertainty associated transportation activity (e.g., the number of New Jersey turnpike corporations created was either 54 (1801-1828) (Durrenberger, 1931) or 47 (1801-1830) (Klein and Fielding, 1992), the state level correlation between number of turnpike incorporations (1801-1845) and population is fairly strong (0.74). This correlation increases to 0.95 for state population and number of plank roads (1850-1858). Not surprisingly, per-capita turnpike activity peaked earlier in New England than it did in other parts of the United States (Figure II-5).

2.5.2 Conditions Conducive to the Use of Toll Facilities vs. Conditions Conducive to the Use of Non-Tolled Facilities

Conditions conductive to the use of toll facilities appear to be the following:

1. the availability of a more reliable funding stream than a more general tax base
2. technology that could collect fees from users without additional negative impacts
3. an ability to exploit new design approaches compared to existing designs
4. an ability to extract fees from a specific market segment.

As an example of Conditions 1 and 4, the high population density of a New York City suburb (Westchester County)—and the employment opportunities in New York City—probably contributed to the feasibility of offering a premium transportation service for a cost between these two points. As an example of Condition 2, literature on the history of electronic toll collection showed that relative to having only manual collection points, the use of new technology could reduce delays by one half—even if only 10% of users participated in an electronic collection approach (Al-Deek et al., 2000).

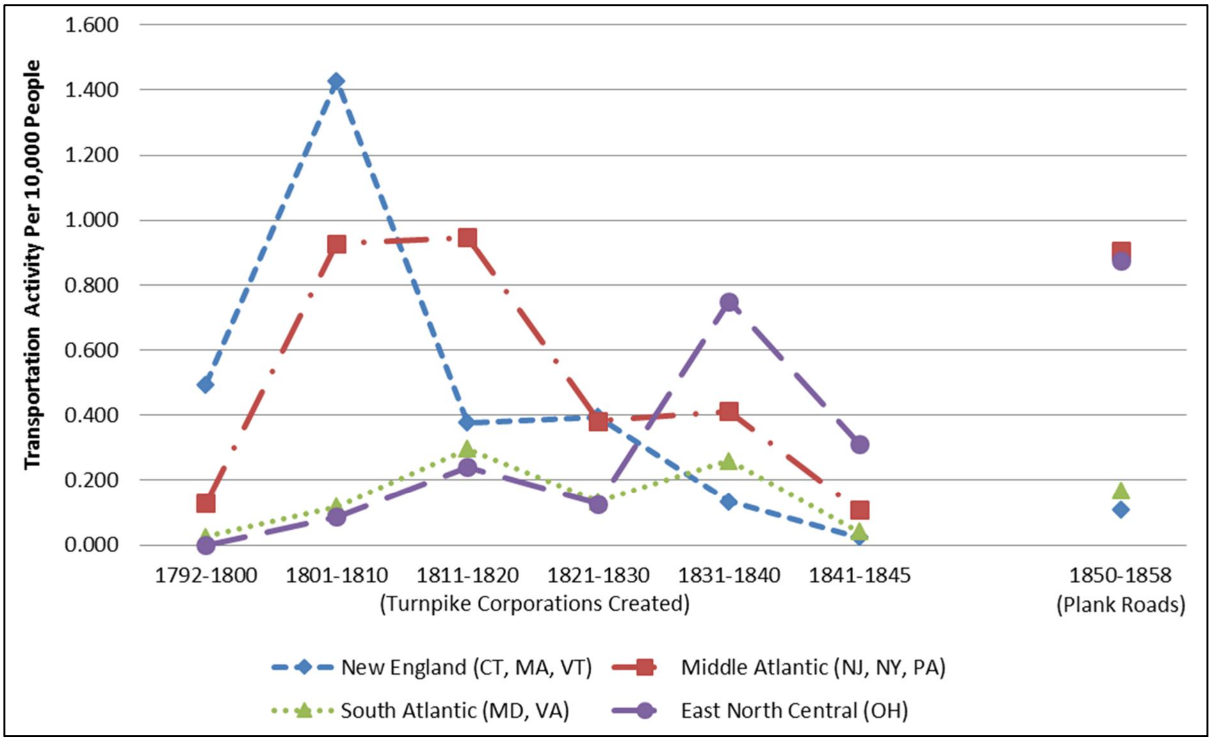

FIGURE II-5. Transportation activity per 10,000 people

Note: The data sources for this figure were turnpike corporation and plank road data from Klein and Fielding (1992), Virginia plank road data (Tompkins, 1928; Virginia Department of Highways, 1932), decennial Census data (U.S. Census of Population and Housing, undated), and Census geographical classifications (U.S. Census Bureau, 2014). Years for plank roads vary by state.

Further, during the same year that the Intermodal Surface Transportation Efficiency Act (which permitted tolls to a greater degree than previous authorizations) was passed, the description of Colorado's E-470 toll road suggested that electronic toll collection would not only minimize delays, it would also help manage incidents (Willett, 1991). As an example of Condition 3, the Pennsylvania Turnpike, designed in the late 1930s, used limited access points, wider lanes, smoother grades, and as noted by Weingroff (2014a), consistency in these elements of design such that the motorist was not surprised every few miles by changes in roadway geometry. Compared to other facilities in existence then, the turnpike's creative design—creative in the sense that geometry was uniform for a long segment rather than varying every few miles as was the case with other facilities at the time—allowed motorists to travel at higher speeds.

If these four conditions indicate conditions conducive to the use of toll facilities, their opposite can suggest conditions conducive to a non-tolled facility. Such conditions appear to be the following:

1. tax revenues that are more reliable than toll facility revenues
2. technology that could collect taxes without adverse consequences for users
3. a need to accommodate an entire class of users who benefit from consistent design standards
4. net societal benefits being larger than benefits to toll facility users.

These conditions extend to both passenger and freight movements; for example, difficulties with road deterioration attributable to heavy truck use during World War I contributed to the system of U.S. highways in the 1920s. As an example of Condition 1, the steady federal investment in postal routes (Lee, 2012) and routes connecting metropolitan areas (Slattery et al., 1992) provided a dependable financial resource for the early 20th century U.S. system of highways. As an example of Condition 2, technology existed during the mid-20th century to collect taxes from users—notably through the fuels tax levied at the pump—without adverse consequences for operations. As an example of Condition 3, the popularity of the Good Roads Movement (Keane and Bruder, 2003) was driven at least in part by a recognition that paved smooth facilities could benefit an entire class of users, i.e., bicyclists. As an example of Condition 4, whereas a specific market niche—Westchester County residents traveling to work—helped make the Merritt Parkway possible, the opposite of such a concentrated niche—notably dispersed farmers who needed to get their goods to market—helped encourage the Office of Road Inquiry to support better transportation facilities generally (rather than solely in a single location). That is, the societal benefit was perceived as large and did not depend on a geographically concentrated group. Another example of Condition 4 was the use of public support for designated postal routes at two instances almost 200 years apart—earlier during the Colonial/Early Federal Period (e.g., the Albany Post Road in 1703) and later during the Anti-Toll Sentiment Era (e.g., the Federal-Aid Highway Act of 1916); in both cases, the broad societal benefits made public facilities appealing.

Table II-7 contrasts the conditions that are conducive to the use of toll facilities and those that are conducive to the use of non-tolled facilities.

TABLE II-7. Conditions Conducive to the Use of Toll Roads vs. Conditions Conducive to the Use of Non-Tolled Roads[a]

Category	Condition	Conducive to Toll Roads	Conducive to Non-Tolled Roads
1	Reliable funding from users vs. taxes	Reliable funding from users allows for routine maintenance to keep the road in good condition (e.g., Pittsburgh Turnpike).	The revenue from taxes allows routine maintenance to keep the road in good condition (e.g., Federal-Aid Highway Act of 1956).
2	Existing technology for collecting tolls vs. taxes	Technology exists to collect tolls from users without adverse consequences for operations (e.g., transponders).	Technology exists to collect taxes from users without adverse consequences for operations (e.g., fuels tax collection at the pump).
3	Benefit of design exceptions (for toll roads) exceeds benefit of design standards (for all roads)	An innovative design makes the road more attractive (e.g., allows faster travel).	Consistency of design standards strengthens network effects (e.g., smoother pavements are amenable to bicyclists and automobiles).
4	Benefits accruing to the toll road market segment exceed the societal benefits.	There are premium users defined by location or time who will pay market rates to use the toll facility, and these monetized benefits are perceived to be larger than benefits to nonusers.	The societal impact (e.g., benefits flowing to others, including those who do not use the facility) is perceived to be greater than the revenue generated by the market (e.g., the transport of goods).

[a] Table II-7 does not show two factors that negatively affect any type of facility: competition from new modes of transportation and the failure of new technology.

2.6 Conclusions

1. *Five periods characterize attitudinal changes toward toll facilities*. Public support for such user fees has been cyclical, rising during the second and fifth periods (the Turnpike Era and the Renewed Interest in Tolling Period), with specific market niches during the fourth period (Post–World War II Era).

2. *Although financial incentives mattered, other factors influenced attitudes toward funding transportation facilities with tolls versus public funds*. Such factors include technology (e.g., successes such as electronic tolling or limitations such as plank roads), perceptions of public benefits (notably trade during the first period and accommodation of pneumatic tires during the third period), and willingness to pay for design innovations (especially during the fourth period). The low rates of return of some privately built facilities, as well as government support of private companies, suggest that the perceived public benefits have often been a major consideration whether or not the facility had a toll.

3. *Four conditions other than site-specific details partially affect the viability of a given toll facility:* (1) the relative stability of revenue streams from user fees (compared to the stability of revenues from a general tax); (2) the existence of toll collection technology that enhances or at least does not harm the user's experience; (3) greater benefits from design innovations for the tolled facility than from consistent design for non-tolled facilities; and (4) revenues from the toll facility being greater than its societal impacts.

These conditions can be related. In the early 1950s, turnpikes—although popular—were not a model for the federal-aid system because the cost of manual toll collection (Condition 2) meant that access points had to be spaced far apart—a design that could not meet the demands of local travel for all patrons (Condition 4).

Further, these conditions can be applied to 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) can influence this success. Reliability can be generalized beyond revenue to include duration of the environmental review process and review required for alternative designs. If a given toll road can be constructed in a shorter period of time than a non-tolled road because of avoidance of some planning requirements (Sandlin, 1989), the appeal of a tolled facility will increase. 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.

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CHAPTER III FACTORS INFLUENCING AGENCY CONSIDERATION OF MULTIMODAL PUBLIC-PRIVATE PARTNERSHIPS

3.1 Introduction

A public-private partnership (P3) is a project that is financed or operated through an agreement between at least one public entity and at least one private entity (Office of Innovative Program Delivery [OIPD], undated a). P3s have been used in 31 countries (Istrate and Puentes, 2011), and over two decades, more than 2,000 P3s representing $887 billion existed worldwide (AECOM Consult, Inc., 2005).

AECOM Consult, Inc. (2007b) suggested that P3s with a multimodal component can yield greater societal benefits and increased private sector participation. As an example of the latter, the multimodal component can improve access to economic development opportunities and more diverse financial markets for transportation investment. Exemplifying the former, for the Regional Transportation District (2014) multimodal Colorado P3 project, every $1 invested in transit infrastructure translated into a $4 dollar return over 20 years; the project added $3 billion into the local economy. Accordingly, P3s may be judged not only by their financial viability but also by their societal benefits, and in some cases, such benefits may justify additional public sector involvement (AECOM Consult, Inc., 2007b).

However, multimodal P3 projects may be hard to build. Reinhart (2011) notes that few of the currently proposed P3 projects can be financially self-sustaining if tolls alone are the only source of revenue. Indeed, Arnold et al. (2012) implies that multimodal P3 solutions may be implementable to the extent that auto revenue can support transit. Ankner (2008) noted that non-compete clauses in concession agreements may hinder the provision of public transportation for a tolled facility. Maloof (2014) showed that the benefits of P3s may be fundamentally different by mode: transit projects might generate revenue through increased land development rather than through tolls. OIPD (2010) noted that one misconception about P3s is that they are a revenue source: although tolls or some other type of user fee may make a P3 viable, for transit modes—especially where a state makes an availability payment based on service level provided—some other revenue source, e.g., value capture (Maloof, 2014), may be required.

In-person meetings with Virginia's Office of Transportation Public-Private Partnerships (OTP3) (in October 2013) and the Transportation Planning Research Advisory Committee of the Virginia Center for Transportation Innovation and Research (in November 2013 and October 2014) raised two pertinent questions. First, to what extent are U.S. P3s "multimodal" (Litman, 2012) in that they serve at least two passenger or freight modes? Second, is there a general process agencies have used to consider these multimodal components? Potential elements of this process might include a definitive point at which a project becomes (or does not become a P3), the manner in which land development impacts are evaluated, the role of diverse stakeholders, and factors that influence an agency's decision to add or remove multiple modes from a P3 project.

3.2 Purpose and Scope

This paper investigates whether there are common themes in other states' processes for consideration of multimodal P3 projects, including how agencies view the inclusion of multimodal components. The study had four objectives:

1. Determine why multimodal projects in other states have been pursued as P3 or non-P3 projects.

2. Determine reasons for other states including multiple modes in an existing P3 project.

3. Identify milestones other states have used for deciding whether to include or exclude multimodal components for P3 projects.

4. Determine expected land development impacts of P3 projects in other states.

A limitation of the study is that the sources of information presented herein—published literature and notes from interviewees—does not account for proprietary information. Accordingly, there may be additional project-specific details that also explain some of the decisions made by transportation agencies. However, a corresponding strength is that by reviewing multiple projects, common themes with respect to the decision-making process may be identified.

3.3 Methodology

Three steps were used to achieve the study objectives.

3.3.1 Step 1: Select Candidate Multimodal P3 Projects.

Initially, 135 P3 projects were identified based on a review of the literature (e.g., AECOM Consult, Inc, 2007a; Center for Transportation Public-Private Partnership Policy, 2014; Public Works Financing, 2014), project lists (e.g., Maze, 2013; OTP3, 2014), and funding from the Transportation Infrastructure Finance Innovation Act (TIFIA) program (e.g., U.S. Department of Transportation [USDOT], undated; OIPD, undated b). Use of the TIFIA program does not necessarily mean that a project is a P3, but it can be an indicator of that status (Lee, 2012) as the TIFIA program encourages private investment in transportation infrastructure (USDOT, 2015). Then, from these 135 projects, candidate projects were identified if four criteria were met:

1. *One additional source indicated the project was a P3*. Sources included (1) unsolicited proposals; (2) requests for proposals; (3) requests for qualifications; (4) documents associated with the environmental review process (such as a draft or final environmental impact statement or a record of decision; (5) websites maintained by a state department of transportation (DOT) or other agencies (e.g., Center for Transportation Public-Private Partnership Policy, 2014; Maze, 2013; OIPD, undated b); and (6) direct inquiries by email to the director, manager, or coordinator of the P3 office or related division of the DOTs.

2. *The project was in a state that as of 2014 had enacted P3 legislation or had a P3 office or division*. As of February 2014, 33 states and Puerto Rico had enacted laws authorizing P3s for transportation projects (OIPD, undated c; Rall, 2014). As of August 2014, 14 states and the District of Columbia possibly had P3 offices or related divisions as determined by viewing their websites.

3. *Either* the *project's description or related literature suggested the project was multimodal as defined in Step 1.*

4. *The project was not located in Virginia.*

After the projects were screened based on these four criteria, the 135 projects were reviewed again. One project was added: the Rhode Island InterLink project, which appeared to be a P3, despite the state not having P3 enabling legislation and a P3 office (OIPD, undated c; Rall, 2014). It was also determined that what had been thought to be 3 separate projects were in fact part of a single megaproject (Colorado FasTracks). Step 2 thus yielded 35 candidate multimodal P3 projects. Efforts were made to interview staff familiar with the 35 candidate projects, and for the 23 projects for which an interview was granted, the questions in Step 3 were posed. For 12 projects, interviews were not scheduled. For 6 of these projects, the potential interviewee indicated the project was no longer a P3. For the remaining 6 projects, it was not possible to identify an individual who was able to grant an interview.

3.3.2 Step 2: Conduct Interviews

Table III-1 shows two types of interviews that were conducted: a project-specific interview (for P3 projects) and a general interview (for non-P3 projects). At least two researchers were present for each interview.

TABLE III-1. Interview Questions and Target Audiences[a]

Type	Details	
Project-specific interview	Target audience	An individual who could discuss P3 project-specific details. This interview was conducted if the candidate project from Step 2 was confirmed to be a P3 by the interviewee.
	Sample questions	1. Why did the *Rhode Island Department of Transportation* pursue the *InterLink project* as a public private partnership? [If clarification is needed, the following may be stated.] What were the key factors that led to pursuing this as a P3? Clearly P3s are an opportunity to leverage private sector resources, but is there any unique justification for this project that outside observes might not be aware of? 2. Are there project developments milestones where decisions are made to include or exclude alternative modes? [If clarification is needed, the following may be stated.] We asked this question because in Virginia it is possible for a given mode, such as BRT, to be proposed in one phase and then eliminated in another phase. [Then if they ask what phases are used in Virginia, this may be stated:] Typically, in Virginia, P3 projects use 5—phase process is identification, screening & prioritization, development, procurement, delivery. 3. To what extent does consideration of multiple modes influence how a P3 decision is made? [If the interviewee has trouble giving a detailed answer, the following may be stated instead.] In general, what factors lead you to consider multiple modes in a given project? For example, a given project might have included multiple modes as a way to increase revenues for stakeholders. 4. What are the expected land use impacts? Land use impacts include any changes in population, the use of land (for example, changing residential area to commercial area), or land values around the *InterLink project* including rail stations and park-and-ride facilities.
General interview	Target audience	An individual who could discuss the state's approach to P3s. This interview was conducted if the candidate project from Step 2 was ultimately found not to be a P3 project.
	Sample questions	1. I want to confirm that the *SR – 54 & 56 Toll Road Concession project* will not be pursued as a public private partnership (i.e., a P3). 2. I would like to understand the process *Florida* uses for developing P3s. Typically, in Virginia, the development of P3 projects takes place in 5 phases: identification,

		screening and prioritization, development, procurement, delivery. 3. To what extent does consideration of multiple modes influence how a P3 decision is made?

[a] Although the questions shown served as a template for conducting the interview, additional or fewer details were sought based on the interviewee's familiarity with a given project or process. For example, in one interview, Questions 1 and 2 were combined, leaving room for an additional question regarding the concession agreement.

Table III-2 shows that interviews reflecting 23 projects were conducted: 18 initial interviews by telephone, 2 initial interviews by email (at the interviewee's request), and then three additional follow-up communications (1 interview by telephone and 2 queries by email). Permission was sought from the interviewee to record the interview. Then, based on notes taken during the interview and the recording, a transcript was made. The transcript was then converted to a summary that, along with any necessary follow-up questions, was sent to interviewees for verification.

TABLE III-2. Projects for Which Agency Staff Were Interviewed[a]

No.	State	Project (Number of Agency Participants)[b]	P3[c]	Phone or Email Interview Date
1	Colorado	I-70 Mountain Corridor (1)	No	May 30, 2014
2	Georgia	Atlanta Downtown Multi-Modal Passenger Terminal (1)	Yes	June 13, 2014
3	Colorado	FasTracks (2)	Yes	June 18, 2014
4	California	Anaheim Regional Transportation Intermodal Center (1)	No	June 18, 2014
5	Colorado	US 36 Express Lanes (1)	Yes	June 20, 2014
6	California	High Desert Corridor (1)	Yes	September 17, 2014
7	District of Columbia	Washington DC Streetcar PPP project (1)	No	September 24, 2014
8	Alaska	Anton Anderson Memorial Tunnel (1)	Yes	September 24, 2014
9	Florida	Miami Intermodal Center (1)	Yes	October 3, 2014
10	Georgia	Northwest I-75/575 HOV/BRT (1)	Yes	October 21, 2014

11	Florida	SR – 54 & 56 Toll Road Concession (2)	No	October 20, 2014
12	Florida	I-4 Ultimate P3 Project (3)	Yes	October 20, 2014
13	Rhode Island	InterLink (2)	Yes	October 20, 2014
14	Georgia	Atlanta BeltLine (3)[e]	No	October 22, 2014
15	Maryland	Maryland Light Rail Purple Line P3 (1)	Yes	October 30, 2014
16	Florida	I-595 Express Corridor Improvements Project (1)	Yes	November 14, 2014
17	Illinois	Riverwalk Expansion/Wacker Drive Reconstruction Project (1,1)[d]	No	November 17, 2014[d] June 1, 2015[d] June 2, 2015[d] June 10, 2015[d]
18	Illinois	Chicago Transit Authority (CTA) 95th Street Terminal Improvement Project (1,1)[d]	No	
19	Illinois	Chicago O'Hare International Airport (1)	No	
20	Illinois	Chicago Region Environmental and Transportation Efficiency Program (CREATE) (1,1)[d]	Yes	
21	Texas	SH 183 Managed Lanes Toll Concession (1)	Yes	January 21, 2014
22	Texas	Katy Freeway Reconstruction (1)	No	January 15, 2015
23	California	Crenshaw/LAX Transit Corridor Project (1)	No	June 3, 2015

[a] Six projects from 35 candidate multimodal P3 projects are not shown because pre-interview communications with agency staff indicated the projects were not P3s: Highway Goods Movement Package PPP Projects (California), 91 Express Lanes (California), South Capitol Street Corridor Design-Build Project (Washington, D.C.), Eleventh Street Bridge Project (Washington, D.C.), Washington Metro Capital Improvement Program (Washington, D.C.), and Charlotte Gateway Station (North Carolina).

[b] Project titles used in Tables III-2 to III-6 are those used by agencies and information therein is current as of the time the interview was conducted.

[c] Although all projects were initially believed to be multimodal P3s prior to the interview, a “yes” indicates the interviewee confirmed that the project was indeed a P3.

[d] The first interview for the 4 Illinois projects occurred at the same time with one individual. Then, additional queries by email were conducted for the Riverwalk Expansion/Wacker Drive Reconstruction Project (June 1, 2015) and the CTA 95th Street Terminal Improvement Project (June 2, 2015), and a telephone interview with another individual was conducted for the Chicago Region Environmental and Transportation Efficiency Program (June 10, 2015).

[e] At the time of the interview, Atlanta BeltLine project staff were considering the feasibility of adopting a P3 approach. Recent communications with staff revealed that this project is not being pursued as a P3 because of the cost of implementation; however, staff noted this decision might be reconsidered in the future.

3.3.3 Step 3: Synthesize Interview Results.

Each interview summary was reviewed to obtain four pieces of information: (1) factors that determine whether a project is pursued as a P3, (2) reasons for including multiple modes, (3) the presence of milestones for deciding whether to incorporate multimodal components, and (4) expected land development impacts. The authors sought to determine the extent to which a structured process, or at least common themes, existed for inclusion of these other modes. In several cases, the authors supplemented the interview findings with a review of project documents in order to understand better the interview content.

3.4 Results

The lessons learned from the results of the interviews for the 23 projects, related literature, and additional communications with agency staff are presented with respect to four categories:

- Factors that determined why a multimodal project was pursued as a P3 or a non-P3
- Reasons for including multiple modes in a P3 project
- Milestones used to determine whether multimodal components should be included
- Expected land development impacts.

3.4.1 Factors that Determined Why a Multimodal Project Was Pursued as a P3 or a Non-P3

Of the 23 projects examined, most were found to be P3s. Table III-3 shows that 13 projects were being pursued as a P3 and 10 were not.

TABLE III-3. Reasons for a Project Being Pursued as a P3 or a Non-P3[a]

Status	Reason	Example Projects
P3	Obtain private sector financial assistance	• Atlanta Downtown Multi-Modal Passenger Terminal, Georgia • US 36 Express Lanes, Colorado • High Desert Corridor, California • InterLink, Rhode Island • I-4 Ultimate P3 Project, Florida • Miami Intermodal Center, Florida • I-595 Express Corridor Improvements Project, Florida • SH 183 Managed Lanes Toll Concession, Texas • Northwest I-75/575 HOV/BRT, Georgia • Chicago Region Environmental and Transportation Efficiency Program, Illinois
	Increase speed of construction	• Anton Anderson Memorial Tunnel, Alaska • I-595 Express Corridor Improvements Project, Florida
	Obtain expertise appropriate for this effort	• Atlanta Downtown Multi-Modal Passenger Terminal, Georgia • Maryland Light Rail Purple Line P3, Maryland
	Improve service quality	• FasTracks, Colorado
Non-P3	Became non-P3: lack of financial viability was a contributing factor	• I-70 Mountain Corridor, Colorado • Anaheim Regional Transportation Intermodal Center, California • SR – 54 & 56 Toll Road Concession, Florida • Atlanta BeltLine, Georgia
	Became non-P3: public opinion was a contributing factor	• I-70 Mountain Corridor, Colorado
	Became non-P3: incompatibility of design could have become a contributing factor	• SR – 54 & 56 Toll Road Concession, Florida • Charlotte Gateway Station, North Carolina[a]
	Was never a P3	• Crenshaw/LAX Transit Corridor Project, California • Katy Freeway Reconstruction, Texas

[a] The table shows 20 rather than 23 projects for which interviews were conducted. An additional 3 such projects were not being pursued as P3s, but the interviews did not reveal why that was the case. Information for Charlotte Gateway Station (North Carolina) project came from email communications with agency staff.

Reasons for a Project Being Pursued as a P3

Not surprisingly, the most common reason for pursuing a project as a P3 was to obtain private assistance: this reason applied to most (10 of the 13) P3 projects listed in Table III-3. For example, Florida's I-595 Express Corridor Improvements Project required approximately $1.4 billion—compared to about $0.7 billion available in the public sector work program. Even if a shortfall is not apparent, the private sector involvement can address risk: although Colorado obtained subsidies from local governments, federal sources, and the TIFIA program, Colorado recognized that there was a significant risk that the toll revenue would not always cover the operations and maintenance costs for the US 36 Express Lanes project. In some cases, the need for private sector involvement was not initially apparent: it was not realized that California's High Desert Corridor project would be a multi-billion dollar effort until the environmental and preliminary engineering processes were underway. The Rhode Island InterLink and Miami Intermodal Center projects are fundamentally private: rental car agencies are a major landowner in those locations.

Table III-3 shows three additional reasons for pursuing a project as a P3.

1. *Construction time.* For example, without private financing, Florida's I-595 Express Corridor Improvements Project would have been broken into 15 segments that would have been built incrementally over a 20-year period—such that capacity benefits for through traffic might not have been realized for two decades. The P3 approach shortened the time frame to about 5 years. For the Atlanta BeltLine, the P3 approach was considered because it could shorten the projected time frame from 17 to about 10 years or less. The Mayor's

Office of Communications (2013) further noted that pursuit of this project as a P3 would make certain elements—light rail transportation, as well as parks and walking trails—be built more quickly than would otherwise be the case). For Alaska's Anton Anderson Memorial Tunnel, accelerating construction was critical: the federal government altered rules that previously had permitted the hauling of cars on flatcars, meaning that some other approach for providing access to a relatively remote area was needed.

2. *Private sector expertise.* This reason was given for 2 of the 13 P3s in Table III-3. The Georgia DOT sought a master developer who could partner with other land developers; the state wanted experience in such multimodal terminals. Given that Maryland's Light Rail Purple Line requires coordination among the design, build, operations, and maintenance phases in order to account for the life cycle needs of the full project, private sector experience from transit projects worldwide was an asset.

3. *Better transit service quality.* Colorado interviewees noted this reason for making the FasTracks project a P3. Although it had invested hundreds of millions of dollars in the project, the private sector did not want to take the fare box revenue risk. Rather, a public transit provider, the RTD, will make performance-based payments to the private sector. These payments will be based on metrics such as frequency of service (15-minute headways or better), on-time performance, cleanliness of vehicles, and safety record. In short, the desire to improve transit service quality motivated this being a P3.

Reasons for Project to Transition from P3 to Non-P3

One reason for changing from P3 to non-P3 status was that as more information is learned about the project, its financial viability is brought into question—but the way in which this reason manifests is specific to each project. For example, for the I-70 Mountain Corridor (Colorado), after an unsolicited proposal had been received, the interviewee noted that a separate traffic and volume study performed by the state DOT suggested that the revenue could not meet the costs for the project. For instance, The Louis Berger Group, Inc. (2014) indicated that although a peak shoulder lane with tolling could be feasible under some conditions, this was not the case for full widening: if two lanes were added, tolls would not cover the sum of capital plus operating and maintenance costs. In the case of Florida's SR – 54 & 56 Toll Road Concession project, after an unsolicited bid was received, the project was cancelled when the private sector partner requested an additional $100 million (beyond the additional proposal). For the Anaheim's Regional Transportation Intermodal Center, two factors contributed to the project not appearing to be financially viable: the weakening of the economy (in 2008), and the fact that because this was a relatively new business model, it was difficult to find a single entity who could finance, operate, and maintain the facility over a long period of time.

Interviewees and other agency staff provided three additional factors that could terminate pursuing a P3 for a project.

1. *Public perception.* A rural county affected by Colorado's I-70 Mountain Corridor opposed a realignment that might have taken traffic, and hence customers, away from existing businesses.

2. *Design compatibility.* Although the private bid for Florida's SR – 54 & 56 Toll Road Concession project had already been rejected, interviewees noted that had negotiations continued, operational questions (such as how much to charge for transit access to managed lanes) and design questions (such as how to enable transit stations to provide access to adjacent land uses) would have required answers.

3. *Legality.* In the case of the Charlotte Gateway Station, although there was initial interest in a P3, it was determined that state statutes prohibited such an endeavor (and the representative also noted that the layout of the property was not compatible with such a development, relating to the design compatibility factor).

For two projects shown in Table III-3, although they had been listed as P3s in the literature (OIPD, undated b), interviews clarified they were not P3s. Both were design-build projects, and in one case the interviewee suggested this characteristic might have led to the project being considered as a P3.

3.4.2 Reasons for Including Multiple Modes in a P3 Project

Although consideration of multiple modes was largely performed on an ad-hoc basis, four reasons for including two or more modes in P3 projects came from the interviews.

TABLE III-4. Reasons to Involve Multiple Modes[a]

Reason	**Example Projects**
Multiple modes are part of the long-term vision for the region.	• Anaheim Regional Transportation Intermodal Center, California[b] • Northwest I-75/575 HOV/BRT, Georgia

Multiple modes are sought because of public opinion.	• US 36 Express Lanes, Colorado • High Desert Corridor, California • I-595 Express Corridor Improvements Project, Florida • SR – 54 & 56 Toll Road Concession, Florida[b] • Atlanta BeltLine, Georgia[b] • Washington DC Streetcar PPP project, Washington, D.C.[b]
Multiple modes are naturally part of the project.	• Anton Anderson Memorial Tunnel, Alaska • Miami Intermodal Center, Florida • InterLink, Rhode Island • I-4 Ultimate P3 Project, Florida • SH 183 Managed Lanes Toll Concession, Texas • Chicago Region Environmental and Transportation Efficiency Program, Illinois
Use of multiple modes increases availability of financial resources.	• US 36 Express Lanes, Colorado • InterLink, Rhode Island • Atlanta BeltLine, Georgia[b] • I-595 Express Corridor Improvements Project, Florida • Katy Freeway Reconstruction, Texas[b]

[a] The table shows 15, rather than 23, projects because this information was not provided for 8 projects.

[b] The project was initially believed to be a P3; however, the interview, or communications after the interview, showed it was no longer a P3.

1. *The region's vision called for multiple modes.* For Anaheim Regional Transportation Intermodal Center, fixed guideway service in the 820-acre Platinum Triangle area had been part of city plans for two decades and would support existing mixed-use development. For I-75/575, future transit plans included express bus service on several Atlanta radial freeways. Further, the authors of two recent studies—one by the Greater Regional Transportation Authority and one by the Georgia DOT—also envisioned multiple modes, leading regional partners to identify locations that required both transit service and roadway improvements.

2. *The public favored multiple modes.* For two projects, this pressure appeared to begin with public participants making their voices heard through public officials. The High Desert Corridor interviewee noted the public was interested in green energy (using the right of way to transmit energy from solar sources and wind farms) and support for rail and bicycle modes; in particular, the public did not want to see such decisions made during a separate environmental analysis but rather wanted them to be an integral part of the project's definition. For the Atlanta BeltLine, demand for a bicycle lane and transit was evident from a survey of 4,500 people showing that almost 74% supported additional transit service. For four other projects, this pressure was evident through the actions of elected officials. For example, an executive order required that multiple modes, including transit, be considered within Colorado's P3 process; a draft policy, provided by the interviewee, shows this consideration for managed lanes projects. Staff with the Washington, D.C., streetcar project noted that a policy decision is made regarding inclusion of multiple modes before finances are discussed; this is consistent with Florida's I-595 Express Corridor, where bus service was included because it was desired by the county (Broward) where the improvements were made. For the SR – 54 & 56 Toll Road Concession (Florida), interviewees noted that although multimodalism was not the main component of the P3 proposal, this aspect was of interest to the county, the metropolitan planning organization, and the Florida DOT.

3. *They were fundamental to the project.* The Miami Intermodal Center grew from a need to link disparate transportation services—train, taxi, rental car, and bus—to reduce congestion at Miami International Airport. The InterLink—which enables Rhode Island's T.F. Green

Airport to serve as a reliever to Massachusetts' Boston Logan International Airport—accommodates a street-level bus stop, a bus layover facility, commuter rail, rental cars, and a moving skywalk. Alaska's Anton Anderson Memorial Tunnel already provided rail service, but highway service was needed in response to federal rules that limited rail's ability to move vehicles. The I-4 Ultimate P3 Project and the SH 183 Managed Lanes Toll Concession were sought to provide an uncongested transit alternative.

4. *The P3 structure allowed for financing that would otherwise not have occurred.* An additional fee placed on car rental customers will pay the InterLink project bond. For US 36 (Colorado) and the BeltLine (Georgia), transit is subsidized through different mechanisms. For US 36, the transit operator was the beneficiary of a tax increase enabling bus rapid transit service as part of a managed lanes project. For the Atlanta BeltLine, interviewees noted that pursuit of the P3 enabled consideration of more expansive transit service rather than acquiring service for "absolutely the least amount of money," which could be the case for projects relying solely on federal sources. Florida's I-595 interviewee noted that consideration of multiple modes may depend on how payment is structured: rather than a true toll where the private sector takes the risk, the state makes an availability payment that does not vary with traffic. An implication is that use of alternative modes will not reduce the amount of money received by the private sector, yet the public sector benefits from up-front financing provided by the private entity. Although not a P3, cost sharing by the transit provider and the toll road authority was a reason for interest in multiple modes for the Katy Freeway Reconstruction (Texas).

3.4.3 Milestones Used to Determine Whether Multimodal Components Should Be Included

No interviewee noted the existence of a decision point specific to the P3 project development process where multiple modes were formally considered. The two reasons were that (1) milestones cannot be used until the project is well defined, and (2) project conditions are evolving such that milestones are not appropriate. Both reasons lead to multimodal inclusion being decided on an ad hoc basis. Illustrating the first reason, interviewees affiliated with the Anton Anderson Memorial Tunnel and the High Desert Corridor explained that the inclusion or exclusion of such modes defined the project. As examples of the second reason, InterLink interviewees noted that the most important factor (in terms of deciding whether to include or exclude modes), was the interdependent interests of stakeholders; for instance, the decision to involve multiple modes resulted, in part, when the airport, nine rental car companies, a commuter rail system, and the local mayor realized that there could be joint benefits to developing a corridor linking an existing airport and train station. A related example was from the City of Anaheim (California): until more experience with P3 projects are obtained, the decision will be governed by the "current economy, policy, and funding"—all of which can change rapidly. Not surprisingly, several P3 projects in Table III-5 are in the top two rows.

TABLE III-5. Reasons for Not Having Milestones for Consideration of Multiple Modes in P3 Projects[a]

Reason	Example Projects
Milestones cannot be used until the project is well defined.	• Anton Anderson Memorial Tunnel, Alaska • High Desert Corridor, California
Milestones are not used because project conditions are evolving.	• I-4 Ultimate P3 Project, Florida • Atlanta Downtown Multi-Modal Passenger Terminal, Georgia • Anaheim Regional Transportation Intermodal Center, California[b] • InterLink, Rhode Island • Atlanta BeltLine, Georgia[b]

Milestones are not needed because other processes are in place.	• Northwest I-75/575 HOV/BRT, Georgia • I-595 Express Corridor Improvements Project, Florida • Miami Intermodal Center, Florida • Chicago Region Environmental and Transportation Efficiency Program, Illinois • FasTracks, Colorado • Katy Freeway Construction, Texas[b]
Formal milestones for P3 projects are being considered.	• I-70 Mountain Corridor, Colorado[b] • US 36 Express Lanes, Colorado

[a] The table shows 15, rather than 23 projects as for 8 projects the interview did not indicate an answer regarding the use of milestones.

[b] This project was initially believed to be a P3; however, the interview, or communications after the interview, showed it is no longer a P3. The Katy Freeway Construction interviewee noted that project milestones exist but not for the consideration of multiple modes.

Interviews for five projects noted that additional P3-specific milestones are unnecessary because the alternatives analysis phase within the environmental process already considers multiple modes: I-75/575, FasTracks, and Chicago Region Environmental and Transportation Efficiency Program staff noted the federal National Environmental Policy Act (NEPA) process, and Florida's I-595 and Miami Intermodal Center staff noted the state environmental component; both processes would, for a given location, consider a variety of alternatives. Florida's I-595 staff further noted the role of local support in deciding whether to include multiple modes, which is part of the environmental review process. Colorado FasTracks staff noted that because they served as a public transportation provider, the decision as to whether multiple modes should be included was made before the project was given to their agency.

However, staff of two Colorado projects (I-70 Mountain Corridor and US 36 Express Lanes) are considering the development of a policy with specific project development milestones for the inclusion or exclusion of alternative modes. At the time of the interviews, the plan was to consider multimodal alternatives—including transit—for each project and to have surplus toll revenue be applied toward transit or other forms of multimodal transportation.

3.4.4 Expected Land Development Impacts

Of 18 projects for which information on expected land development impacts was available, the type of expected impact varied in terms of specificity: no impact (3 projects); more intense development in a specific location identifiable on a map or otherwise quantifiable (5 projects); more intense development but not in a specific location per se (8 projects); and some type of value capture (2 projects). Table III-6 represents anticipated impacts: actual impacts will not be known until after the projects are completed.

TABLE III-6. Expected Land Development Impacts[a]

Type of Land Development Impact	Example Projects
None: no land impact is expected (e.g., the project is an already developed area)	• SH 183 Managed Lanes Toll Concession, Texas • I-595 Express Corridor Improvements Project, Florida • I-4 Ultimate P3 Project, Florida
Specific: more intense development in a well-defined location (e.g., 20 million square feet of commercial development)	• US 36 Express Lanes, Colorado (Transit-Oriented Development) • Miami Intermodal Center, Florida (Joint Development) • InterLink, Rhode Island[b] • SR – 54 & 56 Toll Road Concession, Florida (Transit-Oriented Development)[c] • Atlanta BeltLine, Georgia (Transit-Oriented Development)[b,c]
General: more intense development in an amorphous location (e.g., near new access points for a given freeway)	• Northwest I-75/575 HOV/BRT, Georgia • High Desert Corridor, California • Washington DC Streetcar PPP project, Washington, D.C.[c] • Katy Freeway Reconstruction, Texas[c]

	• Anaheim Regional Transportation Intermodal Center, California[c] • Anton Anderson Memorial Tunnel, Alaska • Maryland Light Rail Purple Line P3, Maryland • Chicago Region Environmental and Transportation Efficiency Program, Illinois
Value capture (e.g., land near the facility is sold to developers)	• FasTracks, Colorado • Atlanta Downtown Multi-Modal Passenger Terminal, Georgia

[a] The table shows 18 rather than 23 projects because information on expected land impacts was not available for 5 projects.

[b] The fact that transit-oriented development is an expected impact for this project was obtained from planning documents (City Centre Warwick, 2015; Atlanta BeltLine, Inc., 2010)

[c] This project was initially believed to be a P3; however, the interview, or communications after the interview, showed it was no longer a P3.

There were three cases where specific land development impacts were not expected. Florida's I-4 Ultimate P3 Project is in an established corridor with urban development already adjacent to the facility: although it should reduce congestion, the corridor has been in place for the past 30 years. The I-595 Express Corridor Improvements Project had a similar rationale: when the highway first opened in 1989, it influenced land development but additional land use impacts were not expected. Interviewees associated with the I-4 Ultimate P3 project noted that a separate companion project, a commuter rail line, might indeed influence land development near the stations. Consistent with the literature (Meyer and Miller, 2013), such projects illustrate the view that incremental capacity improvements have a lesser land use impact than improvements that provide brand new access.

One land impact is more intense development at a specific location. The Miami Intermodal Center is expected to attract retail and hotels near the facility, and the land is zoned for mixed use; another Florida project (SR – 54 & 56 Toll Road Concession) is expected to help support 15 large-scale developments that have been approved but not built. The InterLink (Rhode Island) supports a transit-oriented development; interviewees reported that the master plan includes a rezoning and the elimination of setbacks, and examination of the master plan shows up to 2 million square feet of additional development centered on the InterLink (City Centre Warwick, 2015). Atlanta BeltLine interviewees cited examples of investment (e.g., almost $2.7 billion of development occurring near the facility), with the various subarea plans (e.g., Atlanta BeltLine, Inc., 2010) showing locations of high-intensity development near transit stops.

For some projects, land development impacts were defined as additional land development, but these impacts were not necessarily quantified. For the High Desert Corridor project, population growth—and additional economic development—is expected at both ends of the corridor (where stations will be situated) and near highway ramps. Because I-75/575 is a retrofit, growth is expected at the new access points where the facility connects with local arterials. For the Anaheim Regional Transportation Intermodal Center, staff noted that investors have periodically expressed interest in development opportunities; however, there has not been a formal solicitation for interest since the initial request for expressions of interest (after which the city could not find one entity willing to serve as a master developer). The Chicago Region Environmental and Transportation Efficiency Program does not expect direct land use impacts (e.g., transit oriented development), however, the investments in rail and interchange capacity should stimulate two types of commercial growth: logistics industry employment (given Chicago's role as a rail hub), and land development in the suburbs and the central business district (given the better connections provided by faster commuter rail service).

Two projects suggested some form of value capture where the facility will increase the worth of adjacent land, which may help finance the facility's operation or construction. For FasTracks, the increased real estate values near the facility will help pay back the federal loans: a TIFIA program loan and a railroad rehabilitation and improvement financing loan; they, along with land sales, account for 70% of the project cost (Nichols, 2012). For another potential P3 project (Atlanta Downtown Multi-Modal Passenger Terminal), staff noted the possibilities of additional land development and air rights. For example, this project could result in the development of 4 acres of green space above the center, including 12 million square feet of retail, office, and residential development.

These projects suggest that even if a project is not defined as a P3 per se, there can be utility in examining how the project may influence land development and using that analysis as a way of providing financing for the project. For example, although the possibility of pursuing the Atlanta BeltLine Project as a P3 was raised but not resolved, this uncertainty did not prevent the project from benefitting from a form of value capture: tax increment financing, which accounts for about a third of the expected revenue (Atlanta BeltLine Inc., 2013). In this case, a roughly 10 square mile "tax allocation district" was established, with increases in property taxes above the amount collected in 2005, for a 25 year period being used to fund Atlanta BeltLine Projects (Atlanta BeltLine Inc., 2013). (In reference to Atlanta but not explicitly the BeltLine per se, DeLoach [2013] noted that tax allocation districts also have the advantage of being useful at sites with "persistent" problems such as environmental remediation.)

3.5 Conclusions

Clearly, the conditions supporting a multimodal P3 are diverse. Although some multimodal P3s comprise the implementation of a region's long-term vision, others resulted from public pressure, a unique opportunity to bring together stakeholders to create a project that was otherwise infeasible or to solve a specific problem (notably the Anton Anderson Memorial Tunnel in Alaska). The consolidation of rental car companies (e.g., InterLink and the Miami Intermodal Center) was a fundamentally different partnership than the proposed Florida SR – 54 & 56 Toll Road Concession (where private financing is used for what has traditionally been a public sector operation.) In that sense, one might argue that the interviews merely confirmed a suspicion that, after all, every project is unique. There are, however, five themes that are perhaps more germane to the process for using multimodal P3 projects—and knowledge of this process can help stakeholders be aware of how P3 decisions are made.

- *The process is iterative.* While this is true of transportation project decisions generally, it is not unusual for a project's status to change from P3 to non-P3. This transition occurred for roughly two-fifths of the projects studied: (e.g., 10 of the 23 projects for which interviews were conducted were found not to be P3s and of the initial list of 35 candidate projects, 16 were found not to be P3s). Reasons for transitioning to non-P3 status include a lack of financial viability, negative public reaction, an unanticipated conflict with state statutes, and potential design conflicts; in addition, some of the projects may never have been a P3.

- *Milestones for considering multiple modes in P3s are not generally used.* In concert with the first conclusion, this was not surprising. For the 15 projects, where data were available, specific milestones did not exist for including or excluding multiple modes. Interviewees pointed out that such decisions are part of the environmental review process (6 projects) and that conditions are so fluid that milestones are infeasible (7 projects); however, for 2 projects, formal policies for considering multiple modes in P3s are under consideration.

- *P3 projects have diverse emphasis areas.* At first glance, a key factor might appear to be acquisition of private financing, which was cited as the motivating factor for most (10 of 13) projects pursued as a P3. However, additional factors included improved transit service quality (e.g., FasTracks may reduce payment by up to 25% if performance standards are not met), the use of alternative energy (e.g., right of way for solar and wind energy transmission for the High Desert Corridor project), and speed of construction.

- *In the process of evaluating P3s, land development impacts were considered in most (at least 18 of 23) of the projects, but the level of specificity varied by project.* Although staff expected 3 projects to have no identifiable land use impacts, for 5 projects more intense development was expected in a specific location, and for 2 additional projects, some form of value capture from the increase in land value was anticipated. For an additional 8 projects, land development impacts were not attributed to an exact location but are anticipated—for example, for the Chicago

Region Environmental and Transportation Efficiency Program, the rail switching impacts are expected to facilitate additional development in the central business district as well as support the logistics industry.

- *The process includes different allocations of risk—and risk is explicitly considered.* Contrary to the traditional view of a P3 in which the private sector assumes the risk (Dochia and Parker, 2009), several interviewees (I-595, I-4, and FasTracks) noted the use of availability payments, as defined by OIPD (2010), that are made to the concessionaire regardless of demand. In the case of the Miami Intermodal Center, the initial loan was taken by the Florida DOT rather than the concessionaire. Another form of "risk" is public perception (as noted for Florida's SR 54/56 project).

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CHAPTER IV EXPLORING URBAN FORM IMPACTS IN MULTIMODAL PUBLIC-PRIVATE PARTNERSHIPS WITH A NEW SPATIAL DISSIMILARITY INDEX

4.1 Introduction

A wealth of studies have been conducted on the relationship between urban form and transportation (e.g., Cervero and Landis, 1997; Miller and Ibrahim, 1998; Hanson and Giuliano, 2004). An issue that has yet to be comprehensively explored, however, is that multimodal public-private partnerships (P3s) exert land development effects that differ from those of transportation projects characterized by only single mode and public sector involvement. For example, many P3 projects have used some types of tolling system as a means of financially supporting the initiatives. With such a system, P3s influence urban form or land use in a way that varies from the effects posed by non-P3 facilities. For example, a toll system increases the accessibility of certain areas but only to users who are willing and able to pay toll fees. Thia and Ford (2009) point to *"a positive correlation between higher levels of collaboration and higher levels of economic benefits to the community when P3s are used in the development of infrastructure projects"*. This finding supports the contrasting economic effects of P3s and non-P3s on localities undergoing land development, which is one type of urban form. This difference is attributed to the fact that P3s are a collaboration between private and public sectors. Perceived travel impedance—the apparent difficulty experienced during travel—may also differ under multi- and single-mode P3s because of the potential of the latter to facilitate the integration of a variety of transportation modes, such as bus rapid transit, light rapid transit, and bicycles. This difference also contributes to the variances in urban form effects between multimodal and single-mode P3s.

Some of the effects of P3s, and transportation investments in general, on urban form are as follows: they may cause the expansion or concentration of a given area, stimulate development in a new locality, change travel patterns, and increase the feasibility of industry activities. One particular type of impact that P3s may affect is the balance between employment and housing, which is the focus of this research. Jobs–housing balance is defined as *"an equivalence in the number of an area's jobs and the number of the area's residents seeking those jobs"* (Miller, 2010). This concept has been regarded as a way of describing how urban form may be altered in certain states (e.g., Frank, 1994; Klim and Bilse, 1999). Jobs–housing balance enables the identification of locations that require transportation services that effectively or efficiently connect residents to employment sites. Improved jobs–housing balance (or proximity) produces various activity-related changes that affect urban form; examples of such changes include better accessibility for commuters, increased options for housing, and wider spread of diverse economic groups. Because of these changes, jobs–housing balance can be used as basis in identifying the urban form effects of P3s.

4.2 Purpose and Scope

This research aims to empirically explore the effects of changes in multimodal P3s on urban form (i.e., jobs–housing balance). This analysis is motivated by its potential as an avenue through which researchers and practitioners can capture the particular land development that occur in multimodal P3 localities or through which appropriate plans can be formulated to promote the incorporation of multimodal components in P3 projects. To identify impacts by multimodal P3s, performance measures that can quantify, on some type of scale, the reduced travel impedance resulting from new transportation facilities are necessary. To these ends, this research pursues three objectives:

1. Develop a new spatial dissimilarity-based index for scaling jobs–housing balance.

2. Validate and calibrate the proposed index.

3. Identify the effects of a multimodal P3 projects on urban form scaled on the basis of jobs–housing balance.

This research does not provide insight into causality but focuses on the association between urban form and multimodal P3s.

4.3 Literature Review

4.3.1 Effects of Jobs–Housing Balance on Transportation

Urban form may be described as encompassing the spatial characteristics of an urban environment, and jobs–housing balance is one of the indicators used to measure the effects of urban form (Frank, 1994). This indicator has gained steady interest from researchers because a well-balanced mix of workplaces and houses within communities may facilitate the reduction of commuting time (e.g., Cervero, 1989; Horner and Marion, 2009). In some cases, jobs–housing balance has been used for transportation management in the U.S. Los Angeles County, for instance, adopted this indicator in its proposal for improved transit services (Singa et al., 2004). In the long-term, jobs–housing balance relates to regional planning. The local government of Puget Sound in Washington proposed to increase housing in job-rich areas in its Vision 2040 initiative (Puget Sound Regional Council, 2009). In Virginia, the Code of Virginia (§ 33.1–23.03) indicates that jobs–housing balance can serve as a quantifiable measure and achievable goal in the Statewide Transportation Plan that considers at least a 20-year planning horizon (Miller, 2010).

Numerous studies have been directed toward the relationship between jobs–housing balance and transportation, with researchers particularly focusing on changes in travel behavior, such as commuting distance or time. On the basis of the 1990 Nationwide Personal Transportation Survey, Bento et al. (2003) concluded that a discrepancy between employment and housing (i.e., 10% difference) causes a 114-mile increase in jobs–housing imbalance per household annually. Cervero and Duncan (2006) indicated that every 10% increase in jobs within 4 miles of residence causes a 3.29% decrease in daily work travel distance (miles) and a 3.38% decrease in daily work trip duration (hours). Frank (1994) revealed that in Puget Sound, balanced census tracts with a jobs–housing ratio of 0.8–1.2 results in a work trip distance that is 28% lower (6.87 miles) than that observed in localities with unbalanced census tracts (9.59 miles). Although controversy remains as to the positive effects of jobs–housing balance on commuting distance or time (e.g., Giuliano, 1991; Miller and Ibrahim, 1998), researchers have continued to extensively use jobs–housing balance in investigations of the urban form changes caused by transportation systems.

4.3.2 Methods for Measuring Jobs–Housing Balance

Scholars have put forward a number of methods for measuring jobs–housing balance, the simplest of which is the direct ratio approach. Considerable research has employed the jobs-to-housing ratio (e.g., Giuliano, 1991; California Planning Roundtable, 2008), but various definitions (data sources) have been used to illustrate the concepts of "job" (e.g., wage/salary employment only or total employment) and "housing" (e.g., total housing, total population, occupied housing, or employed population) depending on data availability or research focus (Miller, 2010). Miller (2010) empirically demonstrated that these ratios (jobs/total housing, jobs/household, jobs/labor force, jobs/population) are highly correlated at the jurisdiction level.

A simple ratio analysis presents difficulties in terms of capturing *"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). To resolve this issue, researchers have used the dissimilarity index, which was originally intended as a measure of spatial segregation between two groups (Massey and Denton, 1988). In approaches that feature jobs–housing balance, this index has been used to calculate the proportion of employment and population within subareas in relation to total area employment and population; the end result was the percentage of an area's population (or employment) that should be moved to employment (or residential) sites to enable identical distribution (Miller, 2010; 2011). Charron (2007) and Horner and Marion (2009) argued that despite the ease of interpretation offered by the dissimilarity index, it could possibly provide unreasonable results because it cannot capture potential spatial interactions among population groups. Such interactions inherently occur in many areas where residence is located close to places of employment. Another alternative is the exponential dissimilarity index, which employs the exponential decay term and accounts for the intrinsic effects of adjacent jobs- and population-rich zones (Horner and Marion, 2009; Miller, 2010). Nevertheless, although the exponential dissimilarity index facilitates satisfactory intraurban analyses that consider potential spatial interactions, it assumes that the level of potential interaction (also described as the deterrence or decay function) among zones will follow the exponential function. Previous evidences have indicated that various distribution patterns (i.e., power, exponential, or gamma) can describe the observed trip length distribution between origins and destinations (e.g., Hyman, 1969; Shrewsbury, 2012). The National Cooperative Highway Research Program (1998, 2012) also reported that the gamma distribution strongly replicated observed trip length distribution. Given these considerations, an endeavor worth pursuing is determining which function most effectively represents actual trip length distributions. For the future use in analyzing urban form, ascertaining this function enables the formulation of a new spatial dissimilarity index for jobs–housing balance.

4.4 Methodology

4.4.1 Gamma Distribution-based Dissimilarity Index

As previously stated, this research probes into the effects of multimodal P3 projects on urban form. A dissimilarity index with a specific decay term is needed to scale jobs–housing balance. Among the power, exponential, and gamma distributions, the first was disregarded in this work because of its limitations in elaborating intrazonal trips or short-distance travels (When trip cost approaches zero, the function increases to infinity.).

Six multimodal P3 project sites (Table IV-1) were selected to validate the two remaining distributions. The impact boundary was set to 13 miles, determined on the basis of the average commute distance in the U.S. (Federal Highway Administration, 2014; Kneebone and Holmes, 2015). The 2014 Public Use Microdata Sample (PUMS) from the American Community Survey (ACS) was used to derive the observed work travel time in the zone pairs of Public Use Microdata Areas (PUMA). A total of 48,673 observations (out of 650,793 observations) were selected for all the feasible transportation modes in the six selected sites.

TABLE IV-1. Details of Six Sites

Site Name[a]	Number of Selected PUMAs (Zones)	Average Travel Time (Minutes)	Number of Selected Observations
Denver Union Station, Colorado	14	32.3	8,323
I-495 Express Lanes, Virginia	22	39.6	15,060
I-595 Express Corridor, Florida	16	36.8	7,808
InterLink, Rhode Island	3	30.5	1,722
Miami Intermodal Center, Florida	19	31.4	7,799
US 36 Express Lanes, Colorado	13	30.3	7,961

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

Figure IV-1 shows density of observed travel time (2014 PUMS ACS) and fitted gamma and exponential distributions by using Maximum Likelihood Estimation (MLE) in six sites.

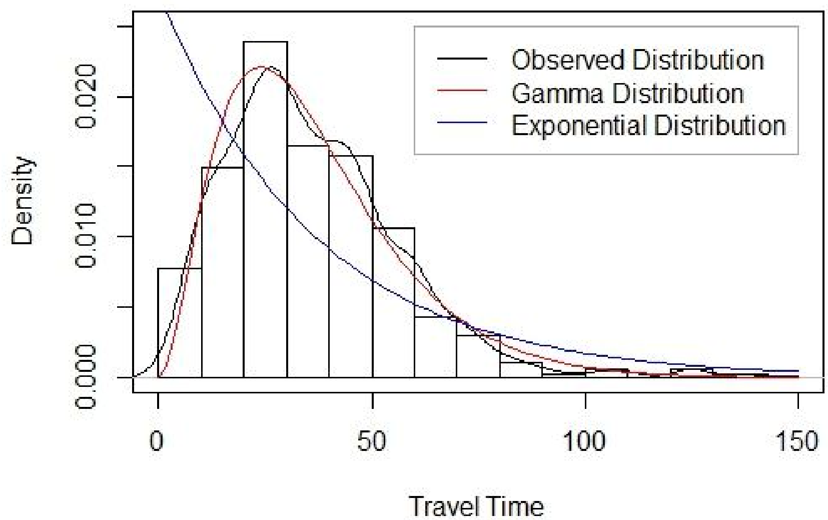

FIGURE IV-1. Graphical result of observed, gamma and exponential distributions based on the six study sites

In addition to graphical observation which supports observed travel time would follow the gamma distribution, one-sample Kolmogorov-Smirnov test was conducted to make a solid statistical conclusion. The one-sample Kolmogorov-Smirnov test is a useful nonparametric method to determine whether a sample distribution differs statistically from theoretical expectations (Lehmann, 2006). A test comparing the observed distribution with the gamma distribution showed a high *p-value* (0.31) which cannot reject the null hypothesis that the two distributions are identical (given that a p-value of 0.05 would be required for such a rejection). However, conducting the same test comparing the observed distribution with the exponential distribution yielded a low *p-value* (<<0.01), which can reject the null hypothesis, that the two distributions are different.

To further compare the goodness of fit of the exponential and gamma distribution with the observed data, the Pearson's correlation coefficient was obtained, based on comparing the probability density function where observations are placed in 10-minute bins. The best fit parameters for each distribution were used, which for the gamma distribution were 2.92 (shape parameter) and 0.08 (rate parameter), and for exponential distribution was 0.03 (rate parameter). The Pearson's correlation coefficient was 0.98 (observed distribution and gamma distribution) and 0.69 (observed distribution and exponential distribution). Consequently, the gamma distribution better reflects the observed distribution of travel time, as reflected in Figure IV-2. For example, a perfect dataset would show all points fitting along a diagonal (the Pearson's correlation coefficient equals 1); Figure IV-2 suggests that the gamma distribution [top row, middle column] has a better fit than the exponential distribution [top row, right column] with observed distribution.

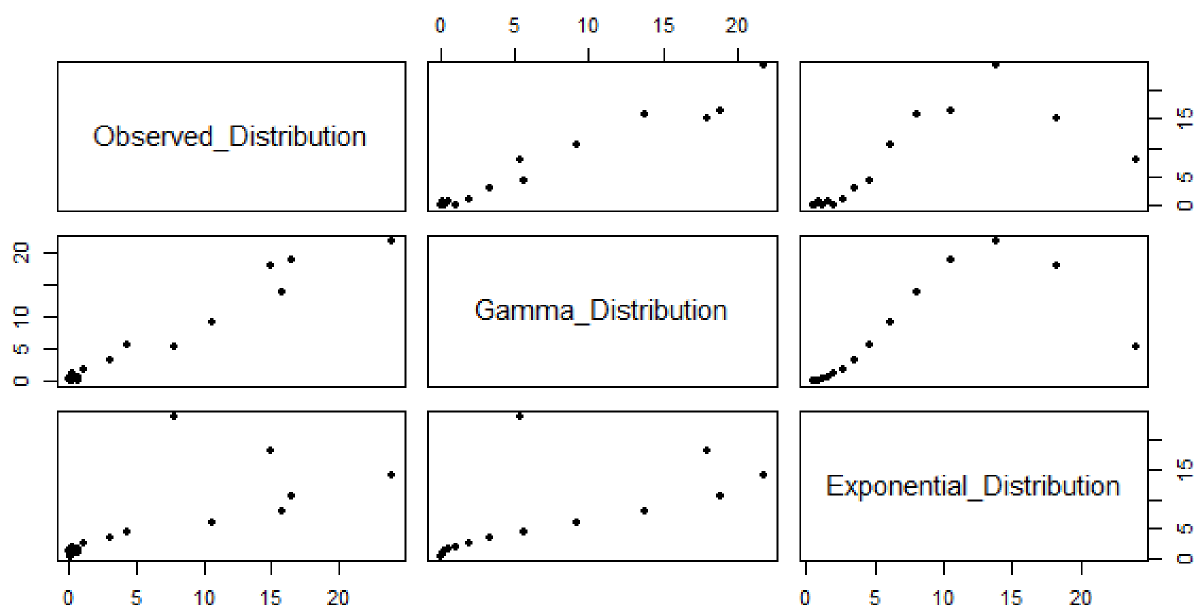

FIGURE IV-2. Scatterplot of observed, gamma and exponential distributions based on the six study sites

Accessibility is defined as "potential opportunity for interaction" in a certain zone to the population (P_j) of interest located in each zone (Horner and Marion, 2009) (see Equation 2). The function ($f(d_{ij})$), denoted as deterrence or decay function, indicates the level of contribution from each zone (Handy and Niemeier, 1997; Hansen, 1959). The form of the gamma distribution (shape-scale parametrization, Equation 1) is incorporated into this function. In theory, Equation (2) enables one to compute a single accessibility measure for a single zone i, given that there are m zones, each with a population of interest (P_j) and an impedance from zone i (d_{ij}).

$$X \sim \Gamma(\alpha, \theta) \equiv \mathrm{Gamma}(\alpha, \theta)$$
$$f(x; \alpha, \theta) = \frac{1}{\theta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\theta}} \text{ for } x > 0 \text{ and } \alpha, \theta > 0 \tag{1}$$

$$Accessibility = \sum_{j=1}^{m} P_j f(d_{ij}) = \sum_{j=1}^{m} P_j {d_{ij}}^{\alpha-1} e^{-\frac{d_{ij}}{\theta}} \tag{2}$$

where,

α = shape parameter

θ = scale parameter $\left(= \frac{1}{\mathrm{rate}(\beta)}\right)$

$\Gamma(\alpha)$ = gamma function evaluated at α.

i, j = specific geography level around a given project

P_j = population in zone j

d_{ij} = travel impedance between zone i and j

This accessibility form is incorporated into the dissimilarity index such that potential opportunity for interaction (accessibility) of each zone and spatial interaction among zones can be accounted for. Recall that Equation (2) enabled the computation of accessibility for a single zone i. Horner and Marion (2009) gives an equation that that replaces the population term (P_j) with worker (g_j) and job (h_j) as shown in Equation (3).

$$D_e = 0.5 \sum_{i=1}^{n} \left| \frac{\sum_{j=1}^{m} g_j exp(-\beta d_{ij})}{\sum_{i=1}^{n} \sum_{j=1}^{m} g_j exp(-\beta d_{ij})} - \frac{\sum_{j=1}^{m} h_j exp(-\beta d_{ij})}{\sum_{i=1}^{n} \sum_{j=1}^{m} h_j exp(-\beta d_{ij})} \right| \qquad (3)$$

where,

g_i, g_j = worker in zone i, j

h_i, h_j = job in zone i, j

β = parameter of exponential function

However, Equation (3) is based on an exponential distribution. Equation (4) is a new proposed dissimilarity index, named "gamma dissimilarity index", based on the gamma distribution. As a travel impedance term, the composite impedance function, comprised of the average actual travel time for each mode, is used. This composite impedance function considers the multimodal component; in contrast to this, previous studies have assumed impedance was direct travel cost, travel time, or straight-line distance (e.g., Allen and Mudge, 1974; Gatzlaff and Smith, 1993).

$$Gamma\ Dissimilarity\ Index\ (GDI) = 0.5 \sum_{i=1}^{n} \left| \frac{\sum_{j=1}^{m} w_j ({c_{ij}}^{\alpha-1} e^{-\frac{d_{ij}}{\theta}})}{\sum_{i=1}^{n} \sum_{j=1}^{m} w_j ({c_{ij}}^{\alpha-1} e^{-\frac{d_{ij}}{\theta}})} - \frac{\sum_{j=1}^{m} h_j ({c_{ij}}^{\alpha-1} e^{-\frac{d_{ij}}{\theta}})}{\sum_{i=1}^{n} \sum_{j=1}^{m} h_j ({c_{ij}}^{\alpha-1} e^{-\frac{d_{ij}}{\theta}})} \right| \qquad (4)$$

where,

w_i, w_j = employment in zone i, j

h_i, h_j = population in zone i, j

α = shape parameter

θ = scale parameter $\left(= \frac{1}{\mathrm{rate}(\beta)}\right)$

c_{ij} = composite impedance function between zone i and j

The preceding material suggests that Equation (4) is preferable because the impedance term replicates the distribution of observed travel time to work. Note, however, that this index encompasses the previous exponential dissimilarity index and the linear dissimilarity index. First, if $X \sim \Gamma(1, \beta)$ (shape-rate parametrization), then X has an exponential distribution with rate parameter β. That is, setting α = 1 enables the gamma dissimilarity index to replicate the exponential-based dissimilarity index (D_e). Second, if two conditions are met: (1) parameter β increases sufficiently such that there is no interaction among zones and (2) intrazonal travel impedance is so small so that there is no difficulty traveling within a zone, the gamma dissimilarity index collapses to the linear dissimilarity index. Again, the scale of possible values for this index is a range from 0 to 1. In practice, however, there will be some difficulty of intrazonal travel; thus, the assumption for a linear dissimilarity index appear to be less realistic.

4.4.2 Calibration of Parameters by Fitting Gamma Distribution

For analyzing the changed jobs-housing balances before and after projects with this proposed index, the different shape (α) and rate (β) need to be calibrated. Maximum Likelihood Estimation (MLE) was employed to find the value of these parameters that maximizes the probability of explaining observed data. In theory, the likelihood function for a gamma distribution (Equation 1) is changed to the log-likelihood (Equation 5) where n is the number of observations and x_i is observation i.

$$logf(x;\alpha,\theta) = -n\log\Gamma(\alpha) - n\alpha\log\theta + (\alpha - 1)\sum_{i=1}\log x_i - \sum_{i=1}\frac{x_i}{\theta} \tag{5}$$

After taking the partial derivative with respect to θ (Equation 6), the maximum for scale term (θ) is easily found to be $\theta = \bar{x}/\alpha$.

$$\frac{\partial}{\partial\theta}logf(x;\alpha,\theta) = -n\frac{\alpha}{\theta} + \sum_{i=1}\frac{x_i}{\theta^2} = 0 \tag{6}$$

Substituting the scale term into the Equation (5), and taking its derivative with respect to α, one obtains Equation (7).

$$\frac{\partial}{\partial\alpha}logf\left(x;\alpha,\frac{\bar{x}}{\alpha}\right) = -n\frac{\Gamma'(\alpha)}{\Gamma(\alpha)} - n\log\frac{\bar{x}}{\alpha} + \sum_{i=1}\log x_i = 0 \tag{7}$$

Unlike the case with the exponential distribution, there is no closed-form solution for obtaining a values for α in Equation (7) and, by extension, the θ parameter shown in Equation (6). That is, because of the gamma function, one cannot establish a set of simultaneous equations based on Equation (7). In practice, however, just as Equation (4) is used (rather than theoretical Equations 1 and 2), theoretical Equations (6) and (7) are not used. Various software packages support to find values for α and θ by maximizing Equation (7). The numerical methods provided by the R program, which includes functions “fitdistr” and “optim”, were used in this research.

4.5 Application and Analysis of Urban Form Impacts

4.5.1 Basic Data Sources

To analyze urban form impacts by multimodal P3 projects, changes in jobs-housing balance, based on the gamma dissimilarity index (Equation 4) were computed at six study sites. While the year of construction for each project was different, necessitating different time periods for before and after data, each site had common data needs as shown in in Table IV-2.

TABLE IV-2. Summary of Necessary Datasets

Component	Data Type	Data Source
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

4.5.2 Changes in Jobs-Housing Balance

The analysis years are selected as 1-year before the construction and the most recent year after the construction. Initially, a 13-mile impact boundary (see Figure IV-3), based on the average commute distance in the U.S. (Federal Highway Administration, 2014; Kneebone and Holmes, 2015), was analyzed. Then, a 5-mile impact boundary was analyzed to determine how changing the impact boundary affects the results. PUMA-level areas were selected when their centroids were located within the 5-mile and 13-mile impact boundaries.

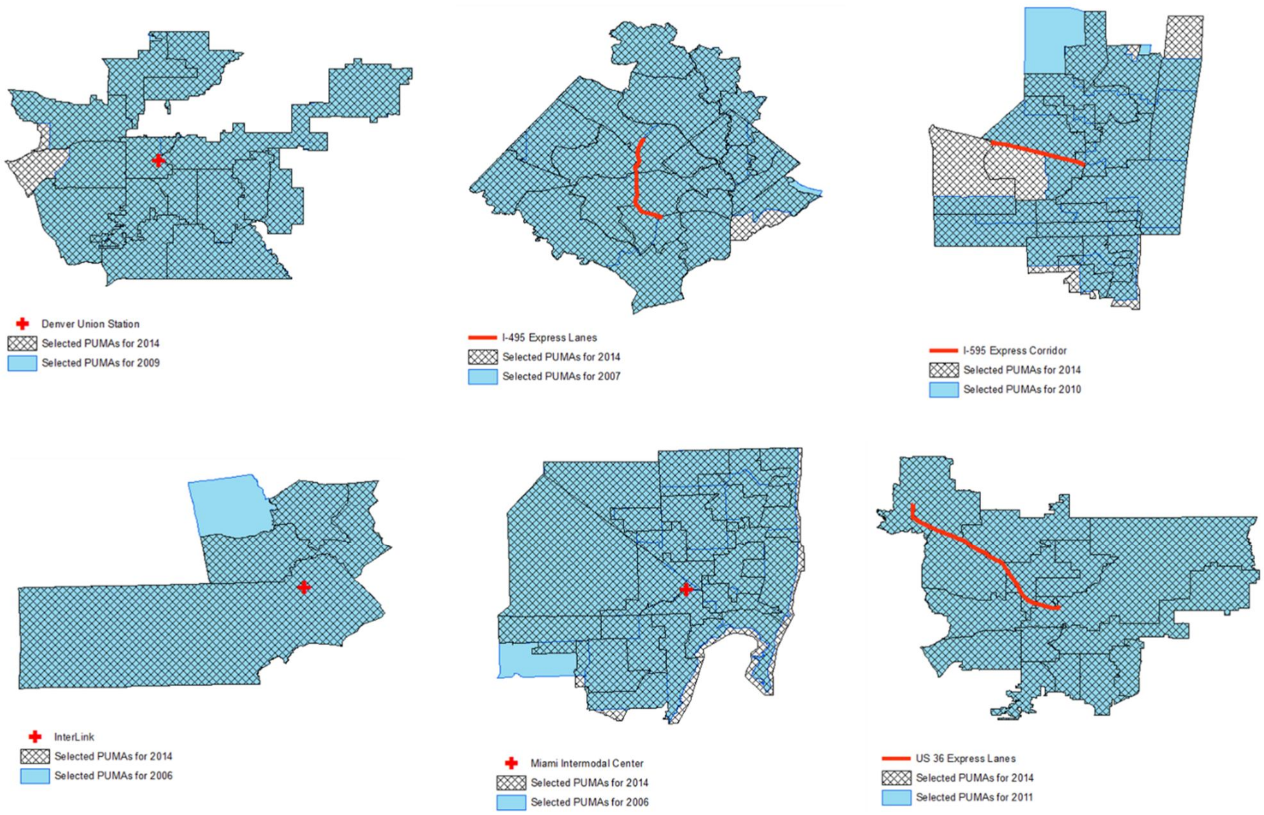

FIGURE IV-3. Selected PUMAs in 13- mile impact boundary of six sites

As the gamma dissimilarity index was incorporated here, each year's parameters (shape and rate) needed to be calibrated from each year's PUMS data sets. With one exception, there was not a statistically significant difference between the fitted gamma distribution and the observed ACS data set, based on the one-sample Kolmogorov-Smirnov test. The exception was the case of (I-495 in 2007 with 13-mile impact boundary), which showed a *p-value* of 0.04. However, the gamma distribution was retained in this case because the exponential distribution showed a lower *p-value* (<<0.01). Further, the Pearson's correlation between observed and predicted frequencies were 0.95 in 2007 and 0.97 in 2014 for the gamma distribution compared to 0.65 in 2007 and 0.57 in 2014 for the exponential distribution. In sum, the gamma distribution replicates observed results better than the exponential distribution.

TABLE IV-3. Number of Selected PUMAs and Calibration Results at the Six Study Sites

Site Name	Analysis Year	5-Mile Impact Boundary				13-Mile Impact Boundary			
		PUMA	Shape	Rate	*p-value*[a]	PUMA	Shape	Rate	*p-value*
Denver Union Station, Colorado	2009	2	2.636	0.092	0.9652	14	2.493	0.080	0.6703
	2014	2	4.137	0.163	0.6518	14	3.202	0.099	0.8137
I-495 Express Lanes, Virginia	2007	3	3.020	0.114	0.9889	17	2.894	0.073	0.0428
	2014	7	3.471	0.109	0.5667	22	3.522	0.089	0.0781
I-595 Express Corridor, Florida	2010	3	2.426	0.094	0.6601	14	1.855	0.052	0.6012
	2014	5	2.250	0.083	0.7447	16	2.270	0.062	0.6141
InterLink, Rhode Island	2006	N/A				3	3.527	0.171	0.9811
	2014	N/A				3	1.992	0.065	0.5507
Miami Intermodal Center, Florida	2006	3	4.181	0.133	0.8811	16	2.709	0.082	0.5940
	2014	5	2.588	0.080	0.9324	19	2.422	0.077	0.8039
US 36 Express Lanes, Colorado	2011	4	3.080	0.135	0.9268	13	3.599	0.126	0.7437
	2014	4	3.026	0.114	0.8242	13	2.917	0.096	0.8774

[a] A *p-value* greater than 0.05 means that based on the one-sample Kolmogorov-Smirnov test, there is not a statistically significant difference between the two distributions

To compare the linear dissimilarity index and gamma dissimilarity index, both indices were computed (see Table IV-4). Recall that because the gamma dissimilarity index considers intrazonal travel impedance to be nonzero and that interzonal interactions are possible, the results from the two indices would be identical if intrazonal travel had no impedance and interzonal travel had infinite impedance.

TABLE IV-4. Comparison of the Linear and Gamma Dissimilarity Indices at the Six Study Sites

Site Name	Analysis Year	5-Mile Impact Boundary		13-Mile Impact Boundary	
		Linear[a]	Gamma[b]	Linear	Gamma
Denver Union Station, Colorado	2009	0.0234	0.0016	0.0206	0.0003
	2014	0.0193	0.0011	0.0139	0.0001
	Change	-0.0041(-17.6%)	-0.0005(-32.5%)	-0.0066(-32.3%)	-0.0002(-67.1%)
I-495 Express Lanes, Virginia	2007	0.0128	0.0013	0.0328	0.0025
	2014	0.0300	0.0018	0.0352	0.0024
	Change	0.0172(134.5%)	0.0005(38.8%)	0.0024(7.4%)	-0.0002(-7.2%)
I-595 Express Corridor, Florida	2010	0.0179	0.0008	0.0290	0.0028
	2014	0.0190	0.0005	0.0262	0.0025
	Change	0.0011(6.3%)	-0.0004(-41.6%)	-0.0028(-9.5%)	-0.0003(-9.9%)
InterLink, Rhode Island	2006	N/A		0.0229	0.0040
	2014			0.0173	0.0015
	Change			-0.0057(-24.7%)	-0.0025(-62.8%)
Miami Intermodal Center, Florida	2006	0.0432	0.0019	0.0333	0.0003
	2014	0.0166	0.0005	0.0279	0.0002
	Change	-0.0266(-61.6%)	-0.0014(-73.0%)	-0.0054(-16.2%)	-0.0001(-43.2%)
US 36 Express Lanes, Colorado	2011	0.0143	0.0005	0.0220	0.0005
	2014	0.0172	0.0007	0.0158	0.0001
	Change	0.0029(20.2%)	0.0003(52.4%)	-0.0062(-28.3%)	-0.0003(-67.8%)

[a] LDI: Linear Dissimilarity Index
[b] GDI: Gamma Dissimilarity Index

Note that an index of 0 means perfect jobs-housing balance and that Table IV-4 presents 22 cases where the index changed over time: 10 cases with the 5-mile boundary (5 sites, each with LDI and GDI) and 12 cases with the 13-mile boundary (6 sites, each with LDI and GDI). Six of these 22 cases showed an increased index—that is, worsening jobs-housing balance: I-495

Express Lanes, VA (two with LDI and GDI in 5-mile boundary, one with LDI in 13-mile boundary), I-595 Express Corridor, FL (one with LDI in 5-mile boundary), and US 36 Express Lanes, CO (two with LDI and GDI in 5-mile boundary). Given that GDI considers potential spatial interactions and nonzero intrazonal impedances, a jobs-housing balance with GDI may be considered more reliable results. With the GDI, worsening jobs-housing balance was shown in 2 of the 11 cases: I-495 Express Lanes and US 36 Express Lanes, both with the 5-mile impact boundary. All sites showed better jobs-housing balance, based on the GDI, using the 13-mile impact boundary.

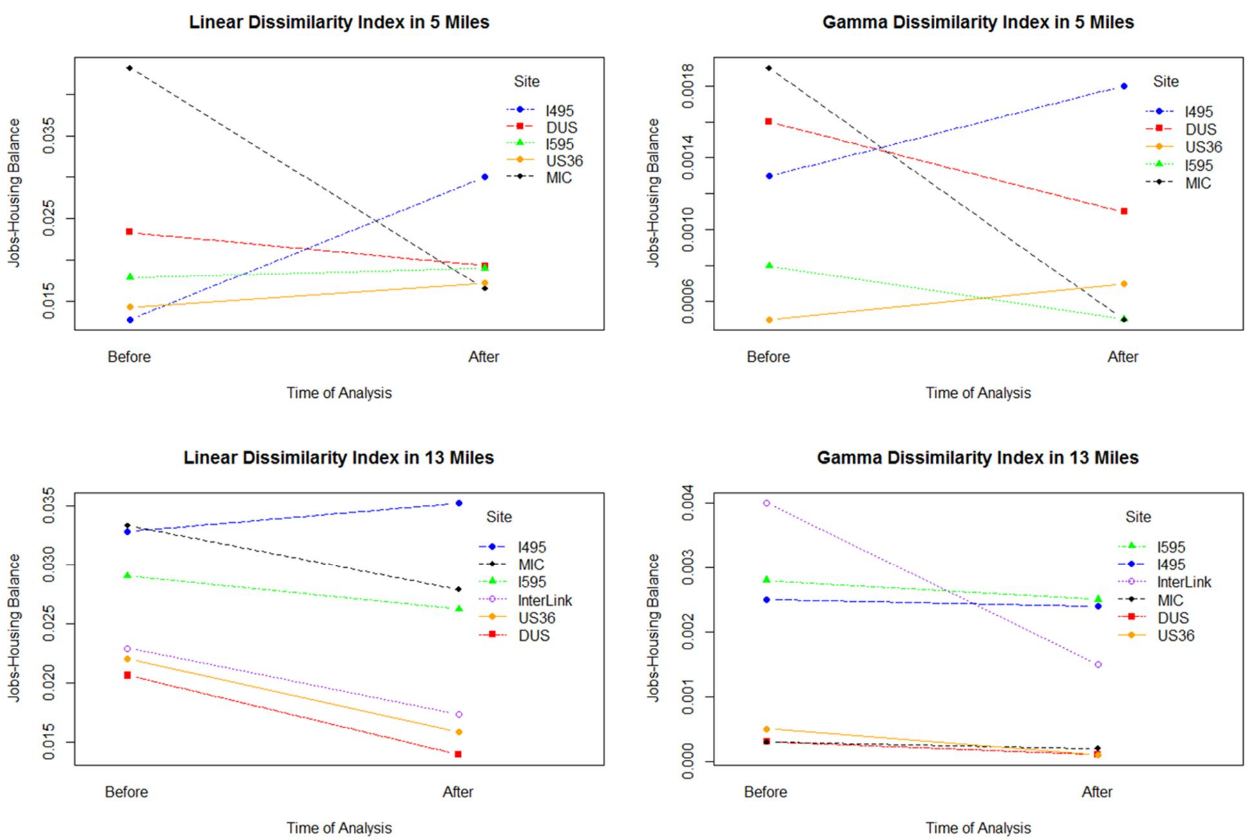

FIGURE IV-4. Before-after interaction plots of jobs-housing balance

Provided that the 13-mile impact boundary accurately represents the average commuting distance to work, only one case (I-495 Express Lanes) with LDI presented negative jobs-housing balance after the construction (see Figure IV-4 and IV-5).

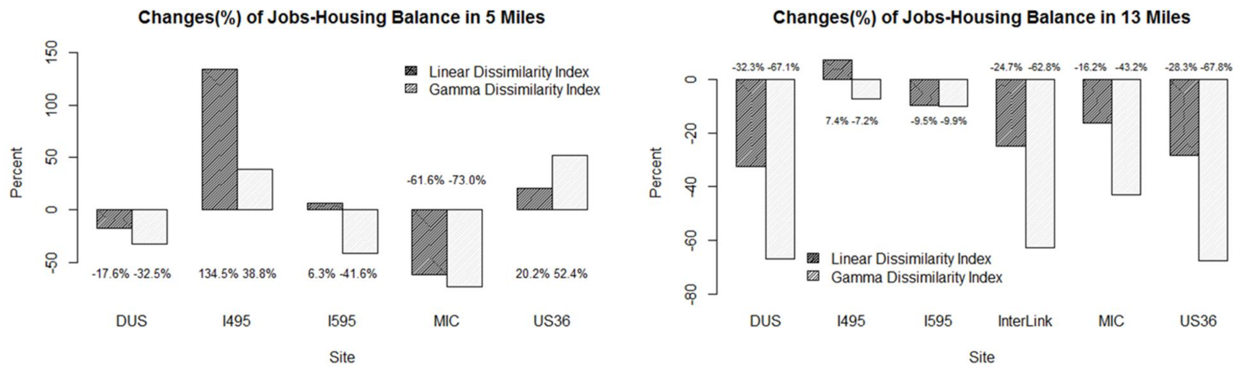

FIGURE IV-5. Comparing chart of changes (%) of jobs-housing balance in 5 and 13 miles

Generally, the LDI and GDI should be similar for smaller impact boundaries and dissimilar for larger impact boundaries. When the impact boundary is very small—such that only one zone can be included—there will be no zone-to-zone travel such that, except for the cost of intrazonal travel, the GDI and LDI are similar. For these six study sites, with the smaller 5-mile impact boundary, the LDI and GDI showed correlation coefficients of 0.95 (Pearson) and 1.00 (Spearman). For the larger 13-mile impact boundary, the correlation coefficients were 0.23 (Pearson) and 0.15 (Spearman). Within the smaller boundary, the interzonal interactions rarely affected commuting trips.

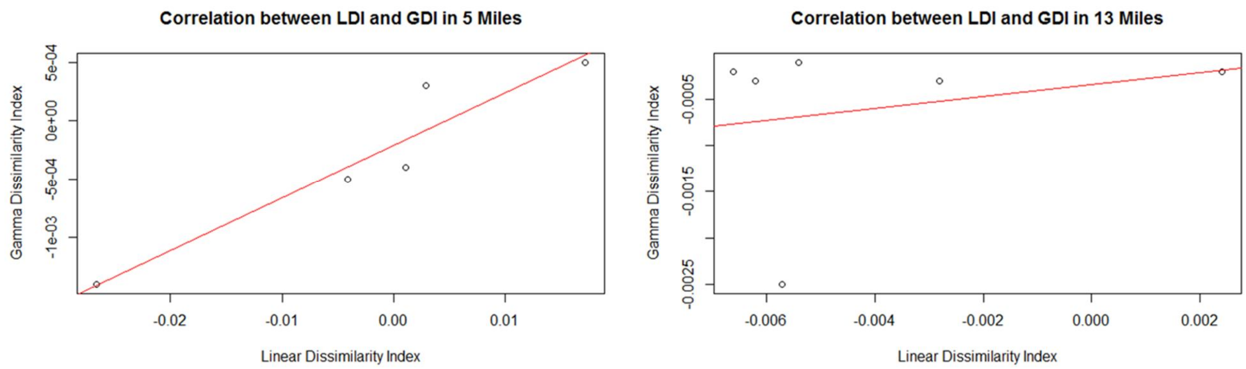

FIGURE IV-6. Correlation plots between LDI and GDI in 5 miles (5 sites) and 13 miles (6 sites)

Similarly, linear regression model with LDI and GDI in 5 miles showed high adjusted R-squared (0.87), while the model in 13 miles presented very low adjusted R-squared (-0.18) with insignificant *p-value* (0.66) of independent variable (LDI).

4.6 Conclusions

As one of the first empirical research efforts that considers urban form impacts on multimodal P3 projects, this research results in several significant contributions on both multimodal transportation and P3-related fields. The specific contributions include but are not limited to:

- A new gamma-based dissimilarity index was developed to scale jobs-housing balance. Based on the data from six sites, this index has a better goodness of fit to the observed trip length frequency distribution than the exponential distribution, and this difference in goodness of fit is statistically significant.

- As is the case with the exponential dissimilarity index, the gamma dissimilarity index does not have to assume intrazonal impedance is zero nor that interzonal impedance is infinite, making it useful for situations where these assumptions are not valid. The gamma dissimilarity index is a more generalized form that can be collapsed to the exponential dissimilarity index (when its shape parameter is set to 1) and a linear dissimilarity index (when its shape parameter is set to 1 and its scale parameter is sufficiently large).

- The scale of the gamma dissimilarity index ranges from a low of 0 (perfect balance) to a theoretical maximum of 1. However, the likely range of the gamma dissimilarity index based on these six studies is relatively small, with values ranging from a low of 0.0001 to a high of 0.0040. These results suggest that future work with the gamma dissimilarity index will need to carefully consider site-specific calibration in order for the index to be meaningful.

- Six multimodal P3 projects were selected to compute the changes of jobs-housing balance before and after the construction. Based on an average commuting distance to work of 13 miles and an impact boundary that is the same, the six multimodal P3 projects appeared to improve jobs-housing balance based on the gamma dissimilarity index.

Although incorporation of a multimodal component has been encouraged in various transportation projects, there is an explicit barrier to make it financially viable because of the perception that multiple modes cannot generate direct revenues. As empirically shown in this research, there are obvious positive contributions on urban form by multimodal P3 projects. Assuming that better jobs-housing balance could lead to less traffic congestion, and enhanced accessibility, the results shown by six multimodal P3 sites can bring instrumental benefits to overall communities. Also, to capture these benefits as revenues, P3 programs can have higher financial viability with multimodal components.

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CHAPTER V DEVELOPMENT OF A MULTIMODALITY INDICATOR AND ITS APPLICATIONS IN MULTIMODAL PUBLIC-PRIVATE PARTNERSHIPS

5.1 Introduction

Because public–private partnerships (P3s) have proliferated in various sectors aside from transportation during the past decade (Kwak et al., 2009), substantial P3 research exists. Nevertheless, most studies revolve around identifying solutions to the problems encountered in P3 projects; from 1998 to 2008, for example, 20.6% of P3 studies were devoted to risk management, 18.2% were directed toward governance, and 12.4% centered on investment environments (Ke et al., 2009). Although some studies have evaluated multimodal transportation systems (e.g., Steiner et al., 2003; Alstadt and Weisbrod, 2008; Kanafani and Wang, 2010), empirical inquiries into multimodal P3 projects are rare. Multimodal components tend to be excluded from final proposals for P3 initiatives because such components do not directly increase revenue to the same extent achieved with auto-oriented modes.

Another challenge that confronts the incorporation of multimodal components in P3 projects is that the decision framework of multimodal schemes requires a measure for determining the level of effectiveness with which multiple modes are integrated into projects. This requirement is motivated by the differences in definitions of "multimodal". Litman (2014), for instance, defines multimodal planning as one *"that considers various modes (walking, cycling, automobile, public transit, etc.) and connections among modes"*. Bielli et al. (2006) illustrate a multimodal transportation system as *"the combination of all traveler modes and kinds of transportation* *systems operated through various systems"*, and Chen et al. (2011) describe it as pertaining to *"the use of two or more modes involved in the movement of people of goods from origin to destination"*. The reality is that ascertaining whether a project is multimodal in nature is difficult to accomplish in practice. According to all three definitions, a transportation station, such as the Miami Intermodal Center in Florida, is a multimodal project: all modes were considered in its planning [in accordance with Litman's (2012c) criterion]; the operation of these modes was examined [in agreement with Bielli et al.'s (2006) criterion]; and more than one mode is included in the system [in congruence with Chen et al.'s (2011) standard]. Similarly, the I-495 Express Lanes on the Capital Beltway in Virginia are multimodal, as ascertained at least from the definition of Chen et al. (2011); two modes—HOV and single auto—were considered. One can argue, however, that because transit services are included in the corridor, this project also satisfies the planning criterion noted by Bielli et al. (2006). The particular challenge emerging from this situation is that virtually any P3 project can be multimodal.

Given that certain P3 projects are more likely than others to be typified by a multimodal emphasis, different multimodal concentrations may exert varied effects on recipient communities. Considering the fact that strong collaboration between private and public sectors engenders increased economic benefits in a community (Thia and Ford, 2009), determining the extent to which multimodal factors influence land development is a worthwhile endeavor.

5.2 Purpose and Scope

To eliminate ambiguity in determining whether a project is of multimodal type, this research newly defines the concept of multimodality as the scaled degree of multimodality endowed to a locality by the multiple modes served in a given project. As a measure of land development, jobs–housing balance is used to capture changes in effects on urban form. This research espouses four objectives:

1. Develop a new multimodal indicator for scaling the degree of multimodality.

2. Quantify the reliability of the proposed indicator as a function of the data elements available.

3. Apply the proposed indicator to actual multimodal P3s.

4. Identify the relationship between multimodality and urban form effects scaled on the basis of the jobs–housing balance caused by multimodal P3 projects.

This research is expected to offer a replicable definition of multimodality for the purpose of further development and use in any type of transportation project. Practical benefits may also be derived from ascertaining the relationship between the degree of multimodality and changes in jobs–housing balance. Eventually, increased interest in incorporating multimodal components in P3 projects may be stimulated. Note that the analysis of jobs–housing balance was presented in the previous chapter and the results of that analysis (see Table IV-4) are used in conjunction with the multimodality indicator in this chapter.

5.3 Methods

5.3.1 Probability-based Multimodality Indicator

As reviewed in previous sources, the term “multimodal” is ambiguous as it is difficult to say in practice whether a project is multimodal or not. 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 address this ambiguity, an indicator measuring the degree of multimodality is 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 1).

$$Degree\ of\ Multimodality\ (DM) = a\left[1-\alpha^2\sum_{i=1}^{l}\left(\sum_{j=1}^{k}(p_i = \frac{w_i\ or\ 1}{mw_i+n}\cdot MS_{ij})\right)^2\right] + b\left[1-\sum_{i=1}^{l}\left(\frac{MC_i}{TC}\right)^2\right] \quad (1)$$

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

α = adjustment parameter

a, b = combining weights

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

n = number of sources that have all trip purposes

Based on this equation, the degree of multimodality tends to be maximized when there are multiple modes with equal mode shares, and when the values of MC_i tend to be equal assuming that the values of p_i are equal.

It is acknowledged that there are three limitations of using mode share data to determine multimodality for a given project. The first limitation is that mode share data only indicate how a corridor is used by existing modes and they do not indicate its capacity for all modes. (For instance an investment in a bus lane with low ridership is nonetheless a multimodal investment, albeit one that might not be characterized as effective.) Thus, some approach is needed that considers capacity for each mode. The second limitation is that rarely is mode share information complete. Accordingly, to estimate the real mode share information, multiple sources are necessary. In terms of demand, a few types of data sources are applicable to estimate real mode share information. Because some data sources only care about home-based work trips, different parameter estimates (p_i) are applied to consider this features of data sources. A third limitation reason is that the mode share of a particular segment does not indicate its purpose within a given system. For example, the construction of an airport connector road may have a bigger impact on multimodal travel (in terms enabling users to use an airport) than the construction of a rural highway segment, even if both have the same percentage of auto travelers. To address the first and third limitations, another multimodal element—the cost or budget for each facility of each mode—is incorporated for a given project's degree of multimodality. Note that this element (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. In sum, this research uses two sources of information —a demand-based source (modal shares) and a supply-based source (budget for each mode)—to address the limitations.

5.3.2 Calibration of Parameters in the Multimodality Indicator

To compute the multimodality (DM), the parameter p_i needs to be estimated. This research used the relative ratio of bias for each of the data sources as estimating parameter p_i. For example, the first source is the American Community Survey (ACS) which is only based on commuting trips (home-based work trips). However, other sources include all trips, regardless of purpose. The ratio of the annual number of trips by transportation mode and trip purpose from the National Household Travel Survey in 2009 (Santos et al., 2011) is used to obtain parameters (see Table V-1). The beauty of the proposed multimodality indicator is that the parameter p_i is automatically calculated based on this relative ratio of bias for each data source.

TABLE V-1. 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 (17.1%)	2,247 (29.9%)	1,854 (4.5%)	1,144 (7.0%)
Work-Related Business	10,525 (3.2%)	264 (3.5%)	684 (1.7%)	469 (2.9%)
Family/Personal Errands	146,158 (44.7%)	2,344 (31.2%)	15,174 (37.0%)	2,859 (17.4%)
School or Church	26,654 (8.1%)	829 (11.0%)	3,542 (8.6%)	6,651 (40.5%)
Social and Recreational	82,887 (25.3%)	1,426 (19.0%)	18,833 (46.0%)	4,576 (27.9%)
Other	4,925 (1.5%)	409 (5.4%)	874 (2.1%)	725 (4.4%)
Total	327,118 (100%)	7,520 (100%)	40,962 (100%)	16,424 (100%)

Another set of parameters, weights (a, b), are calibrated by Principal Component Analysis (PCA), an unsupervised projection method, which can reduce a set of features to a smaller number of representative variables, otherwise known as a low-dimensional representation, that collectively explain most of the variability in a given original data set (Venables and Ripley, 2002). Conceptually, each feature needs a dimensional space, but not all dimensions are equally important to explain all features. The basic idea concept of PCA is to find these representative dimensions, or principal components, 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 solved as an optimization problem as shown in Equation (2) (Manly, 1994; James et al., 2014).

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

where,

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

x_{ij} = features

Equation (2) can be solved by the Eigen decomposition from the linear algebra. After the first principal component is determined, the second principal component ($z_{i2} = \emptyset_{12}x_{i1} + \emptyset_{22}x_{i2} + \cdots + \emptyset_{p2}x_{ip}$, where $\emptyset_2$ = the second principal component loading vector) is decided as the linear combination of sample features that has maximal variance out of all linear combinations that are uncorrelated with the first principal (James et al., 2014). Here, the uncorrelation constraint is equal to the constraint of which the direction $\emptyset_2$ to be orthogonal to the direction $\emptyset_1$ (James et al., 2014). Because the multimodality index has only two features (composite mode share and financial plan), the first principal component loading vector is simply used in this research.

Note that principal components are acquired in order of correlation with original features. To be specific, the first principal component z_{i1} of sample features $(x_{i1}, x_{i2}, \dots, x_{ip})$ from X explains the maximum amount of variance, while the second principal component z_{i2} explains the next largest proportion of variance. That is, $var(Z_1) \geq var(Z_2) \geq \cdots \geq var(Z_p)$, where $var(Z_1)$ denotes the variance of Z_i in the data set being considered (Manly, 1994). In this study, the sum of proportion of variance explained (PVE) by two principal components, also called cumulative PVE, should be therefore one because all the principal components account for 100% of variation in the original data set. James et al. (2014) expresses the PVE of the m^{th} principal component as Equation (3), and the cumulative PVE of the first m principal components can be simply computed by summation of each of the first m PVEs.

$$PVE\ of\ the\ m^{th}\ principal\ component = \frac{\sum_{i=1}^{n}(\sum_{i=1}^{p} \emptyset_{jm} x_{ij})^2}{\sum_{j=1}^{p}\sum_{i=1}^{n} x_{ij}^2} \quad (3)$$

where,

$\emptyset_{jm}$ = loadings (elements of m^{th} principal component loading vector $\emptyset_m$)

x_{ij} = features

Given that there are two major variables—mode share and cost—there are two different ways to apply PCA—with scaling and without scaling. There is literature supporting each approach. One argument for not scaling these data is that the normalization of each dimension is not necessary because when they are presented as a percentage, they have the same scale which ranges from 0.00 to 1.00. Literature supporting this decision not to scale includes Maindonald and Braun (2003). There is also literature suggesting that scaling is appropriate, because these two variables have different means and variances. Accordingly, scaling the variables to have a mean of zero and a variance of one has been suggested (James et al., 2014) to prevent the bias of loading on the principal components. Both approaches—with scaling and without scaling—are presented here.

5.4 Data Collection

5.4.1 Possible Data Sources

Because this research employs interdisciplinary concepts from transportation and urban planning, various data sources are necessary to attain the objectives. Based on the deep observation of mode share data sources, four distinct sources can be applicable to this research. Also, construction or operation/maintenance costs can be extracted from project-related reports such as environmental impact statements and traffic and revenue studies or proposals. Table V-2 illustrates the datasets used for computing the degree of multimodality.

TABLE V-2. Summary of Necessary Datasets

Component	**Data Type**	**Data Source**
Mode share	Annual Average Daily Traffic	Detector count database
	Continuous traffic counts	
	Means of transportation to work	American Community Survey
	Forecasted traffic volumes or trips by mode (travel demand forecasting)	(Final) Environment impact statement, Traffic and Revenue Study, or (Un)solicited Proposal
	Preference survey for travel mode	
Construction or operation/ maintenance cost	Annual or whole costs	

5.4.2 Collected Datasets for Scaling Multimodality

Recall that this research focuses on multimodal P3 projects. Six multimodal P3 projects were selected—three are transportation centers and three are transportation corridors (express lanes or corridors). The analysis years were selected with 1-year before the construction and the most recent year after the construction. An effort was made to include all applicable data sources, but in some cases, specific data sets were unattainable because the facility did not exist or specific datasets were not ordinarily acquired from data sources. Table V-3 describes obtained data sets for the multimodality calculation.

TABLE V-3. Status of Obtained Datasets for Multimodality

Site Name	Analysis Year	AADT	ACS	Forecasted Traffic Volumes or Trips	Continuous Traffic Counts or Survey	Financial Plan
Denver Union Station, Colorado	2009	√	√	-	-	-
	2014	√	√	-	-	√[a]
I-495 Express Lanes, Virginia	2007	√	√	Forecasted Trips[b]	Continuous Traffic Counts	-
	2014	√	√	Forecasted Trips[b]	Continuous Traffic Counts	√[b]
I-595 Express Corridor, Florida	2010	√	√	-	Continuous Traffic Counts	-
	2014	√	√	-	Continuous Traffic Counts	√[c]
InterLink, Rhode Island	2006	√	√	-	Survey[e]	√[e]
	2014	√	√	Forecasted Trips[d]	Survey[e]	√[e]
Miami Intermodal Center, Florida	2006	√	√	-	Survey[f]	-
	2014	√	√	Forecasted Trips[g]	Survey[h]	√[g]
US 36 Express Lanes, Colorado	2011	√	√	Forecasted Traffic Volumes[i]	Continuous Traffic Count	-
	2014	√	√	Forecasted Traffic Volumes[ij]	Continuous Traffic Count	√[j]

[a] Colorado Department of Transportation (2008)

[b] Fluor Daniel (2003)

[c] Bowen Civil Engineering, Inc. (2006)

[d] Devine and Pimental (2014)

[e] Landrum & Brown (2014)

[f] Gosling (2014)

[g] Florida Department of Transportation (Undated)

[h] Adamson (2014)

[i] 36 Commuting Solutions (2012)

[j] Colorado Department of Transportation (2009)

Unlike other data sources, ACS does not provide mode share information on a specific corridor, and transportation centers do not have any specific Annual Average Daily Traffic (AADT) data. Accordingly, to use ACS data, impact boundary was initially set up as 13 miles, based on the average commute distance in the U.S. from previous studies (Federal Highway Administration, 2014; Kneebone and Holmes, 2015). A 5-mile impact boundary was additionally analyzed to see the differences between two boundaries. Public Use Microdata Area (PUMA)-level areas were selected when their centroids were located in 5-mile and 13-mile impact boundary, respectively, to extract necessary data. For AADT data, 5- and 13-mile radiuses are too large to identify influencing mode share to facilities; thus, actual travel distances (5 and 13 miles, respectively) were used to identify applicable detectors. Table V-4 explains the selected number of PUMAs and active-only detectors (which provide valid counts) in six sites.

TABLE V-4. Number of Selected PUMAs and Active-only Detectors

Site Name	**Analysis Year**	**5-Mile Impact Boundary**		**13-Mile Impact Boundary**	
		Number of Detectors	Number of PUMAs	Number of Detectors	Number of PUMAs
Denver Union Station, Colorado	2009	32	2	44	14
	2014	32	2	44	14
I-495 Express Lanes, Virginia	2007	22	3	22	17
	2014	24	7	24	22
I-595 Express Corridor, Florida	2010	10	3	10	14
	2014	10	5	10	16
InterLink, Rhode Island	2006	7	N/A	26	3
	2014	7	N/A	27	3
Miami Intermodal Center, Florida	2006	14	3	19	16
	2014	23	5	31	19

US 36 Express Lanes, Colorado	2011	16	4	16	13
	2014	16	4	16	13

Figure V-1 graphically shows the selected PUMAs before and after the construction in each multimodal P3 project.

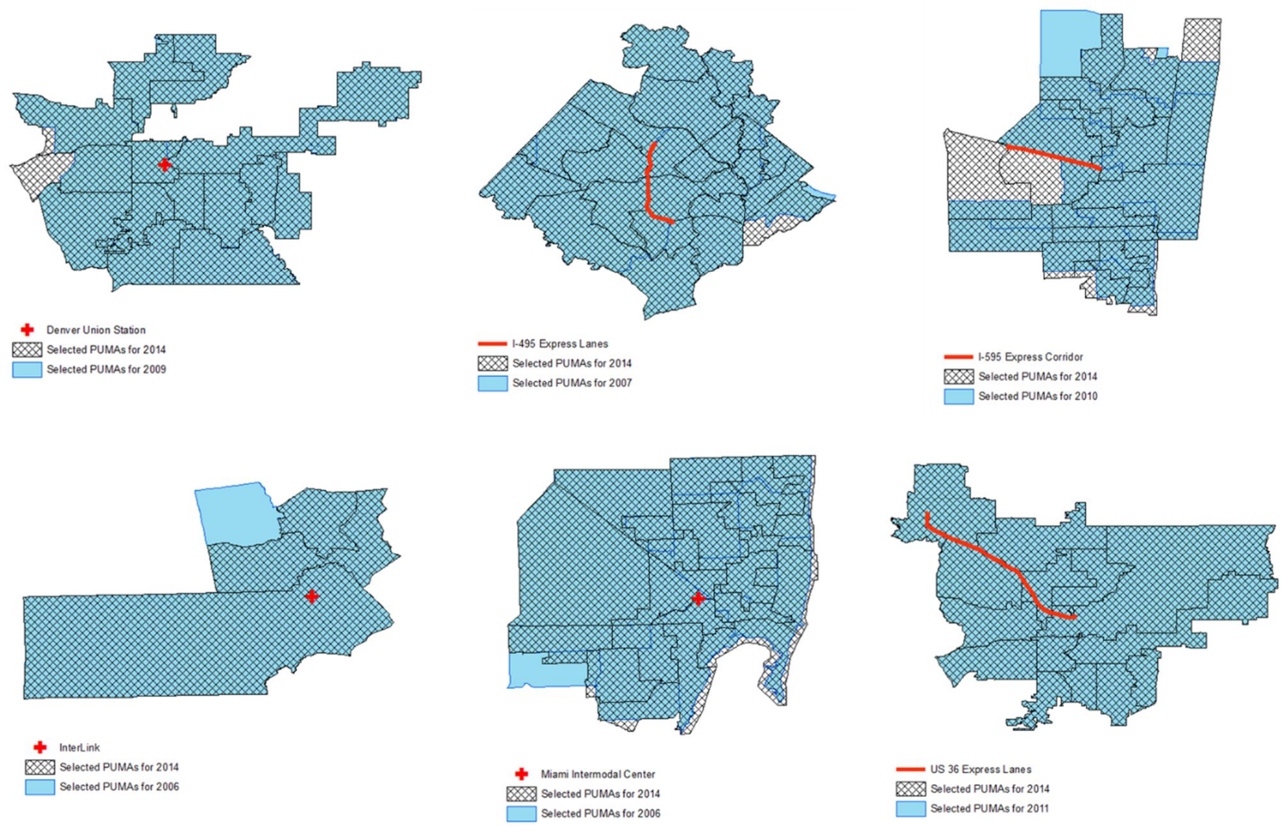

FIGURE V-1. Selected PUMAs in 13-mile impact boundary of six sites

5.5 Results and Discussions

<u>5.5.1 Calibration by Principal Component Analysis</u>

Clearly the two elements measure fundamentally different phenomena: mode share (e.g., the percent of trips using each mode) and dollar amount (e.g., the monetary investment in capital and maintenance for each modes.) For example, Figure V-2 presents the mode share for each mode at Miami Intermodal Center and the cost for each mode at the same site. Because Figure V-2 presents each variable as a percentage, the scale ranges from 0.00 to 1.00, but it is clear that the variance is different; the variance is 0.0449 for mode share and 0.0346 for cost. The question then becomes whether it is appropriate to perform scaling when applying PCA.

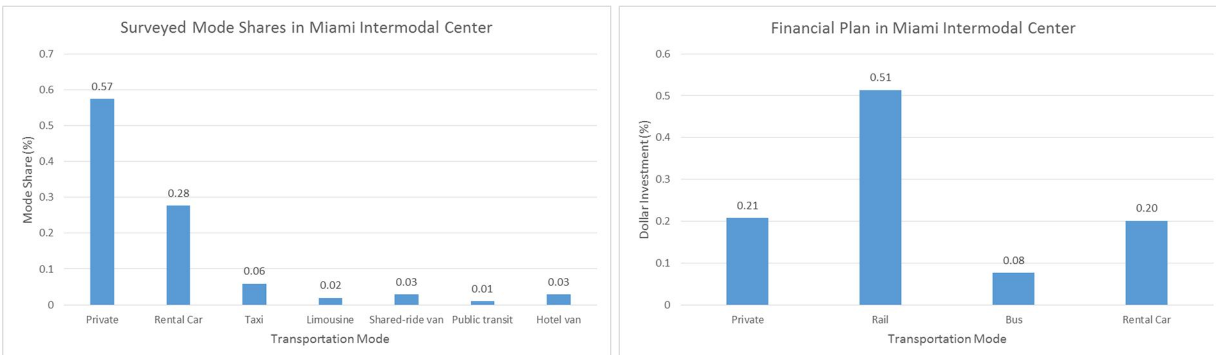

FIGURE V-2. Mode shares and dollar investments

Note: For example, at the Miami Intermodal Center, the left side of Figure V-2 shows that public transit has 1% of trips. The right side of Figure V-2 shows that the mode which is most similar to public transit, the bus, received 8% of all dollars that were invested in transportation.

Results with Scaling

The Pearson's correlation coefficient yielded 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. The proposed indicator requires the combining weights (a, b in Equation 4). Indeed, PCA approach does not always work especially when the original variables—two variables (mode share and financial ratio in this study)—are uncorrelated. After conducting the PCA with scaling, mode share and financial ratio have same first principal component loadings for both the 5-mile impact boundary and the 13-mile impact boundary, but different PVEs (see Table V-5).

TABLE V-5. 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	-0.707	-0.707	0.707	-0.707
Financial Ratio Loading	-0.707	0.707	0.707	0.707
Standard Deviation	1.259	0.643	1.252	0.657
Proportion of Variance Explained (PVE)	0.793	0.207	0.784	0.216
Cumulative PVE	0.793	1.000	0.784	1.000

In Figure V-3, the numbers in plots represent the scores of two principal components (the projected coordinates onto the plane of observations), and the arrows indicate two principal component loading vectors.

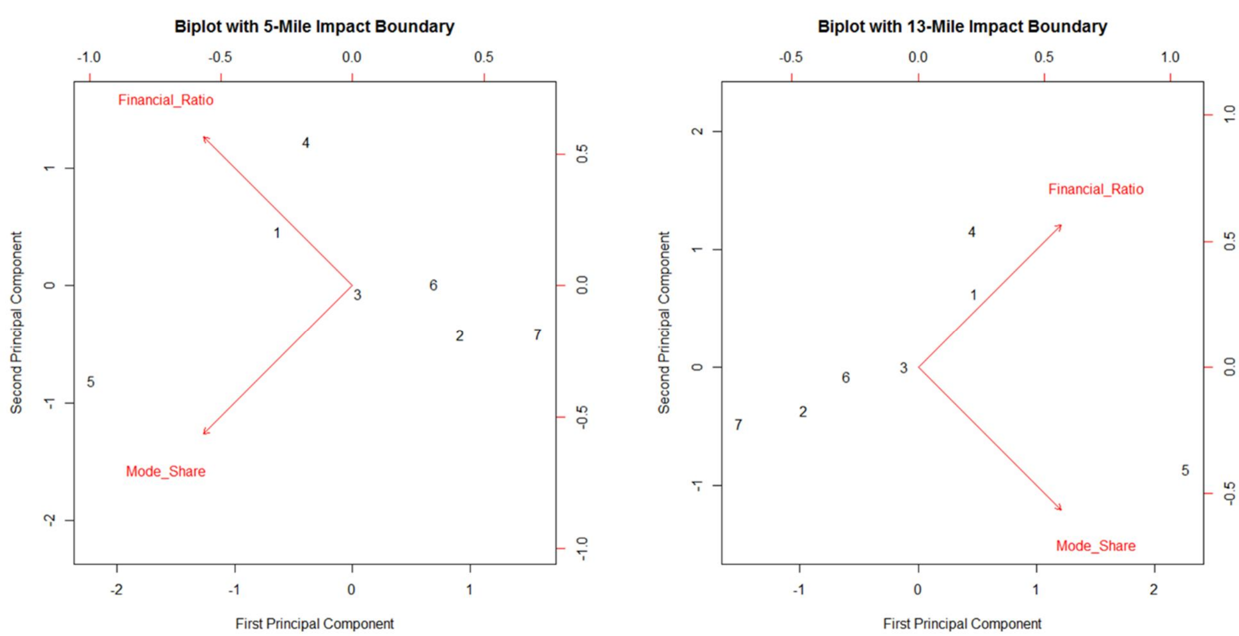

FIGURE V-3. Biplots of PCA result with scaling

By PCA, two-dimensional data (two variables) of multimodality indicator can be projected onto the first principal component loading vector, thereby having a two-dimensional view of the data. That is, one-dimensional representation can successfully explain the major pattern of two-dimensional data: 79.3% of variance (PVE) with a 5-mile impact boundary and 78.4% of variance (PVE) with a 13-mile impact boundary from the original data can be explained by these one-dimensional representations, respectively. Because the indicator uses two variables, two-dimensional representation explains naturally 100% of variance (Cumulative PVE). Consequently, same combining weights (0.5 for each) were applied in that two impact boundaries had same first principal component loadings, regardless of the sign. Flipping the sign does not have any effect because the direction in *p*-dimensional space does not change (James et al., 2014).

Results without Scaling

For comparison purposes, Table V-6 below shows the results of applying PCA without scaling. Comparing these results to Table V-5, note that the information contributed by each of the two variables is not the same, rather, one variable provides more information than the other as reflected by the mode share loading and the financial share loading. Note also that the proportion of variance explained by the first component has changed from about 78.4% (for the 13 mile impact boundary) to 81.0%.

TABLE V-6. Principal Components and PVEs without Scaling

	5-Mile Impact Boundary		13-Mile Impact Boundary	
	First Component	Second Component	First Component	Second Component
Mode Share Loading	0.555	0.832	0.509	-0.861
Financial Ratio Loading	0.832	-0.555	0.861	0.509
Standard Deviation	0.223	0.109	0.218	0.106
Proportion of Variance Explained (PVE)	0.808	0.192	0.810	0.190
Cumulative PVE	0.808	1.000	0.810	1.000

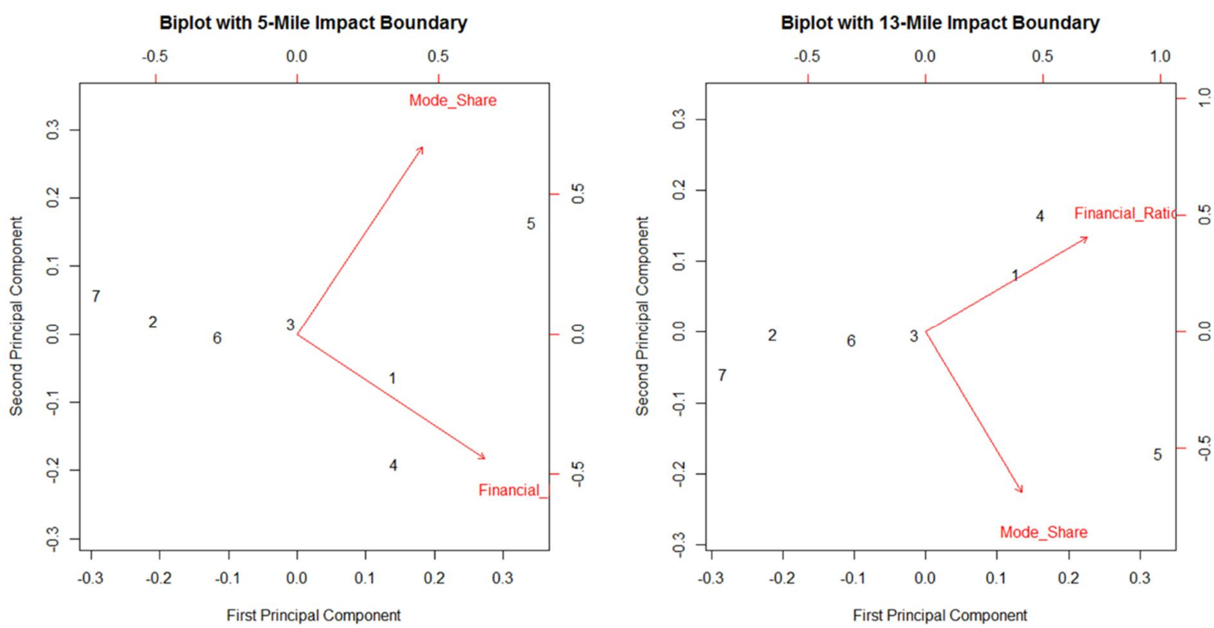

FIGURE V-4. Biplots of PCA result without scaling

Although results without scaling show higher proportion of variance explained, as suggested by James et al. (2014), scaling was adopted to prevent the bias of loading on the principal components because of difference variances of two variables.

5.5.2 Multimodality Results

With all obtained datasets, each mode share, financial ratio and multimodality were computed, as shown in Table V-7. Collected traffic counts from AADT, continuous detectors or forecasted counts were converted to number of persons by using vehicle occupancy rate (Federal Highway Administration, 2014; U.S. Department of Energy, 2015) for unit compatibility.

TABLE V-7. Summary of Mode Share, Financial Ratio and Multimodality

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%)
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%)
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%)
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%)

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%)
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%)

Regardless of the size of impact boundary, the degree of multimodality was increased after the introduction of multimodal P3 projects by 52.7% (5 miles) and 56.4% (13 miles), respectively. These results support the goal of multimodal P3 projects, which emphasize the use of multiple modes rather than other unimodal projects.

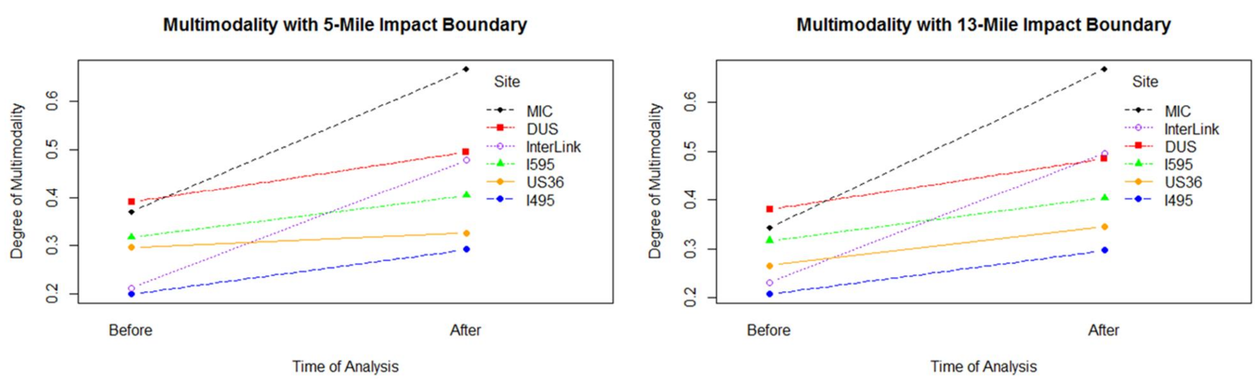

FIGURE V-5. Before-after interaction plots of the degree of multimodality

In both 5-mile and 13-mile impact boundaries, Miami Intermodal Center has the largest multimodality (0.667, 0.668 respectively), but InterLink dramatically increases multimodality (125.8%, 114.8%, respectively) after improvements (see Figure V-5 and V-6).

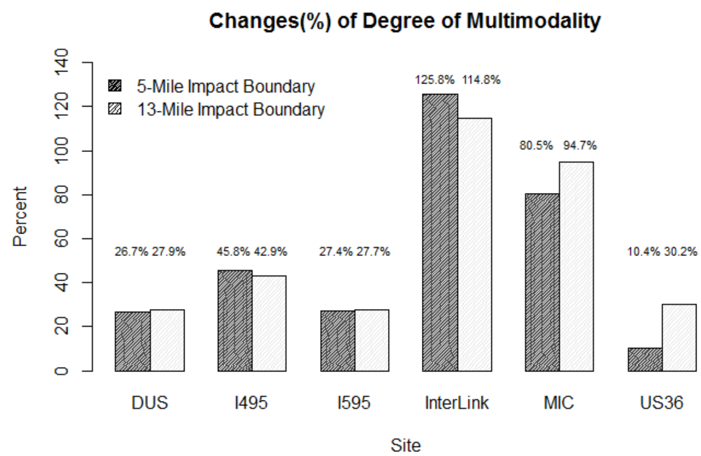

FIGURE V-6. Comparing chart of changes (%) of multimodality in 5 and 13 miles

As shown in Figure V-5, the three transportation centers (Denver Union Station, Interlink, and Miami Intermodal Center) have bigger degrees of multimodality rather than other three express lanes projects (I-495 Express Lanes, I-595 Express Corridor, and US 36 Express Lanes). To see the details of this difference, additional analysis was conducted, which showed bigger changes between two different types of facilities (see Table V-8). This is because although express lanes projects emphasize the multiple modes by providing advantages (e.g., toll free option or Bus Rapid Transit), a transportation center can provide better accessibility or convenience for using and transferring multiple modes.

TABLE V-8. Comparison of Transportation Center and Express Lanes

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

5.5.3 Relationship between Multimodality and Jobs-Housing Balance

One research objective is to determine if there is a relationship between multimodality and jobs-housing balance. Table IV-4 from the previous chapter, and Table V-7, from this chapter, are directly comparable because the case study and impact boundary for each are identical. Table V-9 shows the change in degree of multimodality and jobs-housing balance for the 5-mile and 13-mile impact boundaries.

TABLE V-9. Summary of Change in the Multimodality Indicator and the Jobs-Housing Balance Indicator

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

By conducting Pearson's correlation test, the change of multimodality and jobs-housing balance 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.).

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 fourth site (Interlink) results in a positive correlation. Given that at the 13 mile boundary that all six sites showed that jobs-housing balance improved and that multimodality increased, 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 jobs-housing balance and degree of multimodality is less as the impact boundary grows.

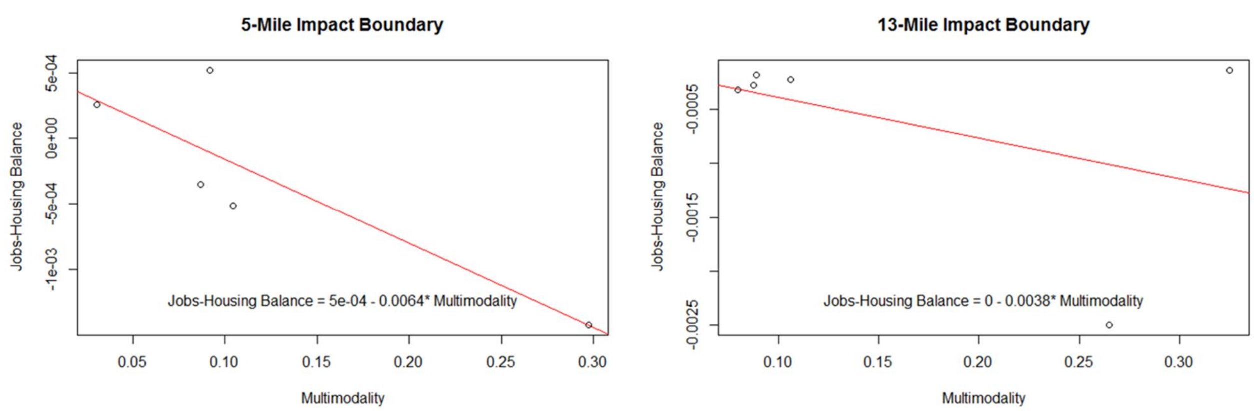

FIGURE V-7. Correlation plots between multimodality and jobs-housing balance

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 jobs-housing balance and multimodality 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 (4) from the previous chapter 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.

5.6 Concluding Remarks

Although "multimodal" projects are conceptually appealing, multimodality is best expressed as a matter of degree rather than as a binary category of unimodal or multimodal.

- A methodology to quantify the degree of multimodality for P3 projects can be developed, where degree is based on two variables: demand—that is, the share for each mode—and supply—that is, the amount of funds for capital and maintenance needs for each mode. The indicator is novel, as existing literature does not indicate the extent to which projects are multimodal. While two variables were used here, the indicator can be extended to additional variables using the principal components analysis approach presented earlier.

- The indicator can be used for a variety of transportation projects, as demonstrated by the six case study sites used to test the proposed indicator. The indicator, for instance, can work with a HOT lane facility as well as a combined light rail transit, bus, and highway facility. For all such projects, the indicator provides the scaled degree between zero and one and thus represents a common way of representing multimodality. For example, for the 13 mile impact boundary during the before period, for six very different projects, the indicator gave a value that ranged from a low of 20.8% (I-495 Express Lanes, Virginia) to a high of 38.0% (Denver Union Station, Colorado)

- Because the indicator is based on different datasets, a new approach from statistical reasoning is employed—principal components analysis. The approach suggests that not all datasets provide the same amount of information. For example, in one instance, using only one of the two datasets provides more than three quarters (78.4%) of the information necessary to explain the variance that would otherwise be explained if both variables were used. Given the high cost of data collection, knowing such a PVE can help analysts determine when they should expend effort to collect additional data or when they can make use of a smaller data set.

- Because the academic literature provides inconsistent guidance as to whether scaling is appropriate for this problem, analyses with and without scaling have been conducted. These results suggest that scaling affects the amount of variance that is explained. Without scaling, using only one of the two variables explains 81.0 % of the variance (that would be otherwise be explained if both variables were used). When scaling was used, this percentage was 78.4%. Also, because scaling results in the amount of information contributed by two very different variables being identical, scaling may eliminate one of the benefits of PCA.

- The six case study sites suggest that multimodality increased after project implementation; in this instance, the degree of multimodality increased by an average value of about 56% across the six study sites. This result suggests these P3 projects are becoming more "multimodal."

- There appears to be a correlation between the jobs-housing balance indicator and multimodality indicator, but the strength of this correlation decreases as the project impact area increases. Recall that a lower jobs-housing balance indicator signifies better balance, and that a higher multimodality indicator signifies higher multimodality, such that a perfect association between these variables would yield -1.00 and 0.00 indicates no association. The correlation between these two variables was -0.87 at the 5 mile impact boundary but dropped to -0.44 with the 13 mile impact boundary. These results suggest that at smaller distances, projects with multiple modes may contribute to better jobs-housing balance—however, this paper does not explore the reasons for why this is the case.

- It is not clear why the relationship between jobs-housing balance and multimodality decreases as the project impact boundary increases. A plausible explanation is that impacts lessen as distance from the project increases; further, because some projects were recently constructed, the transportation and land use may not be in as much equilibrium as they were prior to construction.

An ability to forecast land development impacts of multimodal P3 projects could benefit the public and private sectors. For example, increases in future land value could be captured through increased property taxes; additionally, the right to develop land (or area above the land) could be leased to an entity that is capable of maximizing the economic value of that property. In support of such endeavors, this research provides some evidence of a positive relationship between multimodality and an urban form impact (jobs-housing balance) using an indicator that can be applied to different locations.

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CHAPTER VI EFFECTS OF MULTIMODAL PUBLIC-PRIVATE PARTNERSHIPS ON PROPERTY VALUES: EXPERIENCES ON I-495 EXPRESS LANES IN VIRGINIA

6.1 Introduction

Highway transportation projects in the U.S. are confronted with a fiscal challenge caused by the growing gap between the costs of highway infrastructure and available funding for highway projects (AECOM Consult, Inc., 2007a). The pressure arising from this challenge has motivated the private sector to participate in transportation projects that are implemented through public–private partnerships (PPP or P3). An emerging problem, however, is that private sector involvement may be leaning away from a multimodal focus even as P3s with a multimodal component can yield substantial societal benefits; this preference stems from a desire for immediate revenue generation (AECOM Consult, Inc., 2007b). With an understanding of how multiple modes can engender societal advantages, especially those related to land development, ensuring the financial viability of P3 projects is possible.

In empirical research, the relationship between transportation and land development (or property value) effects has been extensively examined as a two-way process in which one drives the other (e.g., Brueckner and Fansler, 1983; McGrath, 2005). An issue that has been raised in this regard is that a multimodal P3 projects may contribute to changes in property values by altering the balance between the locations of households and firms. The evidences presented in Chapter 4 and 5 are suggestive of this relationship, but an approach that can generate more useful results is determining the extent to which a multimodal P3 project explains property changes. Accordingly, this research conducts a statistical analysis using a hedonic price model to investigate the role of multimodal P3 projects as determinants of increased property values.

6.2 Purpose and Scope

This research quantifies the effect of multimodal P3s on property value changes. This analysis contributes to the literature in two ways: it can capture possible changes in property values and serve as basis in developing a value capture mechanism that can be used to promote the inclusion of multimodal components in P3 projects. There are four objectives:

1. Use open data sources, rather than proprietary data sources, to establish the analytical environment.

2. Characterize the "multimodality" of P3 projects as a variable, or vector of variables suitable for statistical analysis.

3. Calculate the historic multimodality in a given corridor.

4. Quantify the extent to which multimodality and travel impedance influence residential and commercial properties.

The underlying assumption in this research is that if a multimodal P3 project changes the ease of traveling and multimodality with which a given location is accessed, then such change should be reflected in newly calculated property values. With consideration for this proposition, two types of relationships are validated: (1) the relationship between changed potential travel impedance and property values and (2) that between the changed multimodality of a P3 project and property values. Several multimodal P3 projects are implemented in the U.S., but this study selects the I-495 Express Lanes project in Virginia because of data availability and importance of location.

6.3 Brief Background and Literature Review

6.3.1 Property Value Changes Caused by Transportation Projects

Extensive studies have been devoted to the association between transportation projects and property values since the Interstate Highway Program was introduced in the U.S. (e.g., Mohring, 1961). Because interest traditionally centers on highway development, the majority of research underscores the effects of highways on the values of nearby properties. Huang (1994), for example, reviewed more than 60 empirical studies on the effects of transportation infrastructure (highways) on property values. The author found that transportation projects exert local effects and a comparison of 1970s and 1980s projects and those initiated in earlier periods show diminishing effects in the former. A similar conclusion was drawn by Giuliano (1989), who reviewed previous studies that probed into the effects of transportation infrastructure on urban development. Recent years have seen the proliferation of impact analysis research on public transportation given increased interest in this issue. Ko and Cao (2013) examined the effects of light rail systems on non-residential properties, with the authors revealing that a significant price premium is attributed to non-residential properties located near light rail stations. Ko and Cao's (2013) work is one of the few analyses that focus on the effects of transportation initiatives on non-residential properties. Given better data availability for residential contexts, many diverse examinations are directed toward effects on residential property values. Examples include Hewitt and Hewitt (2012), who analyzed the prices of housing located near urban rail stations, and Michael (2011), who measured the influence of transit on housing prices in San Diego, California. A few researchers have also delved into the effects of toll roads on property values (e.g., Vadali, 2008), but case studies on P3 projects are scarce. Particularly lacking is research on the effects of both multimodal components and toll roads. This deficiency is ascribed to the aforementioned uncertainty regarding the financial viability of multimodal P3 projects. Research on this issue should be enriched by probing into the various challenges that arise from multimodal P3 projects; some of these challenges are those related to multimodality, P3 perspectives, and/or multimodal features.

6.3.2 I-495 Express Lanes in Virginia

Virginia has been at the forefront of employing and refining the public–private transportation concept. The Public-Private Transportation Act of 1995 (PPTA), which was conceptually proposed by the private sector in 2002 (Fluor Daniel, 2002), was enacted to supplement public funding with private sources of money and encourage creative, timely, and cost-effective transportation projects. The PPTA resulted in what are now known as the I-495 Express Lanes, which span a 14-mile segment of the 22-mile long Capital Beltway and run through northeastern Fairfax County in Virginia (Fluor Daniel, 2002). Travel demand on the Capital Beltway (multilane circumferential freeway serving the metropolitan area of Washington, D.C.) routinely exceeds capacity during peak periods, thereby resulting in extended hours of congestion (Fluor Daniel, 2003; Transurban Operations Inc., 2015). This problem prompted the 2012 construction of four new high-occupancy toll (HOT) lanes designed to expand capacity and deliver new travel options, such as express bus services and carpool lanes (Fluor Daniel, 2003; Transurban

Operations Inc., 2015). VDOT embraced the initial plan with the PPTA because a partnership with the private sector and tolling was expected to help VDOT rapidly deliver improvements at low taxes, provide new travel choices, and reduce effects on the community and the environment (Transurban Operations Inc., 2015). Two express bus services (Fairfax County's Express Connector and OmniRide Tysons Express) are currently using the I-495 Express Lanes (Fairfax County Government, 2015; Potomac and Rappahannock Transportation Commission, 2015).

6.4 Data Sources

Given this research's concentration on the effects of multimodal P3 projects on property values, a variety of data sources are necessary. Each data source used in this study is briefly explained as follows.

To map the multimodal transportation network in a given impact boundary, this research primarily used two open data sources, namely, OpenStreetMap (OSM) and General Transit Feed Specification (GTFS, previously Google Transit Feed Specification). OSM, which was launched in 2004, is a non-commercial collaborative project intended to create a freely available repository of geographic maps (Yeboah and Alvanides, 2015). It initially focused on street and road maps, but thousands of volunteer contributions have expanded the database to include a variety of geographic objects, such as buildings, land use, and points of interest (Arsanjani et al., 2015). Accordingly, OSM provides substantial geographic details and captures actual multimodal transportation network components, including sidewalks, bicycle trails, railroads, and HOT lanes. OSM also includes information on constructing network datasets (e.g., speed regulations, number of lanes) for network analysis. GTFS is a format for transit information (e.g., stops, routes, trips, schedules, and operators) and associated geographic data (Google Developers, 2015). As an open format, GTFS is voluntarily prepared and maintained by associated transit agencies. As of December 2015, 338 transit agencies in the U.S. have provided GTFS data (GTFS Data Exchange, 2015). Given its high accuracy and detailed information, GTFS can be used to measure accessibility by transit routes on the basis of time and location (Catala et al., 2011). However, because GTFS does not always provide data on all transit services, additional information is obtained from related metropolitan planning organizations (MPOs). In this research, information on one bus route (i.e., OmniRide in Fairfax County) was acquired from the Metropolitan Washington Council of Governments (MWCOG).

To reflect changes in potential accessibility for life activities, the distance from each property to an activity center was calculated on the basis of the Regional Activity Center resource provided by MWCOG. Activity Centers are locations that will accommodate the majority of a region's future growth, which includes existing urban centers, priority growth areas, traditional towns, and transit hubs (MWCOG, 2014). This source was developed by MWCOG's Metropolitan Development Policy Committee as a tool for guiding land use and transportation planning decisions; it has been continually refined since 1999 (MWCOG, 2007). Because the construction of the I-495 Express Lanes caused changes in the features of Activity Centers, only those that remain in operation (52 centers, Figure VI-3) after the construction were selected for the analysis.

The primary data used to carry out this research are the historic property values in Fairfax County. Given that the I-495 Express Lanes had been constructed from 2008 to 2012, multiple-year parcel-level property values (2004–2015) were derived from the Department of Tax Administration of the Fairfax County government. These data consist of 10 tables that provide information regarding the property attributes, assessed values, property descriptions, and parcel information of residential and commercial properties.

The Longitudinal Employer-Household Dynamics (LEHD) survey of the U.S. Census Bureau at 2010 census block level were used to consider the influence of number of jobs on property values within a 1-mile radius of each parcel-level property. LEHD data are very useful sources of number of houses and workplaces, as well as locations, because they are updated yearly and drawn from actual payroll records collected at the state level (Owen et al., 2014).

One objective of this research is to investigate the contribution of changed multimodality on property values after the construction of the I-495 Express Lanes. The datasets adopted in calculating multimodality are identical to those used in the Chapter 5. However, for consistency across the available datasets and concentration on the I-495 Express Lanes in the analysis, historic annual average daily traffic (AADT) and continuous traffic counts from the traffic monitoring system (TMS) of the Virginia Department of Transportation were used. The American Community Survey is also applicable, but this requires a relatively large impact boundary that is beyond the scope of this research. The financial plan from Fluor Daniel's (2003) detailed proposal for the I-495 Express Lanes was also employed to calculate the financial ratio.

Given that the study periods chosen are the two years before (2006–2007) and after (2013–2014) the construction, all the datasets acquired are those concerning these two periods.

6.5 Methodology

The methodology is comprised of four major components:

- Development of the hedonic price models
- Development of the multimodal transportation network
- Establishment of the impact boundary
- Selection of study variables

6.5.1 Development of the Hedonic Price Models

The technique of hedonic price analysis was formalized by Rosen (1974). Hedonic price theory basically assumes that the price (or rent) of a property is a function of several sets of characteristics that collectively describe the property; examples of such characteristics are the quality of construction, the quantity or size of buildings, and the property's location within the relevant real estate market (Iacono and Levinson, 2013). Based on the theoretical framework, the model specification is as follows:

$$\mathrm{P}_i = \mathrm{f}(\mathrm{T}_i, \mathrm{A}_i, \mathrm{S}_i) \quad (1)$$

where,

P_i = the assessed property values of parcel i

T_i = a vector of transportation characteristics describing the ease with which parcel i can be reached by highway, express bus routes and regional activity centers. Essentially, T_i provides an impedance measure for each mode.

A_i = a vector of property attributes (e.g., structure size and age) and type of commercial property (e.g., shopping center) for parcel *i*

S_i = a vector of neighborhood socioeconomic characteristics (e.g., number of jobs) for parcel *i*

Because this research considers two scenarios, another model can be specified with multimodality (where M means the degree of multimodality) as shown in Equation (2). The variable M does not vary by parcel i, but by rather by year.

$$P_i = f(M, A_i, S_i) \tag{2}$$

In Equation (1), the three dimensions of the T variable can be described by (1) the distance from parcel *i* to the nearest HOT lanes ramp, (2) the distance from the parcel to the nearest bus stop for each of the two bus routes using HOT lanes, and (3) the distance from the parcel to regional activity centers; in this way, T reflects perceived ease of travel by multimodal components for a P3 project in a given area. Some literature regarding hedonic price models compares goodness of fit for linear and log-linear specifications and then chooses the specification with the best fit (typically the model with the highest adjusted R^2 [e.g., Boarnet and Chalermpong, 2001]). It should be noted, however, that using R^2 or adjusted R^2 to compare models with different transformations of the same dependents is not legitimate unless values of the dependent variables, transformed or not, are similar in their variance across the models to be compared. This research uses the log-linear specification with ordinary least squares (OLS) regression. The reason for this approach is to ensure property values are never negative. In addition, while previous studies that used the hedonic price model lean heavily on residential properties because of difficult analysis with commercial properties (Ko and Cao, 2013), both residential and commercial properties are analyzed which is one of the contributions in this research.

Two generalized hedonic price models corresponding to the different scenarios in a given multimodal P3 project are written as Equation (3) and (4). Equation (3) presumes the change in the parcel value is based on a change in transportation characteristics *T*, and Equation (4) presumes the change in the parcel value is based on a change in the Multimodality indicator *M*.

$$ln(P_k) = \beta_0 + \beta_1 T + \beta_2 T \times I(After) + \beta_3 A_k + \beta_4 S + \beta_5 \times I(After) + \beta_6 I(After) + \varepsilon \quad (3)$$

$$ln(P_k) = \tilde{\beta}_0 + \tilde{\beta}_1 M + \tilde{\beta}_2 M \times I(After) + \tilde{\beta}_3 A_k + \tilde{\beta}_4 S + \tilde{\beta}_5 \times I(After) + \tilde{\beta}_6 I(After) + \tilde{\varepsilon} \quad (4)$$

where,

P_k = property assessed value in dollars (k=1 for a residential property and k=2 for a commercial property)

T = transportation characteristics reflecting the ease of travel

S = neighborhood socioeconomic characteristics

M = degree of multimodality

A_k = property attributes (k=1 for a residential property and k=2 for a commercial property)

$I(After)$= indicator equaling to 1 for after construction of a P3 project

It should be noted that P_k refers to properties within an impact boundary defined in the study.

6.5.2 Development of the Multimodal Transportation Network

There are a couple of ways to use OSM, but this research used the QGIS (previously known as Quantum GIS) because of the relatively easy function to download and manipulate the OSM data. Once the selected OSM data was downloaded, the OSM data was incorporated into ArcMap GIS in order to combine GTFS data which can be imported by the add-on toolbox provided by ArcMap GIS. Note that two express bus routes using I-495 Express Lanes exist in Fairfax County but GTFS provides only Fairfax County's Express Connector information; thus, OmniRide Tysons Express information was imported separately from the source by MWCOG. Finally, a multimodal transportation network was created for the analysis.

6.5.3 Establishment of the Impact Boundary

There is no exact guideline to designate the suitable impact boundary because considered variables are different in each location or scenario. In this research, with the consideration of disamenities from previous literatures, the impact boundary was set up as buffering from 0.2 mile to 1 mile along with I-495 Express Lanes. 0.2 mile was chosen based on Langley (1976) investigating house prices near the Capital Beltway around Washington, D.C., and 1 mile was chosen based on Ko and Cao (2013) regarding impact of transit on property values in Minneapolis. Parcel-level properties was selected when their centroids are located between 0.2-mile and 1-mile impact boundary. Figure VI-1 shows properties within the impact boundary with I-495 Express Lanes and related ramps.

FIGURE VI-1. Selected parcel-level residential (left) and commercial (right) properties within impact boundary

A total of 29,158 parcels for residential and 1,418 parcels for commercial were selected within impact boundary. Figure VI-2 depicts two express bus service routes using I-495 Express Lanes.

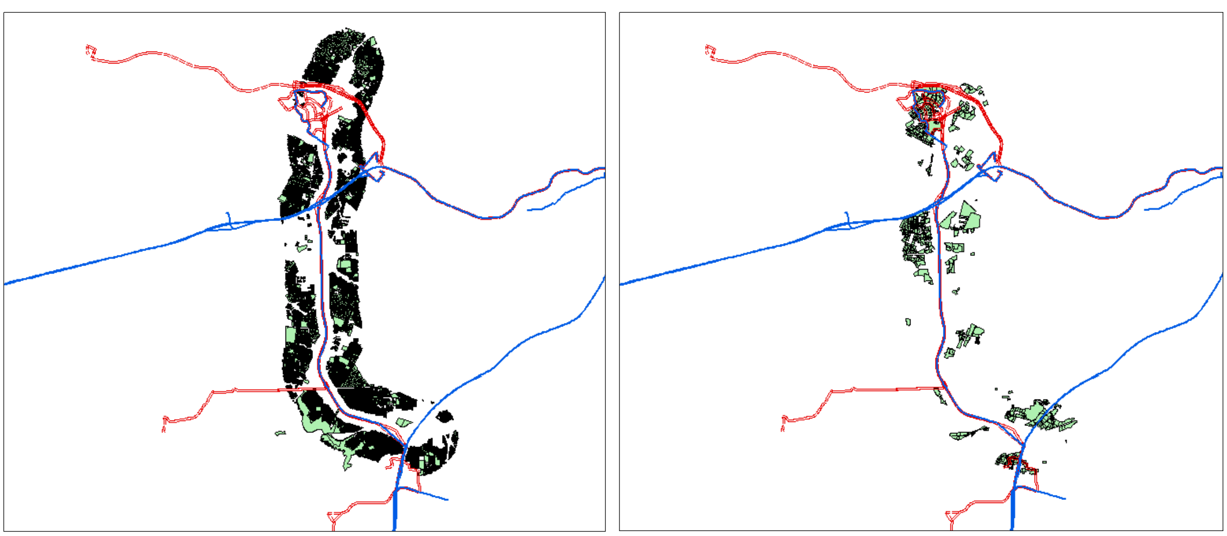


FIGURE VI-2. Fairfax County's Express Connector (dash) and OmniRide Tysons Express (line)

6.5.4 Selection of Study Variables

All variables generated from the data sources referenced above are presented in Table VI-1.

TABLE VI-1. Summary of Variables

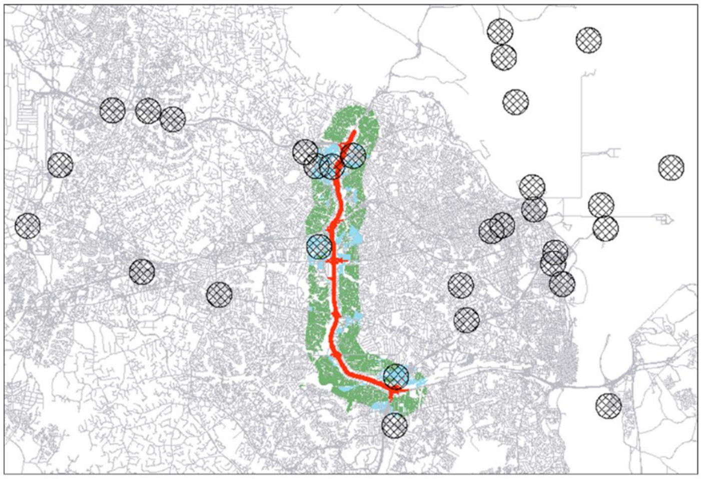
Category	Variables	Definition	Units	Data Source
Dependent Variable				
Property Assessed Value	PropertyValue	Amount total property values assessed for property tax imposition	U.S. Dollar	Fairfax County Government
Independent Variables				
Transportation Characteristics	DistHOT	Nearest distance calculated by geographic coordinates to HOT lanes ramps	Meter	OpenStreetMap
	DistBus	Nearest distance calculated by geographic coordinates to bus routes	Meter	GTFS
	DistActCenter	Nearest distance calculated by geographic coordinates to regional activity centers	Meter	MWCOG
Multimodality	Multimodality	Degree of multimodality	0-1	AADT, TMS, Financial Plan
Property Attributes	No.Story	Number of stories	Count	Fairfax County Government
	No.Unit	Number of units	Count	
	FoundArea	Foundation area	Square Feet	
	BuildUse	Building use	-	
	TotBuildArea	Total area of the building	Square Feet	
	BuildAge	Building age	Year	
	No.Bed	Number of bedrooms	Count	
	No.Bath	Number of full baths	Count	
	LivArea	Livable area	Square Feet	
	RemoYear	Year remodeled	Year	
Socioeconomic Characteristics	No.Job	Number of jobs within 1 mile radius	Count	LEHD

Selection of Dependent Variable

For both commercial and residential parcels, there are three types of property assessments: total assessed values, building assessed values, and land assessed values. However, Pearson's correlation coefficient between any pair of these values, for both residential and commercial properties, was at least 0.92 (and is as high as 0.99); all six correlations were significant ($p < 0.05$) at 95% confidence level. Accordingly, total assessed values were used as the dependent variable. Because the raw data sets from Fairfax County Government consist of several tables, all necessary information (assessed values and property attributes) were joined based on distinct parcel ID. Thus, the residential data set initially had 115,209 cases with 165 variables and the commercial data set had 5,492 cases with 137 variables.

Selection of Independent Variables

Three types of proximity variables were incorporated into the model in order to consider the features of multimodal P3 project. The effect by HOT lanes was measured by the straight-line distance from each property to the nearest HOT lanes ramp. As proven by Boarnet and Chalermpong (2001), the straight-line distance is strongly correlated with road-network distance in a relatively dense network; thus, straight-line distance is used for the analysis instead of additionally computing road-network distance. Also, to consider the effect by multimodal component, the straight-line distances from each property to the nearest express bus route that uses the HOT lanes were calculated. Note that only transit service was considered in this research as a multimodal component because other modes, such as bike and pedestrian, rarely use the HOT lanes and the data of taxi or carpooling is not properly available. The last variable for proximity was the straight-line distance from each property to the nearest regional activity center. This variable was expected to catch any changed travel impedance by I-495 Express Lanes for person's activities. Figure VI-3 describes the regional activity centers that existed before and after construction.



1. Downtown Washington	27. Dulles Corner
2. Georgetown	28. Dulles East
3. Monumental Core	29. Dulles West
4. New York Avenue	30. Fairfax Center
5. Ballston/Virginia Square	31. I-95 Corridor/ Engineer Proving Ground
6. Clarendon/Court House	32. Springfield
7. Crystal City	33. City of Fairfax—GMU
8. Pentagon City	34. Downtown Leesburg
9. Rosslyn	35. Corporate Dulles
10. Friendship Heights	36. Germantown
11. Bailey's Crossroads/Skyline	37. North Frederick Avenue
12. Bethesda CBD	38. Rockville Town Center
13. Silver Spring CBD	39 Shady Grove/King Farm/Life Sciences Ctr
14. White Flint	40. White Oak
15. Twinbrook	41. Greenbelt
16. The Pentagon	42. New Carrollton
17. Herndon	43. Konterra
18. Merrifield/Dunn Loring	44. Potomac Mills
19. Reston East	45. Airport/Monocacy Blvd.
20. Reston West	46. Urbana
21. Tysons Corner	47. Route 28 North
22. National Institutes of Health	48. Largo Center
23. Rock Spring Park	49. National Harbor
24. Beauregard Street	50. Innovation
25. Waldorf Commercial	51. Gainesville
26. Beltway South	52. Woodbridge

FIGURE VI-3. Regional activity centers (dotted circles in the left figure)

Another objective of this research is to investigate the relationship between multimodality and property values. Degree of multimodality was accordingly used as a variable, which is calculated by Equation (5) (proposed in Chapter 5). For the combining weights, 0.5 was used by Principal Component Analysis with scaling. Because only two data sources (AADT and TMS) have all trip purposes applied, parameter (p_i) became 0.5.

$$\begin{aligned} &Degree\ of\ Multimodality\ (DM) \\ &= 0.5\left[1-\alpha^2\sum_{i=1}^{l}\left(\sum_{j=1}^{k}\left(p_i=\frac{1}{mw_i+n}\cdot MS_{ij}\right)\right)^2\right]+0.5\left[1-\sum_{i=1}^{l}\left(\frac{MC_i}{TC}\right)^2\right] \quad (5) \end{aligned}$$

where,

MS_{ij} = mode share information of mode i from j source

p_i = parameter estimates of mode i $(= \frac{1}{mw_i + n})$

MC_i = specific cost for mode i

TC = total cost for a given project

k = number of mode share sources

l = number of modes in given sources

α = adjustment parameter

The variables of property attributes, socioeconomic characteristics and year dummy variables were to control for the real estate cycle, the transportation impedance and multimodality variables that are the focus of this analysis. The property attribute-related variables and socioeconomic characteristics were similar to those used in other hedonic price model studies (e.g., Vadali, 2008; Ko and Cao, 2013). The total number of jobs within a 1-mile radius from each property were computed with LEHD data. Figure VI-4 depicts the locations of jobs and each location has information on number of jobs. The locations are almost the same, but the number of jobs has been changed.

FIGURE VI-4. Locations of jobs in Fairfax County (black dots) (left is before, right is after construction)

6.6 Results and Discussion

Three sets of results are presented:

- Descriptive statistics
- Hedonic price model using a multimodal index (scenario 1)
- Hedonic price model using travel impedance (scenario 2)

6.6.1 Descriptive Statistics

Because this research concerns both residential and commercial property values in multiple years, considered data sets are complicated and require the data cleaning process to check the abnormal values before the analysis. First, unreasonably built years such as '0' or '2100' were deleted, and only properties that had been constructed within 100 years were considered at the stage of modeling. Second, information of year remodeled has too many zero values, meaning that the property has not been remodeled. To reflect this feature, only properties remodeled after 1995 were considered as a variable. Third, residential properties with no bathroom were deleted. Fourth, in terms of livable area for residential properties, and foundation area and total area of the building for commercial properties, zero values are unreasonable, thereby removing those values. Also, as shown in Figure VI-5, livable area information had some unusually large values (e.g., 305,956 sq.ft) which were regarded as outliers in this research. Livable areas over '0'sq.ft and below 95% percentile (3,698 sq.ft) of residential properties were used in the analysis.

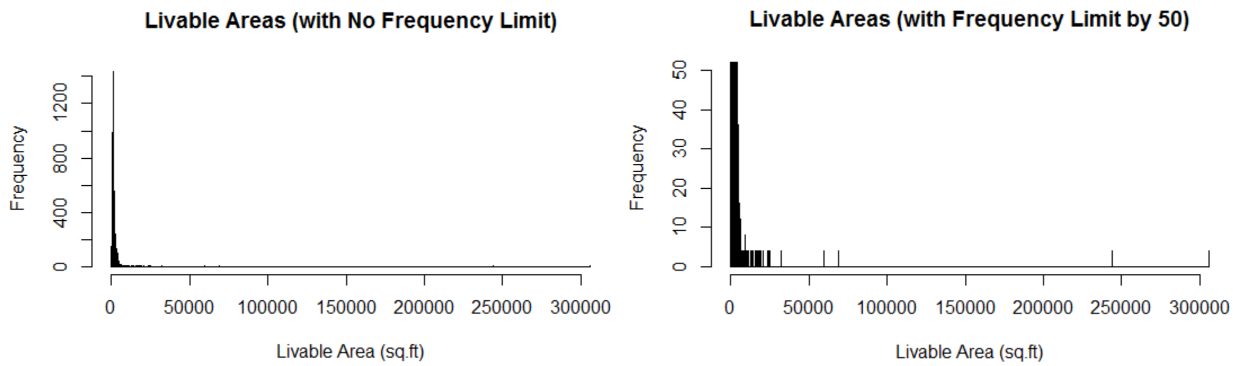


FIGURE VI-5. Histogram of livable areas on residential properties

Fifth, to avoid including outliers of property assessed values, the values over \$0 and below 95% percentile (\$924,978 for residential, \$52,193,883 for commercial) were also selected to make reasonable data sets (see Figure VI-6).

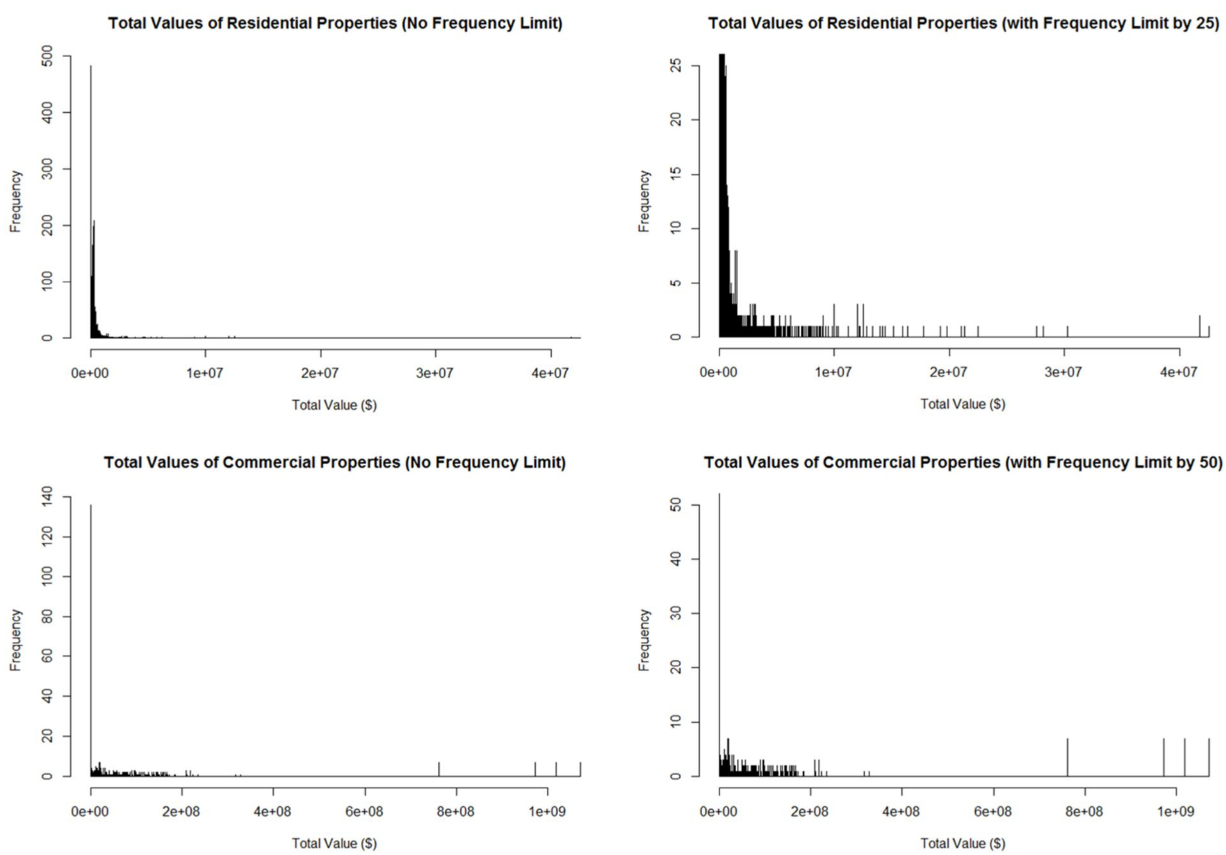


FIGURE VI-6. Histogram of total values on residential and commercial properties

Sixth, the degree of multimodality of I-495 Express Lanes was calculated for the analysis period. After construction, multimodality is changed to 0.197 on average, which is +0.073 and 58.9% increase compared to multimodality before construction (see Figure VI-7).

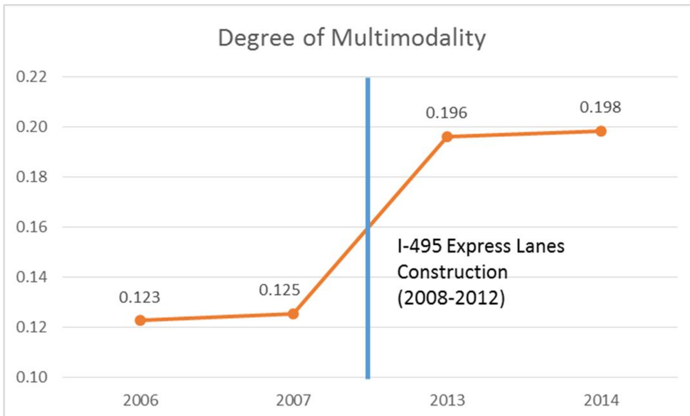


FIGURE VI-7. Trend line of multimodality

Lastly, given that commercial property has a variety of building types, only industrial buildings (39.5%), offices (5.1%), office condominiums (23.6%) and shopping centers (4.4%) were considered for the analysis based on their majority of proportions among 19 commercial building uses. Table VI-2 presents the summary of descriptive statistics with raw data and processed data.

TABLE VI-2. Descriptive Statistics

Variables		**Residential**		**Commercial**	
		Raw Data	Processed Data	Raw Data	Processed Data
Total property assessed value ($)	Max.	42556800	924950	1.071e+09	51914310
	Mean	506003	443272	1.365e+07	6264458
	Median	441070	427610	9.104e+05	2059390
	Min.	0	61480	0	82310

Nearest distance to HOT lanes ramps (meter)	Max.	7105.50	7037.93	5125.88	4968.29
	Mean	2852.01	2797.94	2197.79	2434.64
	Median	2897.88	2847.17	2184.80	2462.13
	Min.	35.44	35.44	24.46	41.86
Nearest distance to express bus routes (meter)	Max.	8534	8444	5153.0	5123
	Mean	2397	2333	1692.5	1667
	Median	2150	2111	1512.4	1378
	Min.	0	0	0	0
Nearest distance to regional activity centers (meter)	Max.	17614	17614	13304.7	13304.7
	Mean	5154	5202	2174.7	1590.8
	Median	4171	4155	454.4	215.7
	Min.	0	0	0	0
Degree of multimodality	Max.	0.1984	0.1984	0.1984	0.1984
	Mean	0.1611	0.1613	0.1617	0.1614
	Median	0.1961	0.1961	0.1961	0.1961
	Min.	0.1227	0.1227	0.1227	0.1227
Number of stories	Max.	3.00	3.00	23.00	17.000
	Mean	1.39	1.36	1.99	2.021
	Median	1.00	1.00	1.00	1.000
	Min.	0	1.00	0	0
Number of units	Max.	-		1989.00	1093.00
	Mean	-		14.76	13.75
	Median	-		0	0
	Min.	-		0	0
Foundation area (square feet)	Max.	-		400000	400000
	Mean	-		8939	20046
	Median			0	9044

	Min.	-		0	324
Total area of the building (square feet)	Max.	-		1637425	779512
	Mean	-		40277	34174
	Median	-		2106	9750
	Min.	-		0	250
Built year[a]	Max.	2100	2014	2014	2014
	Mean	1973	1971	1800	1978
	Median	1969	1968	1980	1980
	Min.	0	1915	0	1900
Number of bedrooms	Max.	9.000	9.000	-	
	Mean	3.054	2.951	-	
	Median	3.000	3.000	-	
	Min.	0	0	-	
Number of full baths	Max.	10.00	7.000	-	
	Mean	2.18	2.043	-	
	Median	2.00	2.000	-	
	Min.	0	1.000	-	
Livable area (square feet)	Max.	305956	3697	-	
	Mean	1746	1511	-	
	Median	1400	1334	-	
	Min.	0	436	-	
Year remodeled	Max.	2015	2014	-	
	Mean	321.6	336.9	-	
	Median	0	0	-	
	Min.	0	0	-	
Number of jobs within 1 mile radius	Max.	4839.0	4839.0	3464.0	3464.0
	Mean	277.4	287.6	186.5	95.2

	Median	24.0	25.0	18.0	18.0
	Min.	1.0	1.0	1.0	1.0
Observations		115,209	102,209	5,492	3,373

[a] A variable of building age is calculated by subtracting built year from 2014.

After data cleaning process, observations of residential and commercial were reduced to 102,209 and 3,373 from 115,209 and 5,492, respectively.

6.6.2 Hedonic Price Model Using a Multimodality Index

Because two different types of properties considered, four hedonic price models were generated. Even if variable estimates which are necessary to specify the hedonic price model do not always meet a strict definition of statistical significance (Bartik, 1988), efforts are made to include variables that show statistical significance at least a 95% confidence level. Table VI-3 and Equation (6) show the result of hedonic price model with multimodality in residential properties. It was conjectured that several included variables such as multimodality, number of stories and building age could be associated with property values in a non-linear fashion. Thus, polynomial terms were included in an initial model specification.

TABLE VI-3. Hedonic Price Model with a Multimodality in Residential Property

Variable	**Coefficient**	**Standard Error**	**t-value**	***p-value***
(Intercept)	2.30e+00	9.02e-01	2.554	0.0107*
Multimodality	2.56e+02	1.74e+01	14.683	< 2e-16***
Multimdoality^2	-2.03e+03	1.11e+02	-18.364	< 2e-16***
Multimodality^3	5.02e+03	2.32e+02	21.662	< 2e-16***
Number of Stories	-1.93e-01	2.97e-02	-6.503	7.92e-11***

Number of Stories^2	6.72e-02	9.76e-03	6.889	5.67e-12***
Number of Bedrooms	4.13e-02	7.97e-04	51.757	< 2e-16***
Number of Full Baths	1.41e-01	1.35e-03	104.673	< 2e-16***
Building Age	-9.56e-03	2.22e-04	-43.114	< 2e-16***
Building Age^2	1.43e-04	2.89e-06	49.52	< 2e-16***
Number of Jobs (in 100 scale)	5.14e-04	1.19e-04	4.32	1.56e-05***
Livable area (in 100 scale)	3.24e-02	1.97e-04	164.737	< 2e-16***
Remodeled in 5 Years (≥2010)	2.61e-02	4.71e-03	5.537	3.08e-08***
Remodeled in 10 Years (≥2005 and <2010)	4.25e-02	4.61e-03	9.218	< 2e-16***
Remodeled in 15 Years (≥2000 and <2005)	3.21e-02	4.03e-03	7.965	1.67e-15***
Remodeled in 20 Years (≥1995 and <2000)	9.19e-02	9.22e-03	9.965	< 2e-16***
Summary Statistics				
F-statistic	1.233e+04			
Adjusted R-squared	0.644			

*** Significant at 0.001 or smaller significance level

** Significant at 0.01 significance level

* Significant at 0.05 significance level

All independent variables are statistically significant at the 95 % confident level, and the adjusted R-square is 0.64. Generally, the variable signs are logical: for example, the number of full baths (with a coefficient of positive 0.141) increases the assessed value. The polynomials that were used requires some careful interpretation but generally these results are reasonable. For example, consider number of stories: the negative coefficient (-0.193) for the single value of this term and the positive coefficient for the square of this term (0.0672) means that, all other things being equal, a building loses value as it increases from one story to two stories but increases value as it increases from two stories to three stories (and beyond). A similar explanation is noted for the age of the building. Notice that because the multimodality term ranges from 0.1227 and 0.1984, the combined impacts of the three coefficients is that increased multimodality may decrease value (up to a multimodality of about 0.17) and then increase assessed values thereafter. To check the normality assumption of variance, the histogram of residuals are drawn in Figure VI-8. A symmetric bell-shaped histogram which is evenly distributed around zero indicates that the normality assumption is likely to be true.

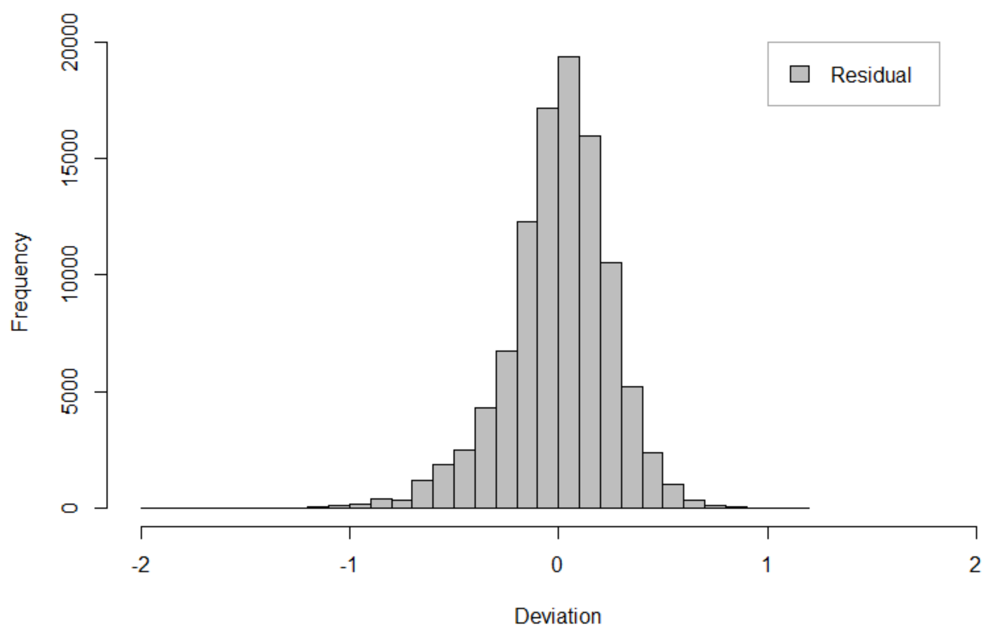


FIGURE VI-8. Histogram of residuals in residential property

The fitted hedonic price model can be described as below Equation (6).

$$
\begin{aligned}
ln(PropertyValue) \\
&= 2.3 + 256 \times Multimodality - 2030 \times Multimodality^2 + 5020 \\
&\times Multimodality^3 - 0.193 \times No.Story + 0.0672 \times No.Story^2 \\
&+ 0.0413 \times No.Bed + 0.141 \times No.Bath - 0.00956 \times BuildAge \\
&+ 0.00014 \times BuildAge^2 + 0.00051 \times No.Jobs + 0.0324 \times LivableArea \\
&+ 0.0261 \times I(YearRemodeled5) + 0.0425 \times I(YearRemodeled10) \\
&+ 0.0321 \times I(YearRemodeled15) + 0.0919 \times I(YearRemodeled20)
\end{aligned} \tag{6}
$$

where,

$Multimodality$ = degree of multimodality

$No.Story$ = number of stories

$No.Bed$ = number of bedrooms

$No.Bath$ = number of full baths

$BuildAge$ = building age ($= 2014 - built\ year$)

$No.Job$ = number of jobs in 100 scale

$LivArea$ = livable area in 100 scale (sq.ft)

$I(RemoYear5)$ = indicator equaling to 1 for remodeling year in 5 years (≥2010)

$I(RemoYear10)$ = indicator equaling to 1 for remodeling year in 10 years (≥2005 and <2010)

$I(RemoYear15)$ = indicator equaling to 1 for remodeling year in 15 years (≥2000 and <2005)

$I(RemoYear20)$ = indicator equaling to 1 for remodeling year in 20 years (≥1995 and <2000)

The focus of this study lies on the impact of multimodal P3 projects on property values while controlling for potential factors influencing the property values. Thus, the discussion of results is centered on parameter estimates of the multimodality variable. Because the model includes polynomials with orders 2 and 3 for the multimodality variable, the result is not easily understood. Given that the main interest for this model is the relationship between the changed multimodality and residential property values, a graph was created to show the relationship while setting other characteristics at conditions prevalent in the data. For example, residential property remodeled between 2000 and 2005 has the largest proportion (37.4%) among all the properties. The graph was accordingly created for the properties remodeled between 2000 and 2005. In a similar manner, other characteristics were fixed to focus on the relationship between multimodality and property value.

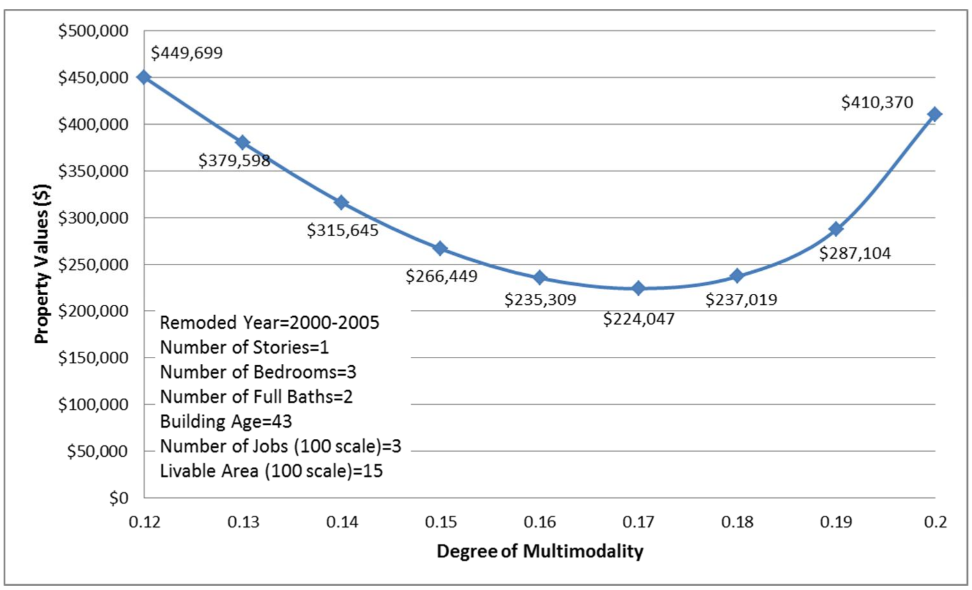


FIGURE VI-9. Estimated residential property values by multimodality change

Since multimodality values range from about 0.12 to 0.2, the cubic relationship is shown for the range in Figure VI-9. Residential property values (remodeled in 2002) are predicted to decrease as multimodality increases until around 0.17 and to increase somewhat rapidly after the turning point of 0.17. This means that, on average, a decrease of $45,131 in a property value is predicted per an increase of 0.01 in the degree of multimodality until 0.17 and an increase of $62,108 per 0.01 of multimodality is predicted after 0.17.

Table VI-4 and Equation (7) show the result of hedonic price model with multimodality in commercial properties. The number of jobs was found to be statistically non-significant at a 95% confidence level and thus was not included in the final model.

TABLE VI-4. Hedonic Price Model with a Multimodality in Commercial Property

Variable	**Coefficient**	**Standard Error**	**t-value**	***p-value***
(Intercept)	-1.33e+02	3.57e+01	-3.715	0.000207***
Multimodality	2.77e+03	6.90e+02	4.01	6.24e-05***
Multimdoality^2	-1.69e+04	4.39e+03	-3.846	0.000123***
Multimodality^3	3.37e+04	9.18e+03	3.667	0.00025***
Number of Stories	2.29e-01	1.83e-02	12.516	< 2e-16***
Number of Units	1.44e-03	4.54e-04	3.166	0.001564**
Foundation Area (in 100 scale)	1.01e-03	1.23e-04	8.277	< 2e-16***
Property Type: Industrial Building	-1.09e+00	1.19e-01	-9.123	< 2e-16***
Property Type: Office	-6.68e-01	1.23e-01	-5.414	6.68e-08***
Property Type: Office Condominium	-2.14e+00	1.19e-01	-18.092	< 2e-16***
Property Type: Shopping Center	1.07e+00	1.80e-01	5.952	2.97e-09***
Total Area of the Building (in 100 scale)	4.39e-04	4.16e-05	10.549	< 2e-16***
Building Age	-1.90e-02	3.11e-03	-6.097	1.23e-09***
Summary Statistics				
F-statistic	208.8			

Adjusted R-squared	0.462

*** Significant at 0.001 or smaller significance level

** Significant at 0.01 significance level

* Significant at 0.05 significance level

All other control variables show reasonable signs at a 99% confidence level, and the adjusted R-square is 0.462 which is near the average value of toll road-related study with hedonic price model (Boarnet and Chalermpong, 2001). As shown in Figure VI-10, the variance is normally distributed, meaning that the normality assumption is likely to be true.

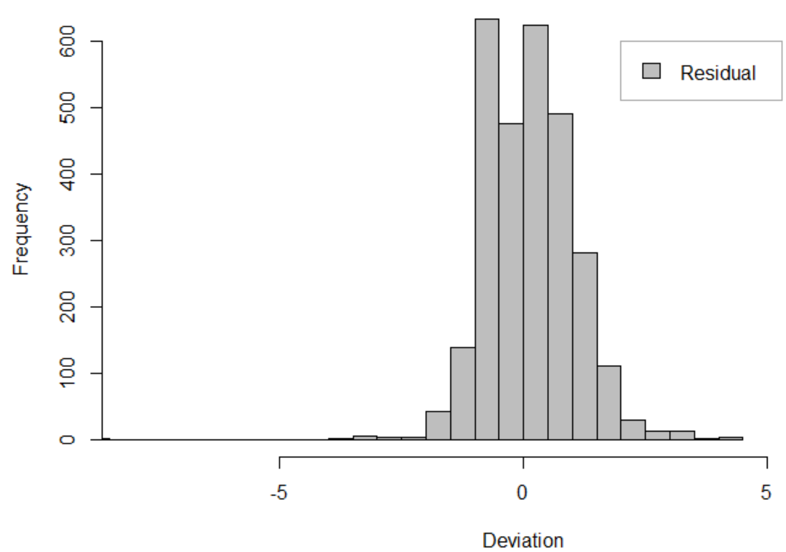


FIGURE VI-10. Histogram of residuals in commercial property

With respect to multimodality, this model also shows a very similar cubic pattern to the one in residential properties. To enhance the understanding, the cubic equation of multimodality is drawn as shown in Figure VI-11. For the same reason, industrial buildings (39.5%) for creating Figure VI-11 were chosen and all other variables were set at conditions near the average values of the data.

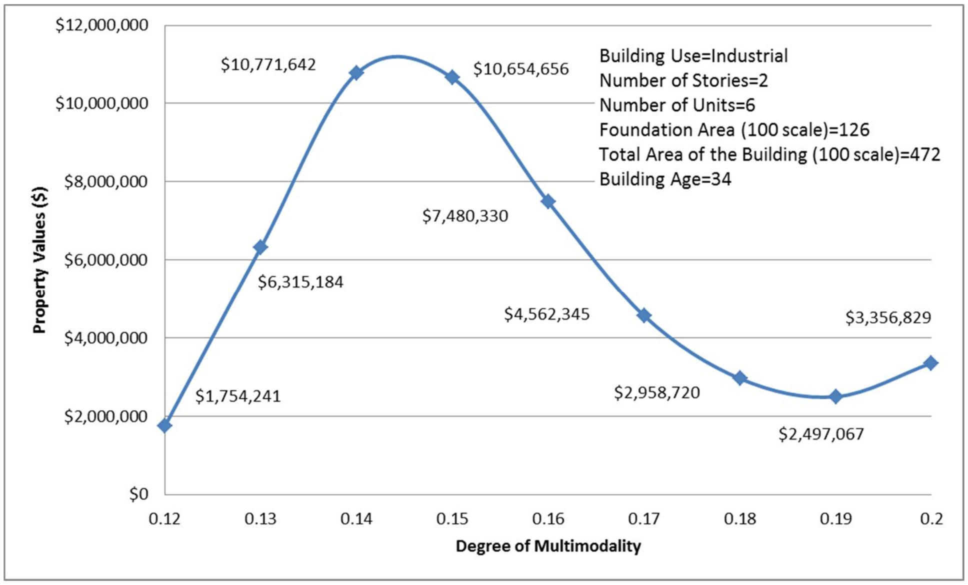


FIGURE VI-11. Estimated commercial property values by multimodality change

The commercial property values increases when multimodality rises from 0.12 to around 0.145, decreases as multimodality rises to 0.19, and the increases for higher multimodality values. Although there is a range reducing property values, the slope of increase is steeper than the slope of reduction on property values. In other words, in the range from 0.12-0.15 of multimodality, the industrial building values are more sensitive than those between 0.15-0.19.

As a result from residential (remodeled in 2002) and industrial building cases, although the multimodality range from 0.15 to 0.17 resulted in a reduction of property values, in other ranges, higher multimodality could contribute larger property values by I-495 Express Lanes.

6.6.3 Hedonic Price Model Using a Travel Impedance

Table VI-5 presents the hedonic price model with travel impedance in residential property. All estimated coefficients are statistically significant at the 95% confidence level, and the adjusted R-square is 0.65 which is quite similar to the adjusted R-square (0.64) for the multimodality model based on residential property. The number of jobs was removed because of being statistically non-significant at 95% confidence level. The model appears to give reasonable results, with some surprises. Consistent with the residential property model using multimodality, increasing the number of stories increases the value of the parcel if one increases to three or more stories, although increasing from one to two stories decreases the value of the parcel. Interestingly increased age reduces the value of the parcel but only up to a point: increasing the age beyond 61 years leads to an increased parcel value. The one result which cannot be fully explained is that remodeling residential properties during the period 2000-2005 is associated with a negative value. That said, the focus of this model is to understand how travel impedance (distance to HOT lanes ramps, express bus routes, and regional activity centers) affects parcel values.

TABLE VI-5. Hedonic Price Model with a Travel Impedance in Residential Property

Variable	**Coefficient**	**Standard Error**	**t-value**	***p-value***
(Intercept)	1.22e+01	2.00e-02	613.306	< 2e-16***
Distance to Express Bus Routes (before construction)	-3.23e-06	9.07e-07	-3.559	0.000372***
Distance to Express Bus Routes (after construction)	-1.20e-05	1.25e-06	-9.619	< 2e-16***
Distance to HOT Lanes Ramps (before construction)	1.97e-05	1.02e-06	19.311	< 2e-16***
Distance to HOT Lanes Ramps (after construction)	2.59e-05	1.41e-06	18.32	< 2e-16***
Distance to Regional Activity Centers (before construction)	-5.50e-06	2.72e-07	-20.272	< 2e-16***
Distance to Regional Activity Centers (after construction)	-5.78e-06	3.70e-07	-15.613	< 2e-16***
Number of Stories	-1.50e-01	2.94e-02	-5.088	3.62e-07***
Number of Stories^2	5.28e-02	9.68e-03	5.461	4.75e-08***

Number of Bedroom	4.23e-02	7.92e-04	53.453	< 2e-16***
Number of Full Bath	1.42e-01	1.33e-03	106.874	< 2e-16***
Building Age	-7.93e-03	2.29e-04	-34.667	< 2e-16***
Building Age^2	1.28e-04	2.93e-06	43.635	< 2e-16***
Livable area (in 100 scale)	3.22e-02	1.96e-04	164.323	< 2e-16***
Year remodeled (≥2010)	2.18e-02	4.66e-03	4.679	2.89e-06***
Year remodeled (≥2005 and <2010)	3.77e-02	4.56e-03	8.28	< 2e-16***
Year remodeled (≥2000 and <2005)	-9.20e-03	4.06e-03	-2.263	0.023658*
Year remodeled (≥1995 and <2000)	7.92e-02	9.12e-03	8.689	< 2e-16***
Indicator for after construction	-1.57e-01	4.24e-03	-37.061	< 2e-16***
Summary Statistics				
F-statistic	1.066e+04			
Adjusted R-squared	0.652			

*** Significant at 0.001 or smaller significance level

** Significant at 0.01 significance level

* Significant at 0.05 significance level

The normality assumption of variance was also checked through the histogram of residuals (Figure VI-12). The histogram is well symmetric bell-shaped around zero.

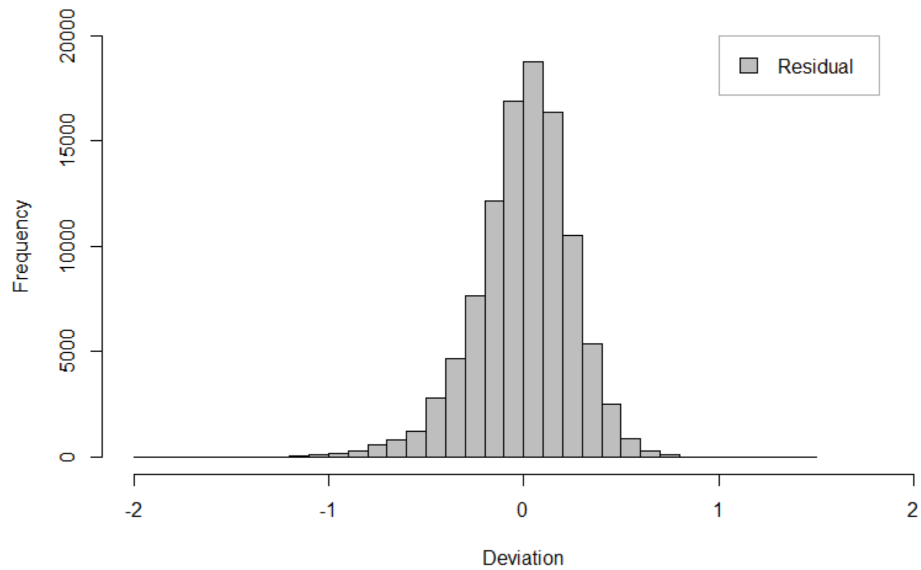


FIGURE VI-12. Histogram of residuals in residential property

For the same reason, residential property remodeled between 2000 and 2005 was chosen to interpret any impacts on property values by the travel impedance. All other variables were set at conditions near the average values of the data (Table VI-6).

TABLE VI-6. Average Values for Interpretation (Residential Property)

Variable	Average Value
Distance to Express Bus Routes (before construction) (meter)	2333
Distance to Express Bus Routes (after construction) (meter)	1184
Distance to HOT Lanes Ramps (before construction) (meter)	2798
Distance to HOT Lanes Ramps (after construction) (meter)	1421
Distance to Regional Activity Centers (before construction) (meter)	5202
Distance to Regional Activity Centers (after construction) (meter)	2618
Number of Stories	1
Number of Bedroom	3
Number of Full Bath	2

Building Age (year)	43
Livable area (in 100 scale) (sq.ft)	15

Proximity to express bus routes that use the I-495 Express Lanes places a premium on residential property values in contrast to other parcels. This premium is not immediately apparent, however, without considering the concept of a "market value change rate" which is analogous to creating a control group. This market value change rate was applied to all property values before construction in order to see the premium. A branch of the Fairfax County Government estimated the median and average market values of residential properties (Economic, Demographic and Statistical Research, 2006; 2007; 2013; 2014). Based on these data, the average residential market values outside the impact boundary but within Fairfax County are \$619,680 (2006), \$626,237 (2007), \$490,659 (2013) and \$494,284 (2014), respectively. The average market value dropped from \$622,958 (2006-2007) to \$492,471 (2013-2014) by an average of 20.9%—hence the change rate use for this analysis. If it were assumed that residential property values (where home remodeling was done between 2000 and 2005) also had the same trend of a 20.9% reduction in value, as shown in the right side of Figure VI-13, then residential property values located at zero distance from the bus routes increased after construction (from \$335,408 to \$370,518). That is, without the positive impacts of the I-495 Express Lanes, residential property values would have decreased from \$424,279 (2006-2007 [see left of Figure VI-13]) to \$335,408 (2013-2014 [see right of Figure VI-13); however, the multimodal P3's impact meant the value dropped not to \$335,408 but rather \$370,518 [also right side of Figure VI-13]. This gap suggests a premium rendered by the proximity of express bus routes using I-495 Express Lanes. However, because of the steeper slope after construction (with respect to the negative impacts of a parcel moving from the bus routes), the "premium" offered by proximity to express bus routes vanishes rapidly as the distance increases and disappears completely at approximately 8,000 meters (about 5 miles) away from the bus routes.

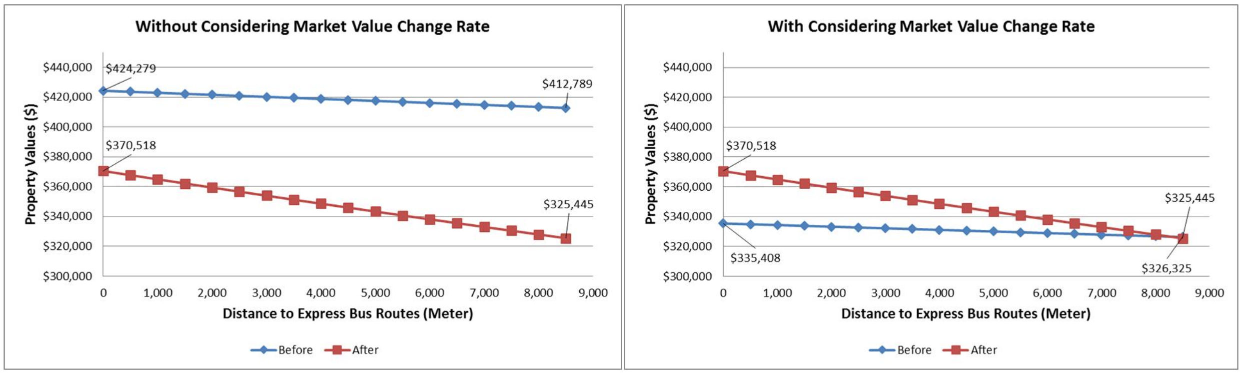


FIGURE VI-13. Property values with distance to express bus routes

Similarly, the proximity to regional activity centers after construction provides a premium for residential property values. After applying the market value change rate, the right side of Figure VI-14 suggests a decreased travel impedance may help prevent residential property values within the impact boundary from dropping, because locations outside the impact boundary did show a decrease in value. The gap between $378,750 and $342,559 (see the right side of Figure VI-14) suggests a premium attributed to the proximity of regional activity centers (with the I-495 Express Lanes serving to increase this access)

FIGURE VI-14. Property values with distance to regional activity centers

Unlike the two previous results which concerned bus travel and regional activity centers, the proximity to HOT lanes ramps have a relatively small impact on property values. As shown in the right side of Figure VI-15, after considering the market value change rate, the I-495 Express Lanes in part contribute to prevent residential property values from being reduced: the value is \$330,765 rather than \$315,081. However, an increase in distance shows higher residential property values. Prior to construction, an increase in distance also increased residential property values, however, the slope is steeper than after than prior to construction. It is possible that, as suggested by previous literature (e.g., Cervero and Duncan, 2002), disamenity effects such as noise, fumes or vibration from the highway could result in lower values near HOT lanes. However, such observations are a reminder that the multimodal P3 only explains a portion of the change in property values.

FIGURE VI-15. Property values with distance to HOT lanes ramps

The final hedonic price model reflects commercial property using travel impedance for the transportation vector. All coefficients have statistically significance at 95% confidence level, and show reasonable signs. Because of high *p-values* of coefficients for the distance to regional activity centers and the number of jobs at 95% confidence level, two variables were considered but omitted in the final model. The adjusted R-square is the same as the model with multimodality in commercial property, suggesting that the transportation vector contributes a similar amount of information.

TABLE VI-7. Hedonic Price Model with a Travel Impedance in Commercial Property

Variable	**Coefficient**	**Standard Error**	**t-value**	***p-value***
(Intercept)	1.53e+01	1.59e-01	96.003	< 2e-16***
Distance to Express Bus Routes (before construction)	-1.34e-04	3.85e-05	-3.468	0.000533***
Distance to Express Bus Routes (after construction)	1.14e-04	4.79e-05	2.381	0.017328*
Distance to HOT Lanes Ramps (after construction)	-1.10e-04	3.76e-05	-2.92	0.003528**
Number of Stories	2.20e-01	1.87e-02	11.746	< 2e-16***
Number of Units	1.53e-03	4.56e-04	3.357	0.000798***
Foundation Area (in 100 scale)	1.08e-03	1.24e-04	8.704	< 2e-16***
Property Type: Industrial Building	-1.05e+00	1.20e-01	-8.764	< 2e-16***
Property Type: Office	-5.90e-01	1.28e-01	-4.606	4.29e-06***
Property Type: Office Condominiums	-2.06e+00	1.25e-01	-16.533	< 2e-16***
Property Type: Shopping Center	1.03e+00	1.80e-01	5.695	1.36e-08***
Total Area of the Building (in 100 scale)	4.19e-04	4.19e-05	9.997	< 2e-16***
Building Age	-1.74e-02	3.15e-03	-5.532	3.45e-08***
Summary Statistics				
F-statistic	208.1			
Adjusted R-squared	0.462			

*** Significant at 0.001 or smaller significance level

** Significant at 0.01 significance level

* Significant at 0.05 significance level

There are two key interpretations of the variables. First, as perhaps expected, proximity to the HOT lanes increases parcel values; distance decreases commercial property values, suggesting that businesses value the greater access to this facility. The second interpretation is more difficult: the distance to the express bus routes changed from negative (prior to construction) to positive (following construction). This result would ostensibly suggest that for commercial properties, there was not a transit premium.

Figure VI-16 shows that the variance is normally distributed around zero which satisfies the normality assumption of variance.

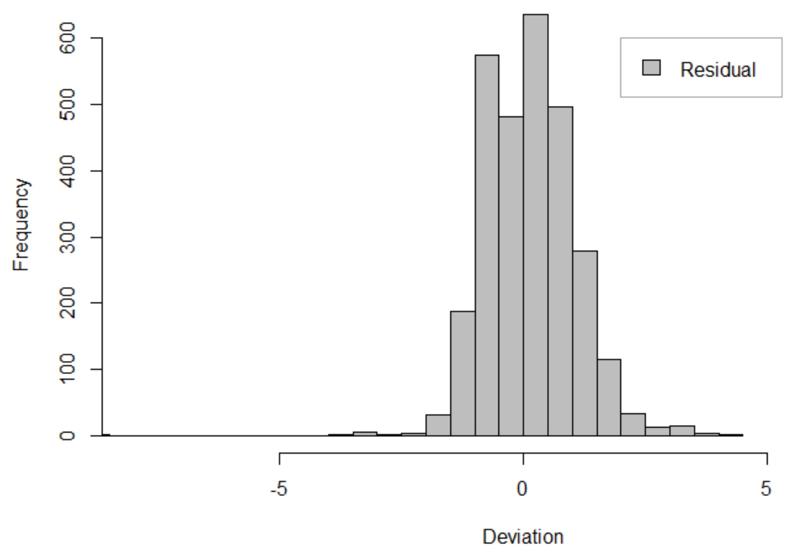


FIGURE VI-16. Histogram of residuals in commercial property

For the same reason, industrial buildings (39.5%) were chosen to draw the cubic equations of distance to express bus routes and HOT lanes ramps, because of its largest proportion among property types and all other variables were set at conditions near the average values of the data (Table VI-8).

TABLE VI-8. Average Values for Interpretation (Commercial Property)

Variable	**Average Value**
Distance to Express Bus Routes (before construction) (meter)	1649
Distance to Express Bus Routes (after construction) (meter)	829
Distance to HOT Lanes Ramps (after construction) (meter)	1134
Number of Stories	2
Number of Units	6
Foundation Area (in 100 scale) (sq.ft)	126
Total Area of the Building (in 100 scale) (sq.ft)	472
Building Age (year)	34

The right side of Figure VI-17 reflects the market value change rate, where the residential rate used earlier (Economic, Demographic and Statistical Research, 2006; 2007; 2013; 2014) was applied to commercial properties (as a commercial-based change rate is not available.) The graphic suggests that proximity of express bus routes helps maintain property values; this impact is reflected by the difference between the after line (in red) and the before line (in blue). Notice that the premium is not very sensitive to distance as indicated by the reduction in slope following construction. In other words, industrial properties, as is the case with residential properties, have higher property values (all other things being equal) for parcels located close to stops serving express bus routes. However, the negative impact of increasing this distance is not at severe following construction as it was prior to construction.

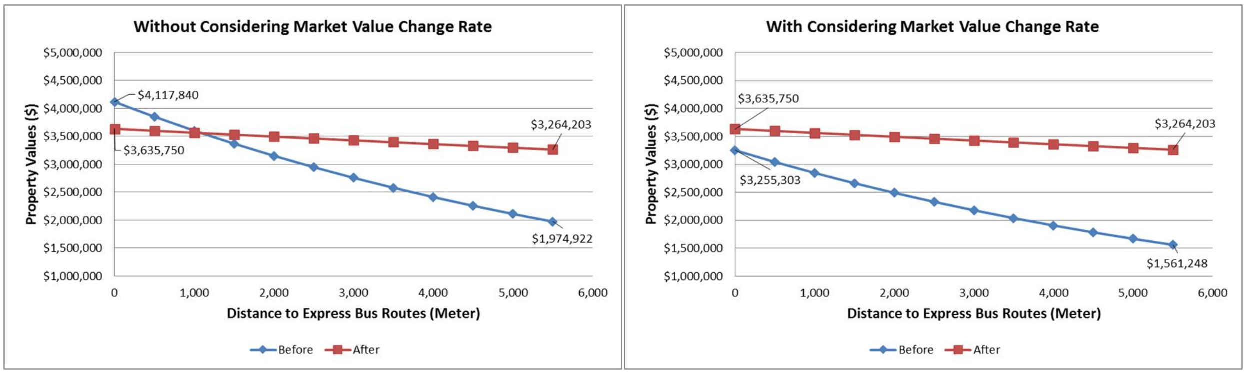


FIGURE VI-17. Property values with distance to express bus routes

The proximity to HOT lanes ramps gives positive impacts on commercial property values (i.e., industrial buildings). Compared to the residential properties, disamenity effects do not exist in this case. This may be because commercial properties' preference for locations where transportation is easily accessible is larger than other factors, such as increased noise, which would cause such properties to lose value. That is, a changed travel impedance by I-495 Express Lanes yields higher property values for parcels near HOT lanes ramps. However, the steeper slope shown in Figure VI-18 means this premium diminishes rapidly as the distance increases and disappears completely at approximately 3,000 meters (about 2 miles) away from the HOT lanes ramps. After 3,000 meters, in fact, the disamenity effects become larger and reduce commercial property values more than was the case prior to HOT lanes construction.

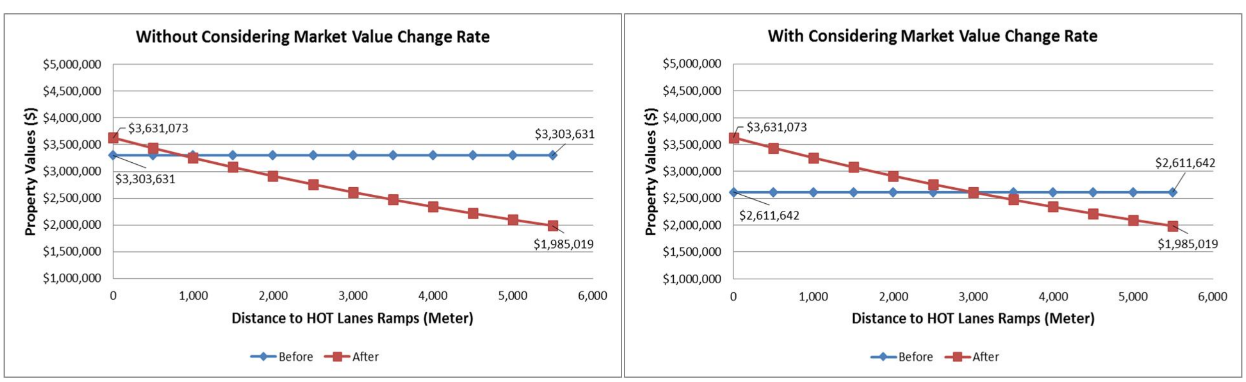


FIGURE VI-18. Property values with distance to HOT lanes ramps

6.7 Conclusions

While P3 projects have generated increased interest, there were relatively few studies that focus on the how multimodal P3 projects impact property values. While one obstacle to such studies is common to other transportation research areas—a dearth of comparable, longitudinal data sets—a second obstacle has been developing a repeatable approach for quantifying the degree of multimodality or otherwise characterizing how multimodal components reduce travel impedance. In that sense, this research provides five contributions based on the application of four hedonic price models.

- Non-proprietary, or otherwise “open” data sources, are sufficiently detailed that they can be used to define a multimodal transportation network. The two data sources used in this effort were open street map and the general transit feed specification, otherwise known as “OSM” and “GTFS.” The availability of these data sources means that users do not necessarily have to obtaining data directly from public agencies (although in some cases, agencies are providing their data to these open sources.)

- It is possible to describe multimodality in two different ways: as a multimodality indicator (which characterizes both mode use and mode cost) and as a vector (of distances to HOT lane ramps, bus stops, and regional activity centers). The value of these two formulations—as a single indicator and as a vector of three impedances—is that one can then attempt to quantify how multimodality affects property values. For example, one can determine whether a given project increased the degree of multimodality and in turn affected property values.

- The multimodality of this corridor increased from 0.123 (in 2006) to 0.198 (in 2014). When one compares the multimodality for a two year period prior to construction (2006-2007) and a two year period following construction (2013-2014) construction, there is a 61% increase in this indicator—that is, the I-495 Express Lanes have increased multimodality.

- Increasing the degree of multimodality has a nonlinear impact on property values. These results suggest that for residential property values, increasing multimodality from its lowest possible value (about 0.12) to 0.17 decreases property values, and then increasing above 0.17 increases property values. When all other factors are held constant, increasing multimodality from value of 0.17 to its maximum observed value appears to have increased property values by 83.2%. For commercial property values, the impact is also nonlinear, and in fact, early results do not suggest that maximizing multimodality maximizes commercial property values, but there are specific ranges (0.12-0.15, 0.19-0.2) that contribute to increasing property values,

- For residential properties, the P3 project may have resulted in a greater premium being placed on proximity to transit. This is suggested by the fact that following construction of the I-495 Express Lanes, a greater negative coefficient is observed for the variable indicating distance to transit. The model suggests that, following construction, a parcel's value drops by approximately $5 for each additional meter the parcel is located away from the express bus routes.

- For commercial properties only, the model suggests the better proximity to HOT lanes may have increased parcel values. This premium is large enough to cancel out the disamenity effects which are observed in residential properties. After construction, a commercial property's value decreases by approximately $300 for each additional meter the parcel is located away from the HOT lanes ramps. (Keep in mind that commercial properties have larger values than residential properties which is why the $300 noted here is so much larger than the $5 noted in the bullet above.)

The initial question of interest was whether a multimodal P3 project's impact on travel impedance could be reflected in new property values. Given that changes in property values have been empirically detected, a future value capture mechanism could enhance the financial viability in multimodal P3s. Because residential and commercial properties showed different impacts on property values, and because these impacts varied as a function of location and travel impedance, site-specific calibration is necessary. Eventually, it is hoped that empirical evidence from this research can be used to increase private and public sector participation in multimodal P3 projects.

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CHAPTER VII CONCLUSIONS AND RECOMMENDATIONS

7.1 General 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 distinct 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 dissertation research consists of five subtopics, or five publishable papers, which in the aggregate provide some evidence that multimodal components may be used in a value capture mechanism to support implementation of multimodal P3s.

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.

The second topic, Chapter 3, examined how agencies view the inclusion of multimodal components in P3s. The interviews revealed that both the definition of P3—and the extent of multimodality—varied widely; the interviews suggested that some published literature is simply not a reliable way for determining what a P3 project is. Based on interviews for of agency representatives pursuing 23 candidate multimodal P3 projects in 10 U.S. states, few projects explicitly considered value capture in P3 project development—yet land development impacts were considered to some degree in most projects. This suggests that being able to quantify land development impacts—as done in the last chapter of this dissertation—may be a goal that agencies would like to be able to achieve.

The third topic, in Chapter 4, 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.

The fourth topic, in Chapter 5, quantified the degree of multimodality for six P3 projects and related this degree to jobs-housing balance. Based on the larger impact boundary, all P3 projects contributed to increase the multimodality. This finding supports the concept that more emphasis on multimodal components could have a positive impact on urban form.

The fifth topic, in Chapter 6, analyzed the effects of multimodal P3s on property changes with one Virginia case study. Two types of relationships were validated: (1) the relationship between changed potential travel impedance and property values and (2) the relationship between the changed multimodality of a P3 project and property values. The results explicitly show that within a given range of multimodality values, better multimodality may yield higher property values; however, this relationship is not linear but parabolic, meaning that site-specific calibration is essential. Further, it was demonstrated that a changed travel impedance resulting from a multimodal P3 project can provide increase both residential and commercial property values. Given that the changes on property values are detected, this could be used in a future value capture mechanism as revenues by taxes or fees.

In a purely academic context, one might argue that only the third, fourth and fifth topics are critical. However, the authorizing environment to pursue the fifth topic would not exist without a rationale that articulates why multimodal P3s merit detailed study. That rationale exists only by completing the first four topics—understanding why private participation has historically been attractive, recognizing the context agencies face when considering whether to make a P3 project "multimodal", being able to define this multimodality and a social goal—jobs housing balance—in a defensible manner, and empirically relating the two. In short, it has been the author's strategy to align these subtopics to reach the goal of this research: an empirical model demonstrating how multimodal P3 projects influence property values—so that such a model could eventually support a value capture strategy.

In addition, Meyer and Miller (2013) have noted that the transportation planning process is "inherently political" rather than 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). In California in 2010, strong interest in sustainability supported the California High Desert Corridor P3 project. Stakeholders' values for each of these three examples differ: the first valued geometric improvements (as documented by the Good Roads Movement), the second valued reduced reliance on government, and the third valued green energy and rail travel. If the author had been trying to encourage multimodal P3s in the environment of the first example, then the dissertation would have focused exclusively on how P3s can improve geometric design. If the author had been trying to encourage multimodal P3s in the second example, the dissertation would have focused more heavily on how such P3s could reduce government regulation and outlays. If the author had tried to encourage P3s in the third example, the dissertation would have focused on the twin objectives of increased rail mode share and reduced fossil fuel consumption.

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 dissertation 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.

7.2 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 several significant contributions to multimodal enhancements in P3s. Key contributions include the following:

- 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.

- The factors that influence key decisions practitioners make with multimodal P3s, including land impacts, were qualitatively identified based on interviews with related-agencies for pursuing multimodal P3s. Some of this interview-based information is not available from other sources.

- A new gamma-based dissimilarity index was developed and statistically proven to better replicate observed trip length frequency distributions from six sites. This more generalized form can be collapsed to the 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 was identified. There is not literature that currently provides an indication of the extent to which these projects are multimodal.

- A hedonic price model was incorporated to detect relationships in two situations: (1) between multimodality and property values, and (2) between potential travel impedance and property values. The model used real, publicly accessible data to define the multimodal transportation network, suggesting repeatability in other situations is feasible. The author is not aware of literature that has such relationships.

- The analysis in Chapter 4 to identify land development impacts in terms of jobs-housing balance by multimodal P3s may be used as an element of guidelines one might consider positive changes in urban forms by multimodal P3s.

- The positive correlation between multimodality and land development impacts and property values from Chapter 5 and Chapter 6 can be used to emphasize multimodality in transportation projects both in non-P3 projects and P3 projects.

- The statistical approach in Chapter 6 can help evaluate where and what properties can be expected for future property value increases that can be captured to support multimodal P3s.

This research was demonstrated by promising examples of multimodal P3s in the U.S.; therefore, it will bring instrumental benefits to the overall P3 programs to enhance the multimodal components for the future. In addition, given this research is very interdisciplinary, the results from each chapter can be practically used by practitioners and researchers from various fields, such as urban planning, transportation planning, and transportation economics.

7.3 Limitations and Future Research

There are several additional directions for future research.

- 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 from practitioners. The comparison could suggest additional data sources for the indicator, such as net present value of project costs.

- From Chapter 4 and Chapter 5, intermodal centers show higher multimodality and better urban form impacts within given impact boundaries. Accordingly, analysis with hedonic price models in different cases (e.g., Miami Intermodal Center) can bring meaningful contributions compared to those of case studies for express lanes (e.g., I-495 Express Lanes).

- With multimodal transportation networks built from open data sources, it is possible to calculate estimated travel time before and after construction; thus, composite travel times of multiple modes can be used as a variable to explain the multimodal aspect in hedonic price model.

- Chapter 6 uses only impact boundary from 0.2 to 1 mile. To visualize additional spatial impacts, different impact boundaries need to be applied such as 13 miles based on the average travel distance to work in the U.S.

- The time horizon for each project varied, but longer time horizons are of interest. 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 impacts of that project were not necessarily been apparent until some time had elapsed following the project's implementation.

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