The Geography of Strategy: An Exploration of Alternative Frameworks for Transportation Infrastructure Strategy Development

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This thesis introduces the notion of a strategy development framework for transportation infrastructure systems. A strategy development framework has several dimensions: the organizations that own infrastructure, the ownership structure employed, the type and quantity of revenues generated, the revenue allocation methods for re-investing in the infrastructure, the degree of integration across transportation modes and other sectors, and the geographic scales controlled. We analyze the behavior of a range of alternative frameworks through a combined quantitative-qualitative approach, using Portugal's highway transportation system as the context.

Drawing on strategy literature from the management field, we begin by defining and characterizing a range of alternative strategy development frameworks for transportation infrastructure systems. Next, we analyze these frameworks quantitatively using an agent-based model which simulates the evolution of Portugal's intercity highway network over time and space. By varying the frameworks' dimensions (e.g., type of revenue, revenue allocation method, geographic scale of control), we observe differences in the resulting investment decisions for the network. We evaluate the performance of these investment decisions according to a range of metrics in order to determine which frameworks lead to desirable outcomes. The simulation, however, cannot fully capture the relationship between a framework and investment outcomes for the highway system, so we complement the model with a qualitative analysis which combines empirical cases and predicted stakeholder dynamics. The integrated quantitative-qualitative evaluation allows us to explain a wider range of trade-offs associated with each alternative framework.

The contributions of this research are threefold: (1) we offer the notion of strategy development, which allows for recognition and inclusion of emergent outcomes, as an alternative to the narrower concept of transportation planning; (2) we determine the influence of advanced transportation technologies (typically studied for their operational benefits) on *strategy* development; and (3) we explore the consequences of fundamental changes to the strategy development framework, notably along the dimension of geographic scale. While our theory and methods are applied to the case of Portugal's highway system—and we strive to produce results of value to that nation—we believe they can be profitably applied in other transportation contexts as well.

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Dedication

For my family

Acknowledgements

Shortly after undertaking the research effort that became this thesis, I participated in the New York City Marathon. Family, friends, and distance running specialists helped me to prepare, and on the day of the race several million people lined the streets of the five boroughs to offer anonymous but enthusiastic encouragement. Looking back, I cannot imagine completing that race alone. Likewise, the road to this thesis has been an intellectual marathon. I cannot fathom doing this alone, and I offer my sincere thanks to everyone who has cheered me on. A few deserve special mention.

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Conducting research in an unfamiliar context such as Portugal represented an additional challenge. Fortunately, I had a number of guides who made navigation of the complex institutional and physical landscape interesting, fruitful, and fun. My thanks to my friends Luís Martínez, Ana Capote, Carlos Azevedo, Elisabete Arsenio, and Maria Spandou for sharing their opinions as well as their contacts and to João Morgado for an extensive tour of Portugal's highway infrastructure. I am particularly grateful to Dra. Mariana Abrantes de Sousa for opening the doors of the Portuguese transportation sector, illuminating every corner, and insisting that I explore far beyond my initial intentions.

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Finally, my thanks to my advisor, Professor Joseph Sussman. Joe has been a mentor and friend since I first arrived at MIT in 2003. It's safe to say that I would not have finished this thesis without Joe's guidance, but it's also safe to say that I would never have even started. Joe has challenged me continuously to ask more difficult research questions, while providing ample room for my own intellectual growth in attempting to answer them. When I have struggled, he has been ready with encouragement and guidance; when I have made progress, he has raised the bar by posing ever more challenging questions. My appreciation cannot be overstated for Joe's contributions to this particular thesis and for his contributions to my thinking about how to approach complex problems, how to conduct research, and how to sustain the energy for, interest in, and appreciation of learning and teaching for a lifetime.

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1 Introduction

How should strategy be developed for transportation infrastructure systems? Like many broad policy questions, the short answer is, "It depends." This thesis provides a more complete answer by identifying and exploring a variety of alternative approaches for developing strategy for transportation infrastructure systems, presenting an original methodology for evaluating these alternative approaches, applying the methodology to the specific context of Portugal, and using the results to determine and explain tradeoffs among the various approaches.

To avoid confusion, it is useful to begin by defining several terms used throughout this document: strategy, deliberate strategy, emergent strategy, and strategy development framework. The term "strategy" is used broadly, with a variety of meanings in everyday life and across many fields of study and practice. Many scholars have debated the proper meaning of the word, but for our purposes, we offer the following definition:

> *Strategy* is the dynamic set of processes, rules, principles, policies, guidelines, plans, actions, investments, decisions, behaviors and other heuristics employed by an individual, organization, or region in order to survive and/or thrive in the presence of competition.

We further distinguish between two views of strategy as follows:

- *Deliberate strategy* is the explicitly stated set of processes, rules, principles, policies, guidelines, and/or plans that guides the actions, investments, decisions, and other behaviors of an individual or organization at any given time in pursuit of explicit objectives.
- *Emergent strategy* is the pattern of processes, rules, principles, policies, guidelines, and plans inferred by an observer based on the actual actions, investments, decisions, and other behaviors of an individual, organization, or collection of individuals and/or organizations that are observed over some period of time.

A deliberate strategy may include tangible features such as plans; however, it is at its core conceptual—it is the *intended* strategy. Emergent strategy, on the other hand, is interpreted based on observation of outcomes such as investments that can be seen and measured—it is the *actual* strategy. Deliberate strategies can and do influence what the emergent strategy ultimately is; nevertheless, the emergent strategy of an organization can differ markedly from its deliberate strategy, and often does. Although strategies relate to a range of organizational activities, this thesis is concerned specifically with the *infrastructure investment decisions* of organizations.

Finally, a *strategy development framework* is the environment or context within which deliberate strategies are developed and from which emergent strategies emerge. Although it can be characterized in any number of ways, in this research we decompose the strategy development framework into several dimensions—most importantly the following three: institutional architecture, decision-making process, and geographic scale. For example, the strategy development framework for metropolitan Boston's transportation system includes the institutions that are involved in providing, regulating, and funding transportation systems and their relationships with one another ("institutional architecture"); the processes they follow, whether standardized or ad-hoc, for making strategic decisions, notably collecting and allocating resources to the infrastructure system ("decision-making processes"); and the geographic scales over which they operate ("geographic scale"). Over time, decisions will be made about the metropolitan Boston transportation system that we can observe; this collection of decisions results in some outcome, and from these decisions we can infer an emergent strategy. If we change the strategy development framework, then we can often expect a different set of decisions to be made.

In the remaining sections of this chapter, we explain the motivation for this thesis, pose several specific research questions, describe the context for the questions, outline the approach taken in answering the questions, present hypotheses, and summarize the findings and contributions to the field.

1.1 Motivation

An enduring characteristic of transportation systems management is the separation of infrastructure and operations. *Infrastructure* literally means "below the structure" and, in contemporary usage, refers to such networked systems as highways and railways. *Operations*, on the other hand, refers to the activities of users and system operators occurring on or above the infrastructure such as vehicles traveling on highways and trains traveling on railways.

The physical and economic characteristics of infrastructure are distinct from operations in important ways. Operational decisions are largely made *individually* by users and to some extent by system operators. Individuals tend to make trips of relatively short duration (i.e., measured in minutes) that are difficult to predict, whether by automobile, train, foot, etc. Their decisions result in complex, emergent travel patterns that change often over short time intervals (again, measured in minutes) in magnitude and direction. By contrast, infrastructure investment decisions are made *collectively*, typically by large companies or governments such as countries, provinces, counties, cities, or neighborhood associations. The infrastructures they supply (roads, railroads, sidewalks, etc.) change infrequently over long time intervals (i.e., measured in years). The result is a mismatch between individual users and their infrastructures in both the geographic scale and timing of decision-making.

The principal motivation for this thesis is the notion that advanced technology can address that mismatch by serving as a meaningful link between the real-time, *operational* decisions of users and system operators and the *strategic* infrastructure decisions of system owners and managers. Much of the existing research in and practical development of applications for transportation technology focuses on operational decision-making of users and system operators, essentially taking the underlying infrastructures for granted. For example, applications have been developed to enhance safety, moderate congestion, and reduce emissions. Rapidly evolving, increasingly ubiquitous data sources associated with information and communication technologies not only offer the possibility of enhancing system performance operationally, but these technologies also enable changes in longer-term strategic decision-making about the infrastructure itself, whether by supporting existing strategy development frameworks or by enabling the creation of entirely new ones.

Two corollary motivations for this thesis include opportunities to (1) recognize and strengthen the notions of strategy and strategy development frameworks for transportation infrastructure, which goes beyond the traditional, more narrowly defined transportation planning process and (2) specifically address questions about the geographic scale at which strategy development should occur for transportation infrastructure systems.

1.1.1 Technology as a link between operations and strategic infrastructure decisions

Several decades ago, transportation leaders anticipated the information technology revolution by forming a joint venture of academia, the private sector, and government and branding the new generation of transportation technologies *Intelligent Transportation Systems* (ITS). They positioned the transportation industry to benefit from ongoing advances in sensor technologies, telecommunications, and computing techniques, and they touted ITS as a less costly, less intrusive alternative to conventional expansions of network capacity. Literature from the era identified a wide range of potential ITS benefits such as safer highways, more reliable urban public transit systems, reduced congestion, and fewer emissions (e.g., U.S. DOT, 1993).

Sensors and communications devices now connect users and the infrastructure, enabling freer, faster communications among them, and many naturally view the deployment of such technologies as an opportunity to improve *operations*. For example, using real-time traffic information (collected by sensors and delivered via personal telecommunications devices) and real-time dynamic pricing of services (collected using advanced toll collection methods), system operators can incentivize users to consume travel in a way that enhances total system performance, reduces congestion, reduces emissions, and improves safety.

Researchers have identified the need for strategic and organizational changes as a means of enabling operations improvements (e.g., Lockwood, 2005; Sussman, 2005; Gifford and Pelletiere, 2002). However, the motivation for this thesis is distinct from these past efforts. Rather than viewing strategic and organizational change as prerequisites for technological and operational improvements, we view strategy and technology as co-evolutionary: the data collected by advanced technologies for improving operational decisions can be used to improve strategic decision-making about the infrastructure itself.

1.1.2 Moving beyond planning for infrastructure strategy development

Many transportation infrastructure suppliers throughout the world, including in the U.S., develop infrastructure strategy through an explicit *planning process*. These planning processes are deliberate, typically covering a time horizon of several years or decades to reflect the long lead times required for design and construction of infrastructure networks.

However, planning is but one approach to developing strategy; management literature offers a number of alternative approaches (e.g., Mintzberg et al., 1998). Likewise, for the transportation infrastructure sector, planning should be considered as but one method for developing strategy. Advanced technologies provide data that allow alternative approaches to strategy development, including greater recognition of emergent outcomes. This thesis argues for strategy development frameworks that incorporate deliberate strategy approaches such as planning while explicitly recognizing emergent outcomes and the strategies they imply.

1.1.3 Considering new geographic scales for ownership of infrastructure

Infrastructure suppliers have existed at a wide range of geographic scales throughout history. Today, in the U.S. alone, state governments are the predominant suppliers of highway infrastructure, with geographic scales varying from the very small (e.g., Delaware) to the very large (e.g., California), while passenger rail infrastructure and services are managed at the national level. In the EU, rail and highway networks are typically owned and managed by individual countries, with varying degrees of federalism within each country. Over the past half-century, network connectivity has been coordinated on an ad-hoc basis between individual countries, with growing involvement of the continentally scaled EU in recent years.

A large collection of researchers spanning several disciplines has explored the appropriateness of various geographic scales of ownership for public goods over many decades, including economics (e.g., Tiebout, 1956), political economics (e.g., Besley and Coate, 2003) government (e.g., Alesina and Spolaore, 2003), public finance (e.g., Oates, 1999), and transportation (e.g., Levinson, 2001). Much of this work is theoretical and, with the exception of Levinson, offers few recommendations for specific places or types of goods such as transportation infrastructure. Meanwhile, centuries of practice reveal little consensus as to the appropriate geographic scale for transportation infrastructure ownership and strategy development. As chronicled by Lay (1992), the pendulum has swung between highly centralized and highly decentralized approaches, influenced largely by demographic, economic, and political forces. An additional motivation for this thesis is to characterize the trade-offs of the various possible geographic scales, particularly in light of advanced technologies which enable new thinking about which scales are technically feasible.

1.2 Research questions

At the outset we asked, "How should strategy be developed for transportation infrastructure systems?" But before attempting to answer how it *should* be developed, we must first determine how it currently *is* developed and how it *might be* developed. Motivated by the fact that advanced technologies allow us to consider a broader array of answers to these questions than in the past, we explore the following three sets of research questions, one descriptive, one exploratory, and one normative.

Descriptive: How is strategy developed for transportation infrastructure systems—using what frameworks?

1. <u>Strategy</u>: Fundamentally, what *is* strategy (as a concept) in the context of surface transportation? How do organizations develop strategy for transportation infrastructure? How do "regions" develop strategy for transportation infrastructure?[1]
2. <u>Technology</u>: What are the relationships between surface transportation infrastructure technologies and strategies?

[1] Throughout the thesis we use the term *region* in reference to geographic areas of any extent, including regions with formal corresponding governments (e.g., nations), but more commonly to regions that lack a formal corresponding organization or government, such as "metropolitan regions." In Portugal, the term *region* refers specifically to the 5 sub-national regions defined by the European Union, with explicitly defined borders and corresponding governmental administrations. We attempt with each usage of the term *region* to clarify with modifiers the type of region to which we are referring (e.g., "metropolitan region"). When discussing Portugal specifically, the term *region* refers to the 5 sub-national regions with clearly defined borders (see Figure 4-5).

3. Scale: What are the historic and contemporary spatial scales at/for which infrastructure strategies are developed?

Exploratory: What is the universe ("solution space") of conceivable approaches for developing strategy—i.e., with what frameworks can we imagine developing strategy for transportation infrastructure systems?

1. Strategy: What frameworks for strategy development beyond the existing ones (principally planning) can be applied to the transportation sector?
2. Technology: What current and future anticipated technologies will impact the development of strategies for transportation infrastructure?
3. Scale: Especially in light of advanced technologies, what spatial scales of ownership and strategy development are available for transportation infrastructure systems?

Normative: In order to improve the likelihood of a good strategy and good performance for a transportation infrastructure system, how *should* strategy be developed?

1. Strategy: What is *good* strategy? How *should* transportation organizations develop infrastructure strategy? How should "regions" develop strategy for transportation infrastructure?
2. Technology: What surface transportation technologies are most effective enablers of improvements to infrastructure strategy development?
3. Scale: What are the *appropriate* spatial scales for transportation infrastructure strategy development? What technologies can help us achieve those appropriate scales?

As described next, Portugal serves as a test case for exploring these questions and perhaps as an immediate audience for some of the answers. However, the questions are of a generic character, and the answers are intended for broader consumption and application both within the research community and among transportation practitioners.

1.3 Portugal: A context for exploration of research questions

Portugal is a country of 10.6 million inhabitants located on the western edge of mainland Europe (see Figure 1-1). The country entered 2008 with an ambitious intercity surface transportation investment strategy, developed largely by various elements of its central government. In sum, the central government had committed to build or improve over 2,000 km of new highways at a cost of over €5 billion; construct and operate a 600-km, cross-country, high-speed rail network with two connections to Spain for an estimated €8-10 billion; make substantial expansions to the existing urban rail transit systems in metropolitan Lisbon and Porto; and provide a new light-rail system in metropolitan Coimbra.

Figure 1-1. Locator map of Portugal[2]

Even before the global financial crisis of 2008-2009, Portuguese leaders faced questions about the viability of their transportation infrastructure investment strategy and the methods by which that strategy was developed. Over the previous two decades, Portugal had invested heavily in surface transportation, including substantial improvements to the quality and capacity of the intercity highway network, conventional rail network, and rail transit systems in metropolitan Lisbon and Porto. Faced with a financially dependent, highly indebted transportation sector, the government invited greater participation in transportation finance and operations by private companies and began to consider decentralizing ownership of some infrastructure and investment decision-making authority to Portuguese regional, metropolitan, and municipal governments (Nelson, 2008). The further constraints introduced by the financial crisis of 2008-2009 have brought these concerns into focus and motivated a re-evaluation of Portugal's transportation strategy and the means by which it was developed.

1.4 Approach

The approach in this thesis is designed to answer the three sets of research questions within the context of Portugal. To answer the descriptive questions, we conduct literature reviews and present data collected from stakeholders in Portugal to understand more clearly what strategy *is* conceptually, to describe existing strategy development frameworks, and to explain the relationship between technology and strategy development. To answer the exploratory questions,

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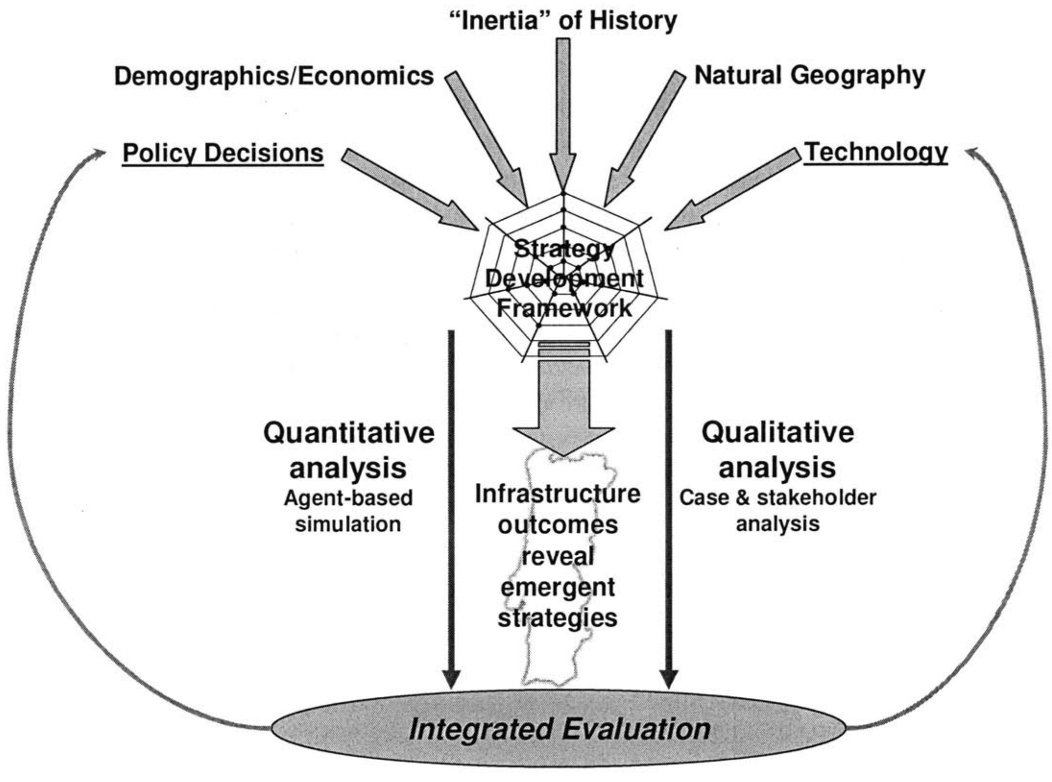
[2] Open source, from Wikimedia Commons: http://commons.wikimedia.org

we survey strategic management practices from a variety of fields and transportation technologies in order to construct possible future states of the practice in transportation. Finally, to address the normative questions, we construct a range of alternative strategy development frameworks and assess their performance through a mixed-method approach combining quantitative and qualitative techniques, as described below.

Figure 1-2 is a high-level conceptual illustration of the approach of this thesis for addressing the normative questions. It shows, at center, strategy development frameworks (represented by a radar chart, or spider diagram). The structure of a strategy development framework is influenced by a range of factors, including demographics, economic conditions, the "inertia" of history, natural geography, active policy decisions of decision-makers, and available technology. In turn, strategy development frameworks for transportation infrastructure guide the actions of various constituent organizations, resulting in investment decisions over time for a physical infrastructure system. The resulting development and evolution of the infrastructure system reveal an emergent strategy for the context in question (in our case, that context is mainland Portugal). We present an approach for analyzing this phenomenon quantitatively through agent-based simulation and qualitatively through empirical cases and stakeholder analysis. Together these analyses allow us to predict and analyze the relationship between strategy development frameworks and measurable outcomes for an infrastructure system. Finally, based on the integrated quantitative-qualitative evaluation, we can determine which frameworks perform best and recommend changes. The primary levers available for influencing the design of a strategy development framework are adoption of advanced technologies and adoption of new policies by decision-makers within the current strategy development framework, represented by arrows which connect the evaluation back to the "policy decision" and "technology" inputs.

Figure 1-2. Conceptual summary of thesis



1.5 Hypotheses

In response to the research questions posed in Section 1.2, we hypothesize the following:

Strategy: There are limitations to our ability to judge the performance of strategy development frameworks. For example, we can judge a framework's ease of implementation, logical consistency, and internal efficiency, but the framework alone tells us little about the performance of the strategies that emerge from it. Consequently, we evaluate the *outcomes* of strategy development frameworks—i.e., by evaluating the performance of the infrastructure network that results from each strategy development framework. By determining which outcomes perform best, we can, working backward, identify strategy development frameworks which are most desirable. We hypothesize that infrastructure outcomes (and the emergent strategies inferred from them) differ from the deliberate strategies. Moreover, we hypothesize that planning in its current state is relatively ineffective at influencing outcomes, and would be better served by recognizing and incorporating expected emergent outcomes. This hypothesis is based on the insight from management literature that firms can improve performance by developing deliberate strategies that adapt easily to complex and unpredictable environments, meaning that strategists must study and anticipate emergent outcomes even as they develop deliberate strategies.

Technology: The performance of a surface transportation infrastructure system can improve as the amount of information used in its strategy development framework increases. Information can increasingly be provided by advanced technologies. We hypothesize that advanced revenue collection technologies represent the most influential technological means of influencing strategy development frameworks, and that frameworks that incorporate direct user fees collected through advanced revenue collection technology will outperform those frameworks that rely on general tax revenues. Unlike general taxation, user fees (e.g., tolling) offer location-specific demand information that enable decision-makers to allocate revenues more effectively—an advantage that is critical for infrastructure networks such as highways which are spatial by nature.

Geographic scale: There are two extreme cases of the geographic extent of strategy development for the Portuguese surface transportation system: (1) In the most highly centralized case, there is one omniscient organization developing deliberate strategy for a single jurisdiction (i.e., all of Portugal), and (2) In the most highly decentralized case, each individual/user of the transportation system constitutes his or her own "organization" and develops his or her own deliberate strategy, with system-wide strategies emerging from the collective behavior of individuals. We hypothesize that the optimal geographic scale for development of transportation infrastructure strategy lies somewhere between these two extremes, but will vary depending upon contextual factors, most importantly the degree to which various performance metrics are valued. For a given context and set of metrics, we hypothesize that we can find the optimal size, and that sub-national geographic scales (i.e., Portuguese region and municipal governments) will perform equally as well as and will, in some cases, outperform nationally scaled governments. When coupled with location-specific information provided by user fees (enabled by advanced revenue collection technologies), infrastructure strategists operating at smaller geographic scales can make locally beneficial investment decisions that match the demands of users; moreover, the underlying demands of users is likely to result in the emergence of larger-scaled networks that would also result from more centralized decision-making, without requiring the existence of a central bureaucracy.

1.6 Findings and contributions

The combined quantitative-qualitative analysis produced a diverse set of results, including some expected results and some contradictory results.

- One of the more important outcomes predicted by both the quantitative and the qualitative analyses is that **larger geographic scales and increasing public ownership tend to increase the quantity of investment** in infrastructure.
- Both analyses confirm that the geographic scale of the agents responsible for making resource collection and allocation decisions within an infrastructure strategy development framework will tend to **address local concerns *before* investing in connections to other jurisdictions.**
- As expected, the quantitative and qualitative analyses both suggested that **public-private partnerships for infrastructure ownership result in more conservative levels of investment** than infrastructure networks administered by a purely public authority.

Several results of the quantitative analysis contradicted the results of the qualitative analysis.

- The quantitative results suggest that frameworks with **highly decentralized (e.g., municipal) geographic scales often fail to invest in long-distance corridors**. By contrast, empirical evidence from the case studies suggests that **some long-distance networks will emerge even under highly decentralized control.**
- Quantitative results suggest that frameworks corresponding to **Portuguese regions perform well** in the context of Portugal, offering consistently strong performance across a range of evaluation scenarios.[3] The qualitative analysis, however, and in particular the stakeholder analysis, suggest that **sub-national geographic scales are unstable** due to the larger number of higher-level stakeholders with the ability to re-assert greater control over the process (the central government, the EU, and financial institutions).

Methodologically, our findings are summarized as follows:

- **It is possible to build a quantitative representation of strategy development frameworks and, through a simulation approach, to predict emergent outcomes.** The agent-based approach applied in this thesis captures the interaction of numerous actors within the context of mainland Portugal, relating the physical elements of the transportation infrastructure system (the environment of the model) to the institutional sphere (the agents) via a set of modeling rules designed to reflect the physical-institutional linkages.
- **We can combine quantitative results from the simulation model with qualitative results of empirical case and stakeholder analyses** in order to derive a more subtle understanding of the relationships between strategy development frameworks for transportation infrastructure systems and the performance of those systems.
- The methodological finding that represents perhaps the most significant departure from prior research is the fact that we demonstrate how **real data from a rather extensive context (the nation of Portugal) can be used as inputs to both the quantitative and qualitative analyses**, allowing us to generate outputs that inform decisions of importance in an actual policy context.

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[3] "Regionally scaled" in this case refers to the 5 explicit sub-national regional authorities designated within mainland Portugal.

Finally, with regard to dimensions of the strategy development frameworks, we offer the following findings:

- *What is the "right" geographic scale?* **The results of the simulation model suggest that regionally and nationally scaled governments offer a robust geographic scale**. Frameworks with regional and national scales perform well across a broad range of scenarios. The qualitative analysis suggests, however, that regional scales are unstable and could easily lead back to more centralized ownership. By the same token, both the quantitative and qualitative analyses also suggest that larger geographic scales tend to increase the level of investment in infrastructure, which creates an opportunity cost for other sectors, particularly if budgets are set in a uni-modal fashion, and can lead to financial problems, particularly if revenues are derived from general taxes.
- *What is the "right" ownership structure?* **If the public sector uses the concession approach in order to gauge which projects are desirable from a market-based standpoint, rather than as a means of financing, then there can be substantial benefits from concessions**. The simulation model results suggest that concession arrangements can allow the public sector to identify and assemble packages of investments, combining some "winners" and some "losers" that, on the whole, are attractive to the private sector. For other portions of the network that are desirable, the public sector is best served constructing these without private participation.
- *What is the "right" type of revenue?* **The quantitative simulation results suggest that general taxes offer better outcomes than user fees. The qualitative analysis, however, suggests that empowering the stakeholder groups of "users" and "residents" is better achieved through user fees**, which allow them to express preferences for location-specific infrastructure investments to system managers. Moreover, user fees shift the burden of infrastructure funding to customers, freeing general tax revenues for other purposes, a benefit that is not captured in the simulation model.
- *What is the "right" institutional architecture?* **Greater integration of organizations across modes and sectors offers potential efficiency benefits through increased competition and synergy, but there are substantial barriers to integration, and integrated decision-making processes are more costly**. The costs of greater integration are, essentially, longer and more costly decision-making processes due to the involvement of more stakeholders, more opinions, and more constraints. The most predictable consequence of greater integration is greater competition: if the vision of integration is to pool resources across modes and sectors and to make resource allocation decisions with broadly measured benefits, then all participants should be prepared to compete in a larger field for those limited resources. Interestingly, the barriers to integration are weaker at smaller geographic scales, due to the fact that strategists operating at smaller geographic scales can "divide and conquer" the entrenched interests in order to pursue a more integrated approach to infrastructure strategy development.

The contributions of this research are threefold: (1) we offer the notion of strategy development, which allows for recognition and inclusion of emergent outcomes, as an alternative to the narrower concept of transportation planning, and present an innovative analytical approach for exploring the relationship between strategy development frameworks and strategies, applied in a real context; (2) we determine the influence of advanced transportation technologies (typically studied for their operational benefits) on *strategy* development; and (3) we explore the consequences of fundamental changes to the strategy development framework, notably along the dimension of geographic scale.

1.7 Thesis organization

The remainder of this thesis is organized to describe the approach for addressing and results of addressing the questions posed in this chapter. Chapter 2 provides more extensive background to the topic, including a high-level review of various fields influencing this thesis, together with a more detailed summary of the overall approach. Chapter 3 explores the concept of strategy and relates it to transportation infrastructure systems. Chapter 4 outlines various alternative frameworks for development of transportation infrastructure strategy. Chapter 5 explains the quantitative simulation model approach in detail, while Chapter 6 summarize the results of the model. Chapter 7 presents the results of the qualitative evaluation and synthesizes the findings with an integrated quantitative-qualitative evaluation. Finally, Chapter 8 presents conclusions, recommendations, and directions for future work.

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2 Background and Approach

Strategies for human-made transportation infrastructure systems have existed for as long as the systems themselves, dating back thousands of years. Meanwhile, users, managers, owners, and other observers have attempted to inform the development of strategy for transportation infrastructure systems through research. Recognizing that this thesis is not the first to ask how strategy should be developed for transportation systems, this chapter synthesizes the considerable efforts of past practitioners and researchers in a variety of fields as background to our own work in later chapters. Additional, more detailed reviews of practice and literature are spread across several chapters to complement the relatively higher-level background presented in this chapter. Drawing on the background presented here, this chapter also describes our approach for addressing the research questions.

This chapter begins by describing the transportation context, including brief histories and descriptions of contemporary activities in several relevant areas of transportation practice, highlighting several gaps in transportation practice and research at which the current approach is aimed. Next, we describe the qualitative and quantitative approaches developed for addressing our research questions.

2.1 Transportation context

The questions posed in this thesis lie at the confluence of several areas of transportation practice and research, including physical transportation infrastructure systems, surface transportation technology innovation and deployment, and public policy and finance. In this section we describe historical trends in each of these fields as they relate to the underlying research questions.

2.1.1 Ways and means

Lay (1992) provides a comprehensive history of transportation systems, arguing that the three fundamental transportation technologies are the path, locomotive energy, and the wheel. The most recent, the wheel, was invented in Mesopotamia circa 5000 B.C.E. In the seven millennia since then, all transportation innovations—even today's—can be viewed as efforts to refine and improve upon these three elemental technologies. Recurring themes emerge from this history of transportation innovation, including:

- Growth in demand for travel continues to drive developments in vehicle technology which, in turn, drive innovations in infrastructure technology.
- Technological advances have long focused on improving the travel experiences of users and shippers.

The first paths to appear on earth were not the work of man, but, rather, of beast. Some historians speculate that many animal paths were later adapted by humans for human use, with some surviving even to this day. Examples include North America's Natchez Trace and parts of the Oregon Trail, which trace their origins to the paths of migrating herds of buffalo. The paths we have inherited in the 21st century, however, are almost entirely the result of manmade innovations.

As commerce increased and civilization grew, people required transport of larger quantities of goods over longer distances. To meet this demand, early humans utilized domesticated animals (mules, oxen, etc.) for locomotive energy. The wheel, together with the axle, expanded capacity and improved travel speed. Lacking large-scale governments or other organizations of humanity, however, primitive roadways remained largely local in nature, providing access to food, water, campsites, and nearby communities.

Despite their shortcomings, man's primitive road facilities endured. Local networks served as convenient building blocks for later development of provincial and national road networks, such as the Roman system of roads. The patterns that emerged in many areas of the world appeared irrational to observers. For example, the 20th century English writer Hilaire Belloc described European roads as "haphazardly established… long neglecting opportunities which would have been obvious to the eye of the most cursory and moderately intelligent survey" (as qtd. in Lay). In part, humans lacked the time, resources, communication technology, and political-territorial organization to conduct cursory surveys, to say nothing of careful ones, in the development of roads. At the same time, in recognition of the prohibitive expense of constructing entirely new roads, builders opted instead to improve existing roads in order to accommodate the increasing speeds, weights, and volumes of vehicles.

From early walking trails to modern highways and railways, many of the issues confronting the builders of transportation infrastructure systems have been largely constant: safety, efficiency, security, and comfort. The demand for safe, efficient, comfortable travel allowed the field of civil engineering to flourish, with design of infrastructure networks becoming an important subspecialty. To this day, civil engineers specializing in transportation learn accepted design rules for trading off safety, efficiency, comfort, cost and other features of roadways and railways, through manuals and texts which summarize the accumulated knowledge of millennia of practice (e.g., AASHTO, 2001).

Several innovations challenged the profession to look beyond the materials and geometric design of infrastructure, to consider additional issues beyond safety, efficiency, and comfort. During the 19th century, a major locomotive energy innovation (the steam engine) led ultimately to the train and the addition of rails to the roadway, with construction of such infrastructure occurring largely in new rights-of-way. Meanwhile, during the 20th century, the internal combustion engine led ultimately to the development of highways as a specialized pathway to serve the automobile. Such long-distance infrastructure was not a new phenomenon; after all, ancient and medieval empires alike maintained extensive road networks. However, whether for military or civilian use, the railway and highway[4] systems that proliferated in the 19th and 20th centuries made transportation infrastructure ubiquitous and led to the establishment of organizational structures, both public and private and at various geographic scales, to manage these new systems.

Our 21st century inheritance consists primarily of railways for trains and highways for automobiles—relatively new surface infrastructure technologies to accommodate relatively new vehicle technologies, built both upon very old networks and in new rights-of-way—as well as organizations designed to sustain, improve, and extend those physical networks. Recognizing the

[4] In this thesis we use the term highway in the traditional civil engineering sense to refer to any paved surface for use by automobiles, from single-lane neighborhood streets to limited-access, multi-lane, divided expressways.

past co-evolution of vehicle technology, infrastructure technology, and organizations informs our approach to understanding and intervening in the continuing co-evolution.

2.1.2 Contemporary technology advances

The application of information and communications technologies to transportation infrastructure systems is the latest in the continuing co-evolution of vehicle and infrastructure technologies in pursuit of higher speeds, greater volumes, and safer, more comfortable travel. Perhaps the advent of advanced technology for transportation is indeed a "revolution," as some technologists assert (e.g., Ghosh, 1999), but whether that revolution will have a comparable impact to that of concrete, the axle, or the internal combustion engine remains to be seen. For now, the significance of advanced technologies lies primarily in the fact that they represent a contemporary opportunity which we can actively shape rather than a historical trend on which we can merely comment. In this section, we summarize major technological advances since 1990 in both highways and railways.

2.1.2.1 Highways

The Intelligent Transportation Systems (ITS) "movement" began in the early 1990s. Motivated by the potential benefits of applying advanced technologies to vehicles and transportation infrastructure, individuals in government, academia, and industry formed a variety of organizations to promote research, funding, development, and deployment of advanced systems. At first, the focus for these activities was in the developed nations of North America, Europe, and Asia, but ITS has become a major emphasis of transportation practice and research worldwide (e.g., SCT 2009). The work of the past two decades in this area exhibits the same trends as earlier technological innovations in transportation: focus on improving users' travel experiences (e.g., through improvements in the speed, efficiency, safety, and comfort of travel).

Technological advances of the past two decades have challenged engineers to retool their thinking about infrastructure design with respect to such factors as efficiency, safety, and comfort. Technologies deployed to-date include in-vehicle safety devices, user information systems, navigation services, and electronic toll/fare collection, while work continues on vehicle-to-vehicle and vehicle-to-infrastructure communications, real-time congestion management via centralized route guidance and ubiquitous pricing, multi-modal information systems, and more (Sussman, 2008). Before ITS, "safety" meant following geometric design standards; after ITS, safety may also include highway-to-vehicle communication systems that alert motorists of real-time hazards such as weather, obstructions, and congestion. Before ITS, "efficiency" meant providing enough lane capacity to serve peak daily traffic demand without gridlock; after ITS, efficiency may also include active traffic management systems which direct motorists and even impose congestion surcharges on them. Before ITS, "comfort" meant providing smooth roads for a comfortable ride; after ITS, comfort may also include providing dynamic signage to reduce the mental effort of travelers and real-time navigation to minimize travel times.

Technological advancement is an enduring and disruptive force facing infrastructure managers. Beyond the technical challenges, which are far from trivial, experiences in practice highlight organizational challenges related to technology deployment. Chief among these organizational challenges is the need to re-structure organizations to deploy advanced technologies and to operate transportation infrastructure systems (in real time) more efficiently and effectively

(Lockwood, 2005; Gifford and Pelletiere, 2002). These efforts cumulatively reflect the recurring theme in the history of transportation technological improvement: that the principal objective is to improve users' travel experiences.

2.1.2.2 Railways

The fundamental phenomena driving technological advancement in railroads are similar to those driving highways technology: demand for greater, faster, more comfortable travel leads to faster vehicles, which in turn pressure infrastructure providers to develop and deploy suitable travel surfaces. Although the physical and economic characteristics of railroads differ from highways, the co-evolutionary relationship between users, their vehicles, and their infrastructure does not.

The steam engine provided the first major incremental leap in speed for rail travel, as rail providers switched from horse-pulled to steam-powered vehicles in the 1830s. Over the next 60 years in the U.S. alone, the length of rail infrastructure increased from a mere 40 miles to over 160,000 miles. Rail vehicles were adapted for electric power beginning in the late 1800s, but this innovation was largely limited to urban areas where there was a ready supply of electricity networks. However, for long-distance inter-city routes, the high cost of electrification infrastructure remains an inhibiting factor in the deployment of electrically powered railroads to this day. For these routes, the Diesel engine replaced the steam engine as the preferred locomotive technology in the mid-20th century and remains the most prevalent.

Perhaps the most significant rail technology development of the past 50 years is high-speed rail (HSR), defined as trains with speeds above 200 km/hour. HSR began in 1964 with the opening of the Shinkansen in Japan. High-speed rail requires infrastructure with electrification, relatively flat grades, grade-separated crossings, and gentle curves, making it more costly than traditional rail infrastructure. HSR today exist in Japan, South Korea, numerous countries in Western Europe, and (modestly) in the U.S., with plans for expansion across the globe, particularly in China and Europe.

2.1.3 Money and politics

As one takes a view of transportation infrastructure broader than the typical one that concerns a design engineer, new issues emerge. Tracing technical advances allows us to observe the state-of-the-art in vehicle and infrastructure technology. Yet, throughout history, transportation *networks* have varied significantly from place to place, even in places with access to similar technology. In order to understand the evolution of transportation infrastructure networks, we must look beyond technology and consider the role of such influencing factors as how to pay for them and how to structure organizations to manage them.

As long as there have been human-made roads, humans have had to figure out how to pay for them. Resources to pay for transportation infrastructure ultimately are derived from one of two categories: fees charged to users and/or beneficiaries of the infrastructure and general taxation of the entire population. Examples of user fees include, in their simplest and most direct form, tolls/fares on users of the facilities, but also taxes on fuels, vehicles, tires, and property adjacent to the facilities. User fees can allow for market-based pricing. More commonly, however, user fees are employed by public road owners, who employ user fees in order to approximate the "benefit principle" of taxation, which states that users of publicly provided services should contribute taxes in proportion to the benefit they obtain from them (Williams, 2007). Some special-purpose taxes also attempt to approximate the benefit principle—for example, property taxes assess owners adjacent to infrastructure, capturing at least indirectly in the form of taxes the benefits to property values based on access to infrastructure. General taxation, by contrast, is assessed across the entire population, without particular regard for the relationship between the source of revenues, the infrastructure being funded by them, or its beneficiaries. Examples include such mechanisms as sales and income taxes (and, in earlier eras, mandatory labor on infrastructure projects, known as the corvée). Borrowed money and private-equity contributions, while sources of financing for infrastructure facilities, ultimately must be repaid through a revenue stream falling under one of the above two categories.

Closely related to the finance problem is the governance problem: by whom and how are decisions about these infrastructure systems made? A wide variety of approaches have been attempted in the past, from purely private to purely public ownership of facilities and strategy development at a variety of geographic scales. Lay (1992) details experiences ranging from very localized ownership of roadways to highly centralized systems. In the most decentralized cases, abutting property owners maintained their individual segments of the road while collecting tolls from users. Under English common law, property owners had an incentive to maintain roadways even without collecting tolls, in order to keep passersby from traveling on their property, instead confining them to specified routes between adjacent properties. Of course, such highly decentralized ownership and management led to the emergence of "haphazard" networks. By contrast, highly centralized systems such as those of ancient Rome and Napoleonic France resulted in more extensive networks with better maintenance. Typically, these more extensive networks were built and maintained either for military purposes or to serve royal residences, and paid for through general taxation. Many modern nationally scaled highway systems in the U.S. and Europe were likewise developed with defense applications as a principal motivation.

Taking a global view, there is no centrally planned network. All the surface transportation infrastructure on earth can be seen as a self-organizing system with emergent hierarchies. Although each portion of the global network has distinct managers of varying spatial scales and resource availabilities (e.g., the U.S highway network emerged very differently with financial resources, decision-making processes, and organizational architectures very different from those of, say, a Portuguese municipality), ultimately the system as a whole is an emergent patchwork comprising these distinct, diverse pieces.

The world today includes a wide range of approaches to funding and governance of transportation infrastructure. The vast majority of roads and rails is publicly owned, with varying degrees of participation from the private sector through maintenance contracts and concession agreements. Meanwhile, the governance structures range from highly spatially decentralized, such as Swiss cantons, to highly spatially centralized, such as the planned (and partially operating) Chinese HSR system. The approaches to strategy development taken in any given part of the world are dynamic, changing over time in response to economic, demographic, and political factors, and often enabled by variations in available technologies.

Given the breadth of practical experiences, it is instructive to investigate which approaches are most successful in varying contexts. Moreover, given the changing technological landscape, it is important to anticipate how changes in the technical characteristics of surface transportation infrastructure will influence the strategy development dimensions such as those discussed here (financing and institutional structure). Next we review past literature that has contributed to this discussion.

2.1.4 Concluding remarks

Transportation practice and research make clear that the question of who should own and make strategy for transportation infrastructure is not new, nor is the question decided with any reasonable consensus. Infrastructure providers ranging from individuals to highly organized administrations covering vast territories have experimented with numerous approaches over several millennia. Political and economic changes were common throughout this time period, leading to many reorganizations of the delivery of infrastructure.

At the same time, technological advances in transportation have accompanied these changes. Vehicle and infrastructure technology encountered several periods of decades—even centuries—without significant advances in design, material, or construction methods. The 19th century, however, gave us the steam engine and the railroad, which transformed surface transportation, only to see it transformed again by the advent of the combustion engine and the automobile in the 20th century. These technological advances represented major steps forward in the operational performance of transportation systems while, at the same time, forcing substantial changes in the organization, delivery, and development of strategy for infrastructure systems.

The 21st century thus far has been marked by a revolution in information and communications technologies, and we are still in the early stages of understanding exactly how those technologies will transform the operational performance of transportation systems. Inevitably, these changes will also force new organizational structures and strategy development frameworks for infrastructure systems, making it appropriate to pose anew the question that has been asked and answered throughout history: how should strategy be developed for transportation infrastructure systems? For the remainder of the chapter, we summarize the approach we will take in exploring that question.

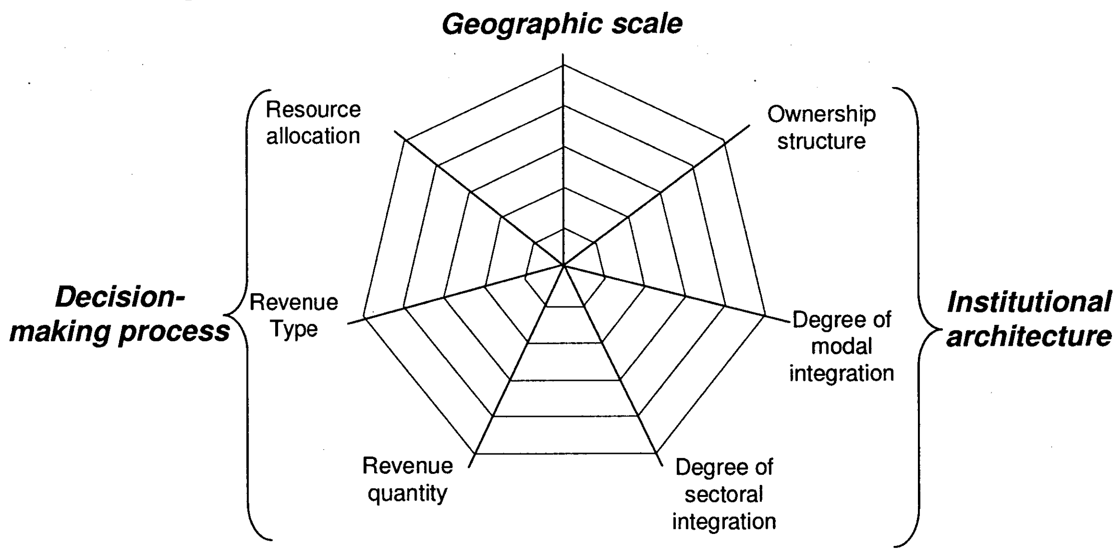
2.2 Summary of approach

This section summarizes the overall approach to addressing the research questions, broken into three basic steps: define and characterize strategy development frameworks, evaluate them quantitatively using an agent-based simulation, and evaluate them qualitatively through empirical cases and stakeholder analysis.

2.2.1 Define and characterize strategy development frameworks

The first step in our approach to addressing the question of how strategy should be developed for transportation infrastructure systems is to define a solution space, which we call a *strategy development framework*, and to describe its characteristics. For purposes of this research, we define a strategy development framework for surface transportation systems as the environment within which strategies are developed and from which strategies emerge—specifically, an investment strategy—for some defined transportation system. Strategy development frameworks can be characterized in many ways, but the key dimensions of interest for our purposes are institutional architecture, decision-making process, and geographic scale. The decision-making process dimension can be further broken down into sub-dimensions reflecting the method of collecting resources (type and quantity of revenues) and method of allocating resources, while the institutional architecture can be further broken into sub-dimensions reflecting the infrastructure ownership structure, degree of organizational integration across modes of transportation, and degree of integration across sectors. By characterizing a strategy development framework in this way, there are 7 possible dimensions, and Figure 2-1 illustrates them as a radar chart. Each dimension can take a range of values, and each possible combination of values for each dimension corresponds to a unique strategy development framework. We explain this characterization of frameworks as well as the available values along each dimension in greater detail in Chapter 4.

Figure 2-1. Dimensions of a strategy development framework



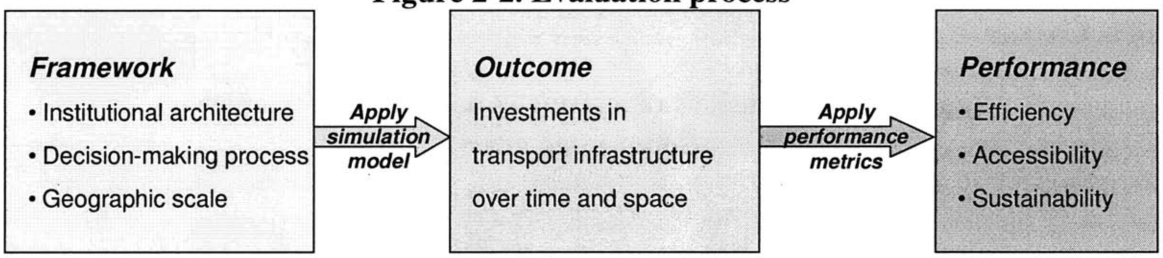
Having defined the dimensions of a strategy development framework, we can characterize a range of alternative frameworks by selecting various combinations of values along each dimension. In the following sections, we summarize the quantitative and qualitative approaches that are used to evaluate alternative frameworks.

2.2.2 Quantitative evaluation

The ultimate objective of the quantitative evaluation is to measure the performance of the alternative strategy development frameworks. We do this by, as described below and illustrated in Figure 2-2, applying models that simulate the emergence of strategies from strategy development frameworks, and then evaluating the performance of the strategies against a set of pre-defined metrics.

A strategy development framework can be described, but, because a framework is a static collection of values, its performance cannot be directly evaluated in quantitative terms. We must first translate a strategy development framework into outcomes, and then evaluate the performance of the outcome. An outcome in our context refers to a set of resource allocations, or investments, over time and space in the transportation infrastructure system in question. Figure 2-2 illustrates this process. Beginning with a framework, we apply quantitative models in order to predict the outcomes that will emerge from it. This prediction is based on quantifiable relationships between the features of the strategy development framework and the resulting strategic investment decisions. Finally, we evaluate the performance of the outcome according to a variety of metrics, including, for instance, efficiency (e.g., cost-effectiveness of speed improvements), accessibility (e.g., shorter travel times to other parts of the network), and sustainability (e.g., environmental impacts of the infrastructure, prospects for economic development, and spatial equity). We apply independent metrics as well as existing metrics from the transportation stakeholders in the Portuguese context.

Figure 2-2. Evaluation process



This evaluation process relies on the premise that the quality of an outcome reflects the quality of the strategy development framework from which it emerged. For example, a "good" outcome indicates the existence of a "good" underlying strategy development framework. While other factors are considered in judging a strategy development framework, for purposes of evaluation, we rely primarily on the premise that the outcome itself is the most important factor in determining the quality of the underlying framework.

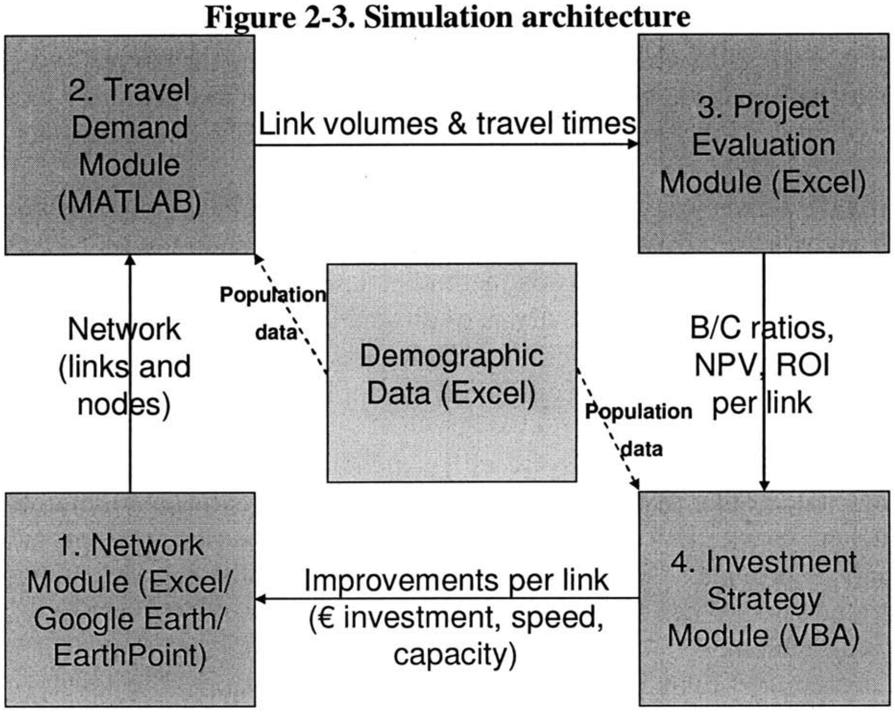
Xie and Levinson (2009) developed a model for simulating network development with similar features and outputs. Both the Xie and Levinson model and the model developed here share a common objective, which is to inform the selection of policy parameters (such as geographic scale of network control) in transportation infrastructure investment decision-making; however, they differ in several ways. First, the model developed here considers several dimensions of a strategy development framework, while Xie and Levinson consider primarily the geographic scale dimension. In addition, Xie and Levinson applied the simulation model to a hypothetical space with no pre-existing network, while this model is applied to a real context (Portugal) which contains many pre-existing links. Some features of the Xie and Levinson model offer more detail than the simulation approach taken here, such as the inclusion of marginal cost pricing and borrowing as a project finance alternative; other features provide less detail, such as the consideration of only capacity-expansion projects.

The purpose of the simulation model is to generate a set of investments in a transportation infrastructure network over time and space based on a set of input parameters that reflect the strategy development framework. Figure 2-3 conceptually illustrates the iterative process followed by the simulation model, which comprises five modules. A run through all five modules represents a single year in time, and for a given model run, we repeat this exercise over a 15 year period.

- A run begins in the lower-left corner with a transportation network (in our case the Portuguese intercity highway network) at time zero, held in a database called the Network Module. The network comprises links (highways) and nodes (Portuguese municipalities).

- Next, a traditional gravity model is applied to municipal population data held by a database called the Demographic Module. This generates an origin-destination travel demand matrix between all the municipalities.
- Next, the trips from the O-D matrix are assigned to the network using a shortest path algorithm in the Travel Demand Module, implemented in MATLAB. At this point, the model reflects a network with predicted travel demand.
- Each link in the network represents a potential project (e.g., by improving the speed or capacity of the link). In the Project Evaluation Module, each of these projects is evaluated using one of two traditional techniques: cost-benefit analysis or net present value analysis, both based on travel time savings. This module represents part of the *decision-making process* dimension of a strategy development framework.
- Finally, projects are selected for implementation in the Investment Strategy Module, which runs in Visual Basic. This module reflects the *geographic scale* and *institutional architecture* dimensions of the strategy development framework, because it specifies the geographic scale at which project implementation decisions are made and allocates budgets and decision-making authority at that scale.
- Once projects are selected, the Network Module is updated to reflect the new network, and the Demographic Module is updated to reflect population in the new year.

Figure 2-3. Simulation architecture



Each run through this simulation represents one year, and data are available to simulate 14 years (1995 through 2009). At the end of the 14 years, the outputs of the simulation reflect the investments made in the infrastructure network in each highway link in each year, along with the evolution of the physical network (e.g., speeds and capacities of links) over time. In some cases, new links are also built during a model run. We refer to these investments over time and the network that results from a model run together as the outcome, from which one can infer the system's emergent strategy. We measure the performance characteristics of the resulting network, including congestion reduction, travel time savings, total costs, and geographic distribution of investments. Finally, we compare these measured characteristics to a set of performance metrics; this allows us to judge which outcomes performed best according to the metrics.

2.2.3 Qualitative evaluation

Qualitative evaluation of the alternative strategy development frameworks takes two forms. First, we describe various frameworks in practice through case analysis, and relate those frameworks to the outcomes and emergent strategies associated with them. The second approach is to analyze existing stakeholders in the Portuguese context, predict their reaction to the various alternative frameworks presented, and inform our understanding of the feasibility of each framework, given the reality of stakeholder dynamics.

Case analysis involves identification of strategy development frameworks for transportation infrastructure systems in practice, selected across a range of places and times on the basis of the richness of information available from them. We select cases along each key dimension as follows:

- Geographic scale: the case of Portugal contrasted with the case of the EU
- Institutional architecture: the case of privately developed turnpikes from 18th century North America contrasted with concessioned motorways from 20th century Portugal.
- Type of revenues: the case of general taxes, illustrated by the *corvée* and *gabelle* used in France during the Middle Ages, contrasted with the case of direct user fees, illustrated by a range of modern-day toll road facilities in the U.S. and Western Europe.

These cases provide a diverse set of examples to compare the relationships between strategy development frameworks, infrastructure outcomes, and emergent strategies as reflected in the infrastructure outcomes. The case analysis method is descriptive, focusing on those observed factors with greatest relevance to the analysis of alternative approaches proposed for application to Portugal, and comparative, comparing the selected cases both to one another and to the generic alternative frameworks being considered for application to Portugal.

We supplement the empirical case analysis with a stakeholder analysis, drawing on analytical approaches from stakeholder theory and data obtained from an extensive literature review process and interviews with key participants in the Portuguese surface transportation sector. The stakeholder analysis provides a picture of the power structure of the current strategy development framework. When viewed in light of alternative frameworks, this analysis suggests the feasibility with which each of the alternatives could be implemented as well as the desirability of stakeholder dynamics resulting from each framework. The levels of feasibility and desirability are important additional factors to consider when judging the performance of alternative frameworks.

2.3 Summary

Our fundamental research question—how should strategy be developed for transportation infrastructure systems—has been considered before in many contexts and various answers implemented throughout history. Yet, it is instructive to pose the question anew in light of the availability of advanced technologies to reshape both what is possible and what is desirable.

Given the availability of advanced technology in Portugal and the ongoing challenges to the country's transportation infrastructure strategy, it is particularly expedient to consider the potential performance of a wide range of alternative strategy development frameworks in that context.

In the next chapter, we explore more deeply the concept of strategy, focusing on the distinction between deliberate and emergent strategies and the implications of this distinction for transportation infrastructure systems.

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3 Review and Synthesis of Strategy and Related Concepts

Strategy is a common contemporary term, applied in a broad range of contexts. We hear of business strategies for corporate competitiveness; personal strategies for self-improvement; military and athletic strategies for victory; political strategies for societal improvement; natural strategies for survival; and more. Within the transportation field, the term is used to describe a broad range of phenomena: individual strategies for minimizing travel time; organizational strategies for managing transportation agencies effectively; planning strategies for infrastructure development; and more.

The discussion of existing surface transportation strategy, strategy development frameworks, and existing technologies in this chapter addresses the following descriptive questions:

- Strategy: Fundamentally, what *is* strategy in the context of surface transportation? How do transportation organizations develop strategy? How do "regions" develop strategy for transportation?
- Technology: What are the relationships among information, surface transportation technology, and the various dimensions of strategy development and organizational design?
- Scale: What are the historical and contemporary spatial scales at/for which strategies are deliberately developed?

Several sections follow. Section 3.1 discusses two broad conceptions of strategy and applies them to surface transportation. Section 3.2 discusses the dimensions of strategy development frameworks for transportation infrastructure systems. In Section 3.3, we summarize the Portuguese strategy development framework for surface transportation. We finish in Section 3.4 with a summary of the implications of this interpretation of strategy for the remainder of the thesis.

3.1 Strategy defined

Literature covering the topic of strategy is often conflicting: researchers disagree on such fundamental questions as how to define strategy, how (and whether) to develop strategy, and how to relate strategy to existence. In this section, we present two schools of thought in the field of strategy – categorized broadly as deliberate strategy and emergent strategy – and describe contemporary strategy in practice in the surface transportation sector. We conclude that strategy is an existential feature of any organization or region of any geographic extent whose purpose is to promote survival among competition. This conclusion provides a framework for understanding and analyzing surface transportation strategies and for exploring alternative approaches to strategy development.

3.1.1 Deliberate strategy

Literature on strategy is most prolific in the field of management, and the majority of strategy writers in that field takes the view that strategy is *deliberate*. The fundamental feature of deliberate strategy is the assumption that strategy can be actively pursued, developed, crafted, or otherwise created by one or more individuals, often through the application of some calculated process. That this view dominates the literature is not surprising, as it allows for development of specific, actionable approaches and tools that managers can use to develop strategy. In this section we summarize some of the major contributions to deliberate strategy thinking.

Management literature provides numerous definitions of strategy, most of them reflecting the belief that strategy is, by nature, deliberate. For instance, Alfred Chandler defines strategy as "the determination of the basic long-term goals and objectives of an enterprise, and the adoption of courses of action and the allocation of resources necessary for carrying out these goals" (qtd. in Moore, 1992). Henderson (1989) defines strategy in relation to competitiveness as "a deliberate search for a plan of action that will develop a business's competitive advantage and compound it." Others (e.g., Porter, 1979; Ghemawat, 1986) likewise emphasize the role of strategy in overcoming competition or, at minimum, surviving it. More specifically, Porter, one of the most recognized scholars in the field of competitive strategy, frames the development of strategy as an explicit response to (or anticipation of) competition, based on empirical study of firms and industries using analytical techniques from industrial economics (1979). Similarly, Ohmae (1988) characterizes strategy as the determination to create value and avoid competition.

An important distinction exists in the literature between *business* strategy and *corporate* strategy. Business strategy relates an organization to its customers and competitors by addressing, for instance, pricing and investment decisions. For example, firms can evaluate their positions according to frameworks such as Porter's "five forces" (Porter, 1980) or by following strategic planning processes or positioning techniques suggested by any number of academics and consultants (e.g., Wack, 1985; Goold & Campbell, 1987). On the other hand, corporate strategy refers to the strategies that relate an organization to its employees and shareholders. Corporate strategies are more complex for organizations competing in multiple sectors. Not only must each unit of business develop a business strategy, but at the corporate level, the company must develop a unifying internal strategy that ties together an often diverse set of units: setting objectives for each unit and defining their roles relative to one another (Moore, 1992). In short, business strategies face external stakeholders while corporate strategies face internal stakeholders. Alignment of such internal and external strategies is a recurring challenge in management science (e.g., Porter, 1987).

In addition to this broad distinction between corporate and business strategy, Mintzberg (1998) distinguishes among a wide range of approaches to deliberate strategy. He characterizes the development of three particular approaches to deliberate strategy as evolutionary, beginning with *design*, followed by *planning*, and leading finally to *positioning*. Mintzberg regards design as an informal approach in which some leader or leaders conceive of and design a strategy for their organization. Perhaps the best known approach to deliberate strategy development in the transportation sector is planning, which entails a *process* of analyzing an organization and its environment in order to determine and make explicit both a strategy and a future-looking plan which reflects that strategy. In planning, the strategy-making process is often emphasized more than the strategy itself. A more recent view of deliberate strategy development is positioning, where organizations choose a "position" comprising one or more strategic factors to distinguish themselves from competitors—common examples in business include low price, high quality of service, and/or fast speed of service. Positions, based on the work of Porter and others, can be determined rationally through analysis of the competitive environment. The process of selecting a strategic position is similar to the planning process, although with greater emphasis on the outcome (the position itself) than the process.

All of these views assume strategy is a set of organizational structures, processes, rules, principles, behaviors, policies or other heuristics which can be created and articulated, perhaps rationally, but in all cases *deliberately*. By implication, a prerequisite of this view of strategy is that it must be developed for and applied to some type of *organization*.

3.1.2 Emergent strategy

Discussion in the management literature of emergent strategy is substantial, although less common than deliberate strategy, and somewhat controversial. The primary point of contention between deliberate and emergent notions of strategy is definitional. While deliberate strategists argue that the deliberation is central to the notion of strategy, those taking an emergent view of strategy argue that observed outcomes are more important.

Henderson (1989) argues against the notion of strategy as emergent when he compares strategy to evolution by natural selection. Strategy, according to Henderson, is distinguished by reason, logic, the ability to recognize the competitive landscape, and the ability to intervene, all of which are skills available only to humans. Strategy in human organizations, he argues, must be reasoned, careful, and deliberate, determined by the organism or organization itself. Anything less is merely natural. Evolution, for instance, is fatalistic, random, and determined by the laws of nature. Henderson's articulation of strategy is representative of the reluctance of many thinkers to concede that strategy is anything but deliberate by definition.

Mintzberg, the most notable scholar on emergent strategy, challenged the notion of strategy as strictly deliberate, pointing out that strategies emerge from human organizations in much the same ways as organisms evolve. Emergent strategy is the strategy exhibited by an entity through a pattern of decisions and behaviors over time, necessarily without being planned or otherwise deliberately crafted; moreover, emergent strategy is often unanticipated and can only be recognized in retrospect. Emergent strategies can also exist independently of any formal organization: a collection of individuals or organizations (such as a metropolitan area) or some other entity exhibit emergent strategy without necessarily having corresponding formal connections to one another.

Organizations and businesses, like species of organisms, constantly evolve in order to survive changes and thrive in their environments. While recognizing that an organization can choose, craft, develop, or otherwise create a strategy deliberately, Mintzberg maintains that, ultimately, the strategy that *emerges* is the strategy that actually matters. Moreover, the emergent strategy will exist regardless of whether the organization even chooses to pursue a deliberate strategy. According to this view, strategy is an existential feature of an organization. And, although it is possible for elements of a deliberate strategy to appear in an emergent strategy, Mintzberg et al. (1998) refer to an empirical study showing that emergent strategies differ from deliberate strategies within the same organization as much as 90% of the time.

Mintzberg is not a lone advocate for the study of emergent strategy, and was not the first to recognize its importance. One of the earliest definitions of strategy was offered by Harvard Business School's Kenneth Andrews, who defined it as:

> The pattern of decisions in a company that determines and *reveals* its objectives, purposes, or goals, produces the principal policies and plans for achieving those goals, and defines the range of business the company is to pursue, the kind of economic and human organization it is or intends to be, and the nature of the economic and non-economic contribution it intends to make to its shareholders, employees, customers, and communities (Andrews, 1971, emphasis added).

Through this definition, Andrews explicitly argues that strategy is a *pattern* of decisions that *reveals* underlying goals and objectives, both notions that support an interpretation of strategy as an emergent phenomenon.

Other nuanced views of emergent strategy exist as well, as summarized in Mintzberg et al. (1998). For example, some political science researchers have characterized strategy as emergent from a process of negotiation. Others conceive of strategy as an organizational reaction to an environment over which the organization itself has little or no control and, therefore, no real strategic "choices" over which to deliberate. This view suggests that, for a variety of possible reasons, the organization is constrained into certain behaviors, a notion which equates the development of strategy with evolutionary processes in nature, over which actors, such as managers, have little control. Although criticized by deliberate strategists as not reflective of the true choices available to managers and other actors in most organizations, "strategy as reaction" accurately describes the strategy development process of some organizations, such as government agencies, that are subject to the strategies and other constraints of higher-level elements of their environment. Still others conceive of strategy development as a learning process, whereby the disparate pieces of an organization "self-organize" and a strategy emerges as patterns recognizable in the decisions of many decentralized individuals or business units. Finally, strategy in the private sector has been suggested as analogous to policy in the public sector, especially among political scientists tackling the topic of strategy and/or policy development (e.g., Alison, 1969). Perhaps the most vivid proclamation of public sector strategies as emergent is the diagnosis by Lindblom (1959) of policy development as "muddling through."

More recently, Kurtz and Snowden (2003) sorted through both deliberate and emergent views of strategy in an attempt to offer a useful unifying framework. They claim that strategy in systems with well-understood behavior can (and should) be deliberate. However, patterns in complex systems with poorly understood behavior can be observed and detected only in retrospect; successful strategies in such contexts, likewise, are adaptive and responsive, emerging over time rather than pursued by a deliberate, reasoned method.

By extension, we argue that emergent strategies exist wherever complexity is present, which spans the whole range of existence, from the scale of the organism to the global scale, even beyond. For example, the "geographic" scales that are relevant for transportation systems range from the very small (e.g., neighborhoods) to the continental—perhaps even global—scale. A consequence of this observation is that strategies exist in transportation systems at *all* of these scales, regardless of the existence of a corresponding organization. While deliberate strategies *can* exist for businesses, transport providers such as urban public transit operators, planning authorities, and governments at a variety of levels, emergent strategies *do* exist for all of these organizations as well as for individuals, neighborhoods, metropolitan areas, sub-national regions, multi-national regions, and other scales for which there is no formal corresponding organization.

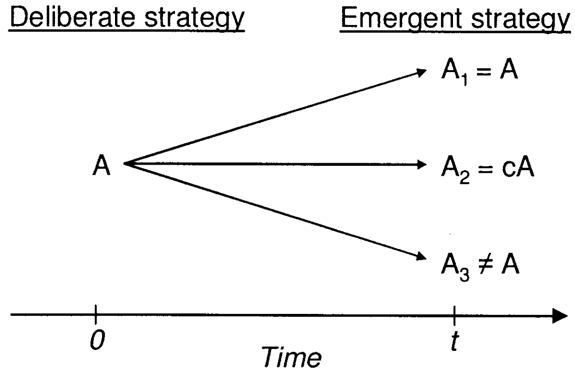
3.1.3 Making sense and use of strategy

Despite the lack of consensus on the preferred conception of strategy (emergent or deliberate), both conceptions are, in fact, accurate: organizations are capable of developing and pursuing deliberate strategies, while, in the end, the strategies that we can actually observe, both for organizations and for regions, are emergent. But which conception is more useful? On one hand, focusing exclusively on deliberate strategy might prevent an organization from recognizing and learning from its own and its competitors' actual, emergent strategies. On the other hand, to recognize emergent strategies alone is hardly useful: what incentive do managers have to create strategies, whether through planning or visioning or some other means, if in the end the true strategy will simply, somehow, *emerge*?

Figure 3-1 illustrates the basic relationship between deliberate and emergent strategies. Consider the deliberate strategy A developed by some organization at time 0. Over time, the organization will make a variety of decisions through which its actual strategy will be revealed. Suppose the organization's decisions follow the deliberate strategy exactly. At time t, the emergent strategy, A_1, will be identical to A and, in this rarest of cases, you could claim that the deliberate strategy and the strategy that emerged were the same. Suppose, at the other extreme, that conditions require that the organization's decisions contradict its deliberate strategy every step of the way, such that at time t there are scarcely any remnants of the deliberate strategy, A, visible in the strategy that emerged, A_3. More commonly, some elements of the deliberate strategy will be reflected in the decisions of the organization over time, while other decisions will be made contrary to the deliberate strategy. In this case, at time t, the emergent strategy A_2, partially resembles the deliberate strategy A, reflected by the constant c which takes a value between 0 and 1.[5] By analogy, a deliberate strategy is a forward-looking map of a journey, while an emergent strategy is a backward-looking assessment of the route actually traveled; rarely will the map and the route coincide exactly. Both interpretations are important and useful for application to transportation systems.

[5] Some special cases also exist. For example, the "deliberately emergent" case involves an organization which, by design, has no deliberate strategy A while the even less-elegantly conceived "accidentally emergent" case involves an organization unaware that it is missing a deliberate strategy A. In both of these cases, of course, the organization will still produce an emergent strategy.

Figure 3-1. Relating deliberate and emergent strategies



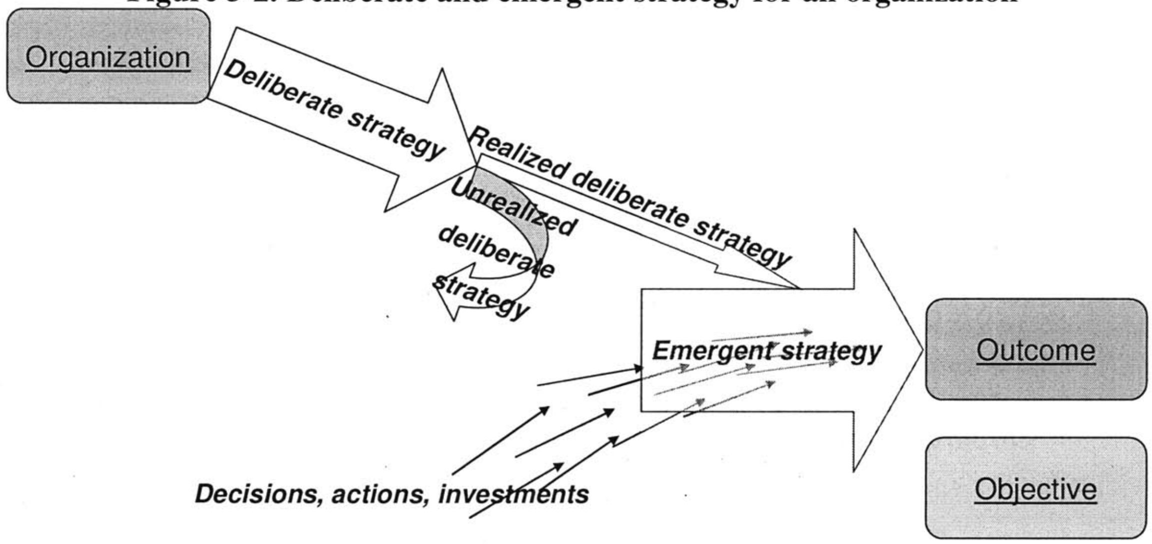
Deliberate and emergent strategy are both important concepts in surface transportation: we can observe elements of deliberate strategy in emergent outcomes. Consider, for instance, Kostof's (1991) observations on cities:

> … the two primary versions of urban arrangement, the planned and the "organic," often exist side by side… most historic towns, and virtually all those of metropolitan size, are puzzles of premeditated and spontaneous segments, variously interlocked or juxtaposed.

Using the terms of the construct illustrated above, the "planned" elements of the city represent outcomes with a value for c close to 1, while "organic" elements represent outcomes with a value for c close to 0.

Figure 3-2 offers another explanation of the distinction between deliberate and emergent strategies for a single organization, based on Mintzberg et al. (1998). Deliberate strategy development is distinguished by the fact that it is intentional, process-oriented, and objective-driven; the objective is illustrated at right. The product of deliberate strategy development is a deliberate strategy, which can be reflected at least in part in a *plan*; however, it may also be reflected in the principles, rules, guidelines, and other heuristics adopted by the organization. Over time, as the organization interacts with its environment, which includes other organizations (e.g., competitors, collaborators, owners), it will make decisions, take actions, and make investments. These decisions combine with decisions taken in concert with the deliberate strategy to reveal an organizational trajectory that results in an outcome. In retrospect, we can observe the emergent strategy inherent in this pattern. Although the deliberate strategy may influence the emergent strategy, the strategy that emerges often differs, sometimes substantially, from the one that was planned deliberately.

Figure 3-2. Deliberate and emergent strategy for an organization[6]



For transportation, however, we are typically interested in the strategy and performance of a physical transportation infrastructure system, which inevitably spans a geographical space, such as a neighborhood, metropolitan area, or country, incorporating multiple organizations. Figure 3-3 builds on Figure 3-2 by illustrating the relationship between a strategy development framework, deliberate strategy, outcomes, and emergent strategy in an explicitly *multi-organizational* environment. Each "row" represents deliberate and emergent strategy development processes for a single organization. The vertical lines represent both formal and informal relationships among the organizations as they collaborate in the development of deliberate strategies and the execution of strategic decisions such as major transportation infrastructure investments. The collection of organizations, their deliberate strategy development processes, their deliberate strategies, and their relationships with one another constitute a *strategy development framework* captured roughly by the box. The framework is the environment within which deliberate strategies are developed and from which emergent strategies emerge. The interactions among these organizations and their environment as part of the strategy development framework produce emergent organizational strategies and outcomes which together contribute to an emergent multi-organization strategy, illustrated at the far right.

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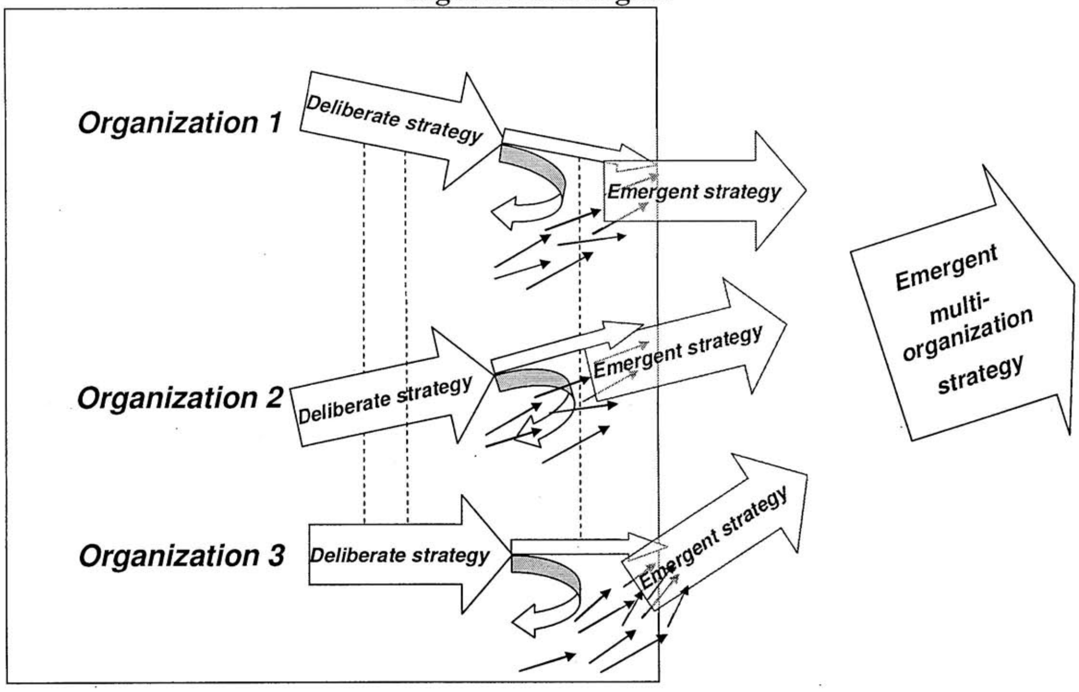
[6] Adapted from Mintzberg, et al. (1998).

Figure 3-3. Strategy development framework and emergent strategy for a multi-organization region



The existence of emergent multi-organization strategies in metropolitan contexts can make difficult the task of detecting and tracing the development of deliberate strategies among specific organizations. For instance, Macário (2007) evaluated mobility strategies for a variety of metropolitan areas around the world. Observations and survey results support the conclusion that strategies and strategic decisions are fragmented by organizational and jurisdictional complexity. This fragmentation prevents the identification of any integrated, coherent, forward-looking (i.e., deliberate) transportation strategies that cut across the entire metropolis. But the absence of (and inability to detect) a deliberate, metropolitan-wide strategy does not signify the absence of deliberate strategies among organizations within the metropolitan area, nor does it signify the absence of an emergent, multi-organization, metropolitan-wide strategy. Rather, it suggests that the identification of a metropolitan-wide strategy is more easily achieved by seeking to observe emergent strategies rather than seeking to document deliberate strategies.

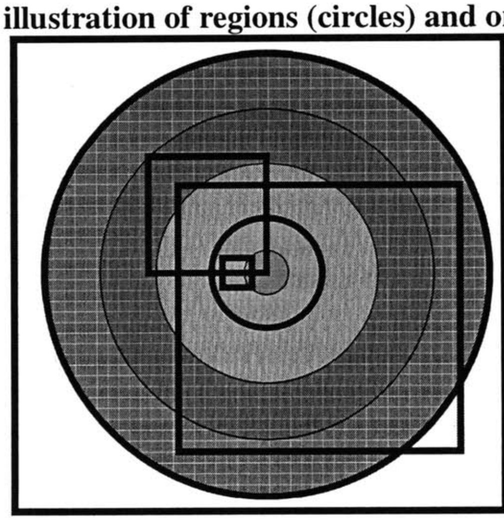
Given these interactions between deliberate and emergent strategies, we as transportation researchers should seek to understand and use both. In order to bridge the chasm between the two conceptions of strategy, however, we propose "survival among competition" as the context that is common to both deliberate and emergent strategy. More specifically, we posit the following:

- Strategy is predicated on the existence of **competition** (real or perceived) in the environment of an organization or a geographically defined region such as a metropolitan area.
- The purpose of a deliberate strategy is to attempt to increase the likelihood that an organization or region will **survive** and/or **thrive** in a competitive environment. On the other hand, an emergent strategy has no intrinsic purpose; it merely exists.

- Deliberate strategies and their development can and do **influence** the emergent strategies of organizations and, therefore, provide an opportunity for organizations and the variously defined regions within which they exist to increase their likelihood of survival and/or success in a competitive environment.
- At least in the context of surface transportation, deliberate strategies only exist within organizations or collections of highly cooperative organizations, while emergent strategies exist both within organizations and for a variety of geographically defined **regions** (e.g., neighborhoods, metropolitan areas, sub-national regions).

Consider Figure 3-4, which conceptually illustrates geographic regions as concentric circles and organizations as rectangles. The five concentric circles could represent a neighborhood, municipality, metropolitan region, sub-national region, and nation, for example. Some of these geographically defined regions have organizations with coterminous boundaries (e.g., the municipal and national government jurisdictions correspond geographically with the municipality and the nation, respectively; these organizations are reflected by thicker borders in the illustration). Meanwhile, the rectangles represent organizations which perform specific transportation-related activities over some strictly defined geographic boundary. They could include, for instance, an urban public transit service operator, a railway infrastructure company, a corridor (e.g., highway and/or rail) management agency, and an airport authority. Each of these organizations makes investment decisions, institutes policies, and/or provides services; moreover, each organization likely has a deliberate strategy. Likewise, the municipal government and the national government may have deliberate transportation strategies. However, deliberate strategies do not exist for the intermediate regions of neighborhood, metropolitan region, and sub-national region (the three regions illustrated as concentric circles with relatively thinner borders). Instead, the strategies of these regions can only be understood as emergent strategies, which are influenced both by the collective decisions and strategies (both deliberate and emergent) of a large variety of individuals and organizations, including especially the overlapping organizations.

Figure 3-4. Conceptual illustration of regions (circles) and organizations (rectangles)



To summarize, for purposes of this research, we offer the following definition of strategy:

> Strategy is the dynamic set of processes, rules, principles, policies, guidelines, plans, actions, investments, decisions, behaviors, and or other heuristics employed by an individual, organization, or region – both pursued intentionally as deliberate strategy and observed in retrospect as emergent strategy – in order to survive and/or thrive in the presence of competition.

By recognizing the important distinctions and interactions between deliberate and emergent strategies, we improve our ability to observe, describe, and analyze transportation strategies for organizations and regions. For our purposes, deliberate strategies represent intentions which may or may not be implemented, while emergent strategies are observed and often-measurable outcomes. We use this understanding as the foundation on which to conceive and evaluate a variety of alternative approaches to transportation strategy development. First, however, we illustrate these concepts in the context of surface transportation by discussing recent evolutions of transportation planning in the U.S.

3.1.4 Strategy in surface transportation

Just as empirical studies in the private sector produced a large and diverse number of interpretations of what strategy is, how it is deliberately developed, and how it emerges, studying transportation organizations and regions reveals a diverse number of realizations of strategy in practice. In this section we apply the notions of deliberate and emergent strategy to transportation, focusing on the rise of transportation planning as the preferred method of deliberate strategy development in the U.S. Despite the prevalence of planning as a deliberate strategy development process, the linkage between deliberate strategies and outcomes remains tenuous, with emergent outcomes in the transportation infrastructure often differing from the intended outcomes envisioned by planners.

In the U.S., deliberate transportation infrastructure strategies are developed today by governments at variety of geographic scales—municipal, metropolitan, and state, for example—typically through a strategic planning process. In addition, functional organizations such as transit operators, toll and turnpike authorities, airport authorities, and other agencies and companies develop deliberate strategies, typically also through strategic planning. The emergent strategies for cities, metropolitan areas, states, and organizations often differ from their deliberately developed strategies due to participation of a large, diverse set of organizations in the delivery of transportation services. At the same time there exist intermediate regional scales (e.g., sub-metropolitan areas and "macropolitan" areas) for which no corresponding organization exists, making transportation strategies exclusively emergent.

Early *transportation planning* efforts were distinct from what we would today call *strategic planning* (or strategic transportation planning). Banister (2002) argues that transportation planning efforts in the mid-20th century lacked "clear theoretical foundations." Instead, transportation planning was, in its early stages, a largely technical activity facilitating the largely political objectives related to transport system investment. For example, in the U.S., the foundations of transportation planning were in rooted in rational analysis; transportation planners used engineering and economic principles to analyze and select the lowest-cost routes for highway facilities. Deliberate strategy development during that era was still largely the domain of elected leaders at the state and national levels, while transportation planning was seen as a technical activity to support the execution of those politically determined strategies.

As vehicle and infrastructure technology improved and transportation networks grew more complex in the latter half of the 20th century, transportation planning processes were continuously refined. Once Interstate highway construction moved from largely rural, inter-city routes and into metropolitan areas, urban residents objected to the highway-focused approach of a civil engineering-dominated field in the late 1950s and 1960s. This led to the "opening" of the transportation planning process from a strictly technical, engineering activity to one that incorporated the perspectives of other interest groups (Gakenheimer, 1976). Wildavsky (1973) reflects the opening of transportation planning during that era by defining the term *planning* as future control, cause, power, adaptation, process, intention, rationality, and even faith, each of which transcends a purely technical perspective. The 1970s saw the transportation planning process expand to include, for example, community and environmental interests, trends which were eventually codified into the continuing, comprehensive transportation planning process, many of whose elements remain in place today (FHWA and FTA, 2007). Throughout this transformative era, transportation planning has been continually characterized as a formal, "rational" process (e.g., Gakenheimer, 1976; Weiner, 1997; Meyer and Miller, 2001), reflective perhaps of its roots in engineering.

As a result, transportation planning in the U.S. today has evolved into *strategic planning*, meaning that in many cases transportation planning has become the process by which organizations *develop* deliberate strategy, rather than simply a tool to support the implementation of strategies developed elsewhere. For organizations such as transit agencies, with responsibility for a single mode, strategic planning is akin to strategy development for a business competing for market share. In the case of organizations such as metropolitan planning organizations (MPOs), with the responsibility to conduct strategic planning for entire metropolitan regions considering not only multi-modal transportation but also energy, economic development, and environmental issues, the strategic planning process generates the transportation strategies that can help to achieve broader, regional objectives such as improving quality of life and competing against other regions for jobs and economic development.

Although the process of developing deliberate strategies is largely in the hands of planners, strategic decisions are often still left to elected and appointed leaders, who may or may not have coherent deliberate strategies, resulting in emergent transportation strategies which often differ from the deliberate strategies of planners. For example, Cambridge Systematics (2007) evaluated the relationships between the formal plans (deliberate strategies) resulting from the strategic planning process of MPOs and state DOTs and the actual programmed investment decisions (emergent strategies) made by the same organizations, concluding that the linkage between strategic planning and programming is weak, "often indistinct, indirect, and difficult to evaluate." In other words, just as Mintzberg, et al. (1998) concluded from their observations of businesses, the deliberate strategies developed by MPOs and state DOTs rarely resemble the emergent transportation strategies of metropolitan regions and states, at least as measured by investment patterns.

To summarize, the process for developing deliberate strategies for surface transportation in the U.S. has evolved considerably just over the past half century, from negotiated, politically driven processes toward more technical, rational strategic planning processes. The strategic planning process itself has evolved out of transportation planning, which is rooted in civil engineering. Nonetheless, despite efforts to codify a strategic planning process for metropolitan regions and states, there is often considerable disconnect between planned (deliberate) strategies and the strategies that actually emerge, both for metropolitan regions and states and for other, intermediate regions for which there is no corresponding jurisdiction.

3.2 Dimensions of a transportation strategy development framework

We now explore in greater depth the environment which produces a strategy, or the *strategy development framework*. For purposes of discussion and evaluation, we decompose the strategy development framework into 3 dimensions: institutional architecture, decision-making process, and geographic scale. Moreover, we further decompose decision-making process into 3 sub-dimensions (revenue type, revenue quantity, and revenue allocation method) and institutional architecture into 3 sub-dimensions (ownership structure, degree of modal integration, and degree of sectoral integration), for a total of 7 dimensions. We discuss the role of each dimension as a factor shaping strategies as well as the technologies historically inherent in each dimension. Table 3-1 summarizes the dimensions, provides several examples of each dimension, and describes some methods and technologies that have been used to enable each dimension in the past.

Table 3-1. Summary of dimensions of strategy development and enabling methods

Dimensions of strategy development framework		Examples	Historical enabling methods/technologies
Institutional architecture	Ownership structure	Government agencies or state-owned enterprises	System monitoring techniques, e.g., manual and electronic traffic counts to verify concession payments
		Public-private partnerships for infrastructure delivery	
		Private infrastructure companies or cooperatives	
	Degree of modal integration	Uni-modal state-owned enterprises (e.g., independent highway and rail companies)	
		Multi-modal agencies with integrated funding	
	Degree of sectoral integration	Uni-sectoral agencies with autonomy	
		Multi-sectoral agencies or highly collaborative uni-sectoral agencies	
Decision-making process	Revenue type	Direct user fees (e.g., tolls, fares, parking fees)	Manual user fee collection, electronic user fee collection, general tax collection methods (e.g., for fuel, sales, property taxes)
		Indirect user fees (e.g., fuel taxes, vehicle sales & ownership taxes, licensing fees)	
		Beneficiary fees (e.g., land-value capture taxes)	
		General taxes (e.g., sales, income, and property taxes)	
	Revenue quantity	High vs. medium vs. low tax and/or toll rates	
	Resource allocation	Political negotiation, e.g., within deliberative legislative bodies or executive administrations	Information collected from constituent feedback, user surveys, manual traffic counts, visual infrastructure surveys, metering, "town hall" meetings, census measurement, and other approaches
		Information-driven ranking of projects via benefit-cost analysis, net present value analysis, etc.	
		Formula-based allocations (e.g., based on population, income, travel demand)	
Geographic scale of deliberate control		National	Vehicle & infrastructure technology, planning methods
		State	
		Metropolitan	
		Local/Municipal	

3.2.1 Institutional architecture

Institutional architecture is a description of the way that organizations are structured internally and relative to one another, including the number and diversity of interacting agents. In this section we review some of the literature on institutional architectures in transportation. This literature describes the impacts that institutions have on strategy.

Sussman's work on Complex, Large-Scale, Interconnected, Socio-technical (CLIOS) Systems stresses *nested complexity*: physical systems such as transportation systems are "nested" within an institutional architecture (e.g., Sussman, et al., 2005). For example, often the design of the institutional architecture specifies which individuals or agencies have intermediate and final authority for making strategic decisions, and the jurisdiction over which they can exercise that authority. Although final approval for strategic decisions in transportation typically rests with elected or appointed officials, the degree to which agencies can influence the decisions of ultimate decision makers varies depending on the particular context.

We have already distinguished between transportation organizations and regions of various geographic scales (e.g., metropolitan regions). Hooghe and Marks (2003) make a further distinction in the political science literature between geographically defined and functionally defined government organizations, labeled Type 1 and Type 2 governments, respectively. According to Hooghe and Marks, Type 1 governments provide a diversity of public services in non-overlapping, spatially defined jurisdictions such as municipalities, counties, and states or provinces. Several layers can exist, as in the federalist structure of U.S. and state governments. Here we might also define other geographic scales, although the absence of formally designated organizations at some of these scales invalidates their applicability to the Hooghe and Marks framework. By contrast, Type 2 governments provide specific services or functions. In the transportation context, port and airport authorities, urban public transit agencies, turnpike authorities, and special highway districts are examples of functionally specific (Type 2) government agencies with relative functional autonomy but substantial spatial overlap. Consider, for example, the functional specificity but spatial overlap of just two of the New York City region's Type 2 agencies (and their many operating divisions): Port Authority of New York & New Jersey (primarily airports, seaports, tunnels, bridges, but also some urban public transit) and Metropolitan Transportation Authority (primarily urban public transit, but also some bridges and tunnels). Meanwhile, the (Type 1) city governments of New York and neighboring municipalities have strictly defined spatial boundaries, as do the region's three state governments: New York, New Jersey, and Connecticut.

Deliberate strategy development in surface transportation is an activity of both geographic (Type 1) and functional (Type 2) government agencies. For example, the transportation planning and investment decision-making activities of cities, MPOs, and states in the U.S. constitute geographically based strategy development. Likewise, the negotiations of the national government in Portugal constitute a geographically based strategy development process resulting in strategic decisions affecting the entire nation. On the other hand, the same strategy development activities can also be performed by transit agencies, port authorities, and turnpike authorities. In this case, they constitute functionally based strategy development processes resulting in strategic decisions for specific organizations. Despite their differences, there is some overlap between the two types of strategy development. For example, the "functional" agencies in both the U.S. and Portugal often depend upon geographically defined governments for authority and funding. As a result, they may participate, to varying degrees, in the strategy development processes of the geographically defined agencies (e.g., transit agencies participating in state DOT planning processes). Alternatively, functional agencies may develop strategy independently, and simply provide their results as an input to the state planning process.

As an example of these institutional dynamics, Chisholm (1989) chronicled the condition of urban public transit in the San Francisco Bay Area in the 1970s and 1980s, which consisted of numerous agencies making planning and operating decisions more or less autonomously. These functional agencies, according to Chisholm, represented a successful institutional architecture (no doubt, one with an emergent strategy at a metropolitan scale), facilitated by a considerable network of informal personal linkages among the managers of the systems. Chisholm did not believe these agencies necessarily required a regionally scaled organization or regionally scaled deliberate institutional architecture.

The relative strengths of geographic and functional governments within a region determine not only of characteristics of the strategy development process but also of strategic decisions. In the U.S. context, the legal powers, political strength, and financial resources of various functional transportation agencies, local governments, regional governments (e.g., MPOs), and state governments are significant factors shaping the strategy development process. For example, Goldman (2007) argues that local governments in some areas of California have become de facto transportation *planning* authorities as they use their power to conduct ballot initiatives to raise taxes for particular transportation projects as a means of bypassing "the formal metropolitan planning process." However, ballot initiatives could hardly be characterized as planning; in our terms, ballot initiatives have bypassed planning to become the preferred local *strategy development process*.

Despite the clear influence of institutional architectures on strategy, strategies can still differ from context to context due to variations in decision-making processes. For example, the Michigan state legislature requires that 90% of all state transportation funding be dedicated to maintenance and preservation. By contrast, North Carolina's state constitution requires a state network of highways such that "90% of... residents have access to a four-lane, divided highway within five miles of their homes," reflecting a clear emphasis on capacity expansion over preservation (Booz Allen Hamilton, 2007). Despite sharing a common heritage and federal government framework, regions and states across the U.S. vary significantly in the way they actually develop and execute strategy. Next we explore the decision-making process dimension of strategy development.

3.2.2 Decision-making process

The second dimension of a strategy development framework is the decision-making process, or the deliberate way in which strategic decisions are made within and among the organizations comprising the institutional architecture. The decision-making process itself consists of many sub-dimensions, but we focus on two: collection and allocation of resources. Resource collection denotes the type and quantity of revenues and the methods of their collection. Resource allocation denotes a potentially more complex set of processes, ranging from politically negotiated allocations to allocations based on rigorous evaluation of information against a set of comprehensive performance measures.

3.2.2.1 Resource collection

As discussed in Chapter 2, there are two broad categories of revenues available for funding infrastructure: fees levied on users/beneficiaries of the infrastructure and general taxation. The type and quantity of revenue sources chosen to fund transportation investments is a function of political factors, demographics, and the technology available to support revenue collection. Revenue sources evolve over time with political forces, demographics, and technologies, oscillating among various types and rates of user fees and taxes. At any given time, the type and quantity of revenues play important roles in shaping the decision-making process, forming an important part of the strategy development framework of surface transportation organizations and regions of various sizes.

User fees have been employed throughout history, at times extensively, and continue to enjoy broad popularity in theory among economists. Tolls were employed to fund transportation infrastructure at least as early as medieval Britain (Lay, 1992). The "user pay" principle was favored in the U.S. beginning with toll-financed private turnpikes of the 1800s. As described by Klein and Majewski (2006), most U.S. interurban highway infrastructure in the 19^{th} and early 20^{th} centuries was constructed by private ventures which raised capital for construction through sale of stock, while raising revenues for operations and maintenance through direct user fees (tolls). Even today, the majority of transportation revenues are derived from dedicated user fees (fees collected are re-invested in the transportation system), including fuel taxes, vehicle licensing fees, vehicle ownership taxes, and driver registration fees, all of which represent indirect user fees. State governments collect the majority of user fees; in addition, with some exceptions, federal user fee revenues are returned to the state governments. Urban transit operators derive a portion of revenues from user fees (fares) and often from real-estate investments, while the majority of operating costs and almost all capital costs are supported through a combination of general taxes (e.g., commonly local sales or property taxes and federal grants for capital expenditures) (TRB, 2006).

Pigou (1924) and Vickrey (1963) discussed the advantages of user fees not only funding infrastructure but also as a mechanism for managing demand of users on that infrastructure. The economic argument is that, by charging users directly for the marginal cost of their usage, they will consume an "economically efficient" amount of travel, and the amount of revenues collected will generally be sufficient to maintain the infrastructure and expand it when necessary (Gómez-Ibáñez et al., 1999). In practice, charging full marginal costs for transportation infrastructure usage has rarely been attained. Marginal social costs, which include externalities such as congestion imposed on other users, emission of pollutants, and noise, are even more difficult to compute and, historically, impractical to collect from large numbers of customers traveling at high speeds.

Owing in part to the impracticalities of direct user fees, many infrastructures are instead funded through indirect user fees or general taxation. For example, since the decline in the U.S. of private turnpikes in the early 20^{th} century, federal and state governments increasingly have relied on indirect user fees (e.g., fuel taxes and vehicle licensing fees) and general fund revenues (e.g., income and sales taxes) to fund investment in highways, particularly since the beginning of the Interstate era. In most U.S. states, fuel taxes are paid at one of three places: the point of import, by wholesalers, or by retailers. In all cases, the per-gallon tax is passed along end users (NCHRP, 2008; Missouri DOT, 2008). Although President Dwight Eisenhower said he "originally preferred a system of self-financing toll highways" for the U.S. (Weingroff, 1996), he ultimately agreed to the indirect fuel tax mechanism for highway finance, which was politically more popular at the time, in the interest of moving the Interstate program forward. Some recent observers contend that the decision not to toll the Interstate system was also influenced by the lack of suitable toll-collection technologies for high-speed, high-volume expressways. Samuel (2007), for instance, commented that "tolling suffered when it came to building the paved roads needed by the early auto era." Former U.S. Transportation Secretary Mary Peters, commenting on Eisenhower's desire for a toll-financed interstate system, stated that "at the time technology just wouldn't have enabled that" (Traffic World, 2008).

Other reasons for utilizing general taxation include difficulty in maintaining a large network through user fees alone, difficulty serving low-density and/or low-income areas with modest travel volumes through user fees, and provision of infrastructure to support other public goods such as for military and defense purposes, geographic cohesion of a political territory, or access to public parklands.

In Portugal, highway construction in the early- to mid- 20th century was financed by appropriations from the general fund of the national government. In the past several decades, however, the national government added two approaches in order to accelerate the construction of highway facilities: real tolls and shadow tolls. Real tolls involve construction of highways by private companies under concession agreements, with financing secured by future toll revenues, increasingly collected electronically. Portugal was an early developer of electronic toll collection (ETC), with its Via Verde system debuting in 1991 (Brisa, 2008). By contrast, shadow tolling involves construction of free highways by private companies, financed by contractually obligated payments by central government in proportion to the volume and mix of traffic on the facilities (Abrantes, 2008). In 2008, the government dedicated a portion of the fuel tax revenues, for the first time, to highways (Silva, 2008).

Table 3-2 summarizes the comparative costs to administer several traditional methods of revenue collection for transportation. These estimates are derived from diverse sources and are subject to several caveats. First, estimates of collection costs vary depending on which costs are included (e.g., administration, auditing and compliance, and losses due to evasion). For instance, the fuel tax collection cost does not reflect evasion, which is estimated in the U.S. as 3-7% of total revenues for gasoline taxes and 15% for diesel taxes (NCHRP, 2008). In addition, using "cost as a percentage of revenues" subjects the comparison to total revenues, which are a function of tax rates, toll rates, and average collections per transaction, factors which do not necessarily reflect the efficacy of each individual method of revenue collection. Finally, the context in which data were collected for these estimates varies: estimates of fuel tax collection costs are an average across the 50 U.S. states, while estimates of manual toll collection are estimated based on data from two turnpike authorities in the Northeast U.S. Nonetheless, the data suggest that general taxes are less costly to administer, while fuel taxation (a form of indirect user fees) is an order-of-magnitude less costly than manual toll collection. General taxes and fuel taxes are also less burdensome to users than manual toll or fare collection, for instance, which impose delays on users. Manual toll collection also increases the risk of crashes to motorists and tollbooth workers, a challenge highlighted by FHWA (2008a).

Table 3-2. Comparative costs of traditional transportation revenue collection methods in the U.S.

Revenue source		Collection costs as a % of revenues	Source
Indirect user fees	Fuel tax	0.88%	50 states (FHWA, 2008b)
General taxation	Sales tax	2%	Washington State (Washington DOR, 2002) and Illinois (Hubbard, 2003)
	Income tax	5-7%	U.S. (Friedman and Waldfogel, 1994)
Direct user fees	Manual toll collection	11-19%	NJ and MA Turnpikes (Friedman and Waldfogel, 1994; Poftak, 2008)
	Mixed manual and electronic toll collection	12-20%	9 Bridges and highways in the U.S. (Washington State DOT, 2007)

Direct, manual toll collection on intercity highways was practical in an era of low speeds and low travel volumes, and remains feasible today in many locations. However, direct, manual toll collection has never been practical in congested urban environments. Instead, revenue sources for investment in urban and other local roadways have historically been derived from general funds of local governments (whose source, in turn, is typically some combination of property, sales, and income taxes). In the U.S., urban roadways are sometimes owned and maintained by private groups such as home-owners' and neighborhood associations (Foldvary, 2008; R. Nelson, 2008). In Portugal, local roadways are the exclusive responsibility of municipal governments (Dinis, 2009). The absence of technology suitable for direct user fee collection on urban roadways has influenced not only the decision to choose to fund local infrastructure from general tax revenues but also the spatial scales at which those revenues are collected.

Some recent, "low-tech" direct user fee revenue collection methods for urban areas include placards and stickers, which allow for slightly more sophisticated, relatively un-intrusive pricing. For instance, the area licensing scheme (ALS) in Singapore, first implemented in the early 1970s, required motorists to display a placard in order to operate legally within the congested central region of the city. In this early form of congestion-based pricing, the placard could be purchased from the government for a fee; however, Singapore has since upgraded its ALS to electronic collection (Menon, 2006). Similarly, as part of a pilot program in Salt Lake City, motorists can purchase and display bumper stickers which allow them access to high-occupancy/toll (HOT) lanes on a monthly basis (FHWA, 2007). Both the early ALS in Singapore and the HOT lane scheme in Salt Lake City are manual congestion-based pricing methods which likewise require manual enforcement by police or other compliance agents.

Outside of transit fares, some tolled highway corridors, and tolled special-purpose facilities such as bridges and tunnels, most transportation funding around the world today is derived from indirect user fees and general taxes. One exception is The Netherlands, which is in the process of transforming its highway transportation funding scheme. The objective of the transformation is to replace the existing combination of fuel taxes, registration fees, vehicle ownership taxes, and other revenue mechanisms with a nationally scaled direct user fee "pay by the kilometer" scheme (Eurlings, 2007). The Netherlands' scheme is enabled by electronic toll collection (ETC) – more specifically, a system which combines vehicle tracking via global navigation satellite systems (GNSS) and ground-based communications via dedicated short-range communications (DSRC) technologies. As the technological capabilities improve and costs decrease, ETC may allow for a more comprehensive replacement of fuel taxes and other assorted fees and taxes with more direct, real-time user charges based on time of day, location, type of vehicle, and other factors.

While technology-enabled road pricing schemes such as that in The Netherlands are typically discussed in the context of addressing congestion, they also provide opportunities for reconsidering the role that revenues play in shaping decision-making processes as part of strategy development. In general, property taxes, income taxes, and other general sources of revenue for transportation do not generate data of value for transportation strategists. Even the fuel tax provides only aggregate information about revenues, which can be used to compute total travel consumption, perhaps with some geographic disaggregation, depending on the precise method of collection. With ETC, however, the data collected from travelers can provide much greater detail, including locations and distances traveled and amount of charges paid (Cottingham, et al., 2007).

Organizations which control revenue collection by selecting the types and quantities of user fees and taxes generally also exercise the greatest control of the resource allocation process. Table 3-3 summarizes the types of data generated as part of the revenue collection process that can be used in the resource allocation process. Indirect user fees and general taxes provide less resolution on travel patterns than direct user fees. Instead, as discussed next, organizations must rely on other data sources together with a combination of analytical tools, historical resource allocation formulas, and political resource bargaining to guide investment decisions.

Table 3-3. Summary of transportation revenue sources

Revenue source	Relative technology investment required	Data generated with relevance to transportation
General taxes (income, sales, etc.)	Low	Demographic
Property tax	Low	Land-use and land-value data
Fuel tax	Low	Aggregate revenues and fuel consumption
Vehicle/driver registration fees	Low	Vehicles and driver demographics
Manual tolling	Low	Facility-specific revenues, aggregated
Electronic tolling	Medium (e.g., DSRC[7], GNSS[8], camera-based)	Facility-specific revenues, disaggregated at the vehicle/driver level
Distance-based tolling	Advanced (e.g., GNSS)	Travel data highly disaggregated at the vehicle/driver level
Transit tokens/cash	Low	Facility-specific revenues, aggregated
Transit smartcards, tap-in	Medium (e.g., RFID[9])	Partial travel data
Transit smartcards, tap-in/tap-out	Medium (e.g., RFID)	Travel data disaggregated at the user level

3.2.2.2 Resource allocation

Two "limiting-case" approaches for allocating resources to transportation infrastructure systems are political negotiation and technical evaluation. Most resource allocation decisions involve lengthy, multi-step processes that incorporate both political and technical considerations. Moreover, within any given region—say, a metropolitan area—a variety of organizations making resource allocation decisions may follow distinct approaches, leading to investment decisions for the metropolitan area which reflect a patchwork of diverse approaches. For example, in the U.S., resource allocation decisions for a metropolitan area over a several-year period might include: a politically negotiated earmark for a transit project administered by the federal government; a highway capacity enhancement project decided through a state DOT prioritization process; and a municipal streetscape improvement decided through a local government's public works department. Although metropolitan planning organizations (MPOs) may facilitate these projects and provide coordination among the various agencies involved, ultimately each actor pursues its own resource allocation independently. For all their differences, resource allocation approaches generally share in common the fundamental feature of attempting to maximize some objective. In this section we discuss the range of resource allocation approaches and the ways in which they are influenced by technology.

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[7] Dedicated short-range communications

[8] Global navigation satellite system

[9] Radio frequency identification

In practice, both purely technical and purely political resource allocation decisions are rare. Instead, they reflect a mixture of inputs. For example, in the U.S., state DOT highway investments for preservation, safety, capacity enhancement, and other needs are typically recommended by engineers and other technical specialists who predict benefit-cost ratios, net present values, environmental impacts, and other measurable outcomes of various investment alternatives in order to rank them. Next, these recommendations often must be approved by a commission of elected or appointed officials. Simultaneously, legislators can allocate resources for specific projects through a process known as earmarking. Likewise, in Portugal, the decision to invest in new highway infrastructure historically has been a political decision of elected or appointed members of the government. However, such decisions are informed to varying degrees by technical input on such factors as costs, travel demand, safety benefits, and, in the case of highway investments, conformity with the national highway plan (Dinis, 2009; Ginjeira, 2009).

Improvements to the analytical tools used by engineers, economists, and others represent a broader movement to shield transportation resource allocation decisions from political influence and to move toward greater, more "rational" technical decisions. Doig (2001), for instance, chronicles the founding of the Port Authority of New York and New Jersey, putting the early history of the agency in the context of the Progressive movement of the early 20th century, when elected officials, interested in more rational resource allocations, increasingly relied on specialists such as transportation engineers to guide major decisions. However, as with politically driven resource allocation decisions, even the rational methods employed by specialists can fail to satisfy the needs of the large and diverse public served by major infrastructure investments.

Other examples of mixed political-technical approaches for resource allocation decision include formulas and rankings. Under a formula-driven approach, an organization devotes resources to various projects or districts based on a formula informed in part by technical input and in part by political negotiation. Formulas can require equitable distribution of a portion of resources across projects or districts, distribution of a portion based on population, and so on. For example, the state of North Carolina distributes highway capacity funds to sub-state districts based on the following formula: 25% of funds are shared equally across all districts, 25% of funds are shared on the basis of the number of miles left to complete the portion of the intrastate highway system in each district, and 50% are shared on the basis of district population. Rankings-based approaches require the multi-dimensional merits of projects to be measured using standard procedures so that projects with the highest score can be recommended for implementation.

For formula-based and other technical resource allocation decisions, data play a major role. And as with revenue sources, technology largely determines what data are available. For example, in the U.S., MPOs use regional travel models as part of their planning processes, which require substantial input of regional travel data such as the physical transportation network, land uses, and demographics (e.g., population, density, income, age, employment). Models are validated using origin-destination surveys and traffic counts on all modes of travel. At state DOTs, travel volumes, pavement conditions, bridge conditions, and other data are typically collected manually (Booz Allen Hamilton, 2007). Transit agencies monitor ridership through manual ride counts (and increasingly from electronic farecard data), validated by revenues (Farzin, 2008). They may also monitor congestion and performance through automated vehicle location (AVL) systems.

Other sources of transportation data useful for informing resource allocation decisions include customer feedback and input from the general public, for example through public hearings and "town hall" meetings.

There are many advantages to using data generated by advanced technologies to supplement or replace existing sources of data that inform resource allocation decisions. For example, FHWA (2005) characterizes transportation data when collected by traditional means versus when collected using advanced technologies such as ITS. Whereas traditional survey data are collected infrequently, cover only small periods, and require intensive labor, ITS data are collected continuously and automatically. Tradeoffs include the higher cost of storage for ITS data and greater difficulty in checking errors. Table 3-4 presents several examples of types of data that can be supplemented and/or replaced with data from innovative, technology-enabled sources. These are discussed in greater detail in Appendix 1.

Table 3-4. Examples of innovative data sources for strategy development

Type of data	Traditional sources	Innovative sources	Advantages
Vehicle volumes	Sampled manual counts at specific points	Complete, continuous counts across a network	More complete coverage of road networks, spatially and temporally
Transit ridership	Sampled manual ride checks	Automated passenger counters and farecard data	More complete coverage of transit networks, spatially and temporally
Travel demand	Mode choice and origin-destination surveys	Tracking of individuals and vehicles via GPS, DSRC, and/or mobile phones	Continuous O-D vehicle flows across a network provide broad coverage, activity-based surveys
Crash data	Police crash reports	Automated crash reporting systems	More complete records; improved accuracy of crash location and other aspects

Together, these data provide decision-makers with measures of the current conditions and performance of infrastructure as well as some insights into future expected conditions and performance. The practice of using information systematically to inform the resource allocations for maintenance, preservation, and operations of highway infrastructure that meet organizational objectives is referred to as asset management, and asset management techniques have increasingly been adopted by highway agencies in both the U.S. and Portugal (NCHRP, 2002; Dinis, 2009). On the other hand, resource allocation decisions for expansion of highways and construction of new highway links are more complex. They rely on a broader range of information, including economic and demographic forecasts, travel demand forecasts, financial forecasts, and, often, political input.

A potential source of friction between the political and technical forces that shape resource allocation decisions is the time scale over which decisions are made. Political decisions tend to focus on shorter-term outcomes, while technical decisions may often focus on longer-term outcomes. For example, early metropolitan transportation plans in the U.S. employed horizons for decision-making ranging from 20 to 40 years. According to Boyce, et al. (1970), the reason for these time horizons was that planners modeled their projections of demographic trends and travel demand together with fully elaborated alternative visions of future metropolitan-scaled transportation networks, including highways and transit. The alternative future networks would take decades to build. Consequently, in order to observe any meaningful differentiation among the modeled performance of alternative future networks, planners had to build and test transportation scenarios at a future time in which the networks could be reasonably expected to be fully built (e.g., CATS, 1962). Today, per federal regulations, state and MPO long-range transportation plans must employ a minimum 20-year strategic planning horizon (FHWA and FTA, 2007). Likewise, transit operators must perform financial planning over a 20-year horizon. However, the recommendations emanating from such long-term technical evaluations may conflict with the shorter-term objectives of elected leaders who in many cases are the ultimate decision-makers, particularly when resources are collected and allocated by legislative bodies and executive administrations rather than functional agencies. Of course, the time frame of technical decision making may also be shorter-term in nature, depending on the type of project or program under consideration and the political environment within which it is pursued.

The approach an organization takes for allocating its resources to transportation infrastructure depends on political factors and technology. In general, advances in transportation technology have the potential to deliver greater amounts of technical information to the process of developing resource allocation decisions. Higher levels of technical input can, in turn, shape not only the way in which strategies are developed within the political sphere but also what they look like.

3.2.3 Geographic scale

The third dimension of interest for strategy development frameworks is geographic scale. As discussed in Section 3.1, transportation organizations develop deliberate strategies that apply to particular geographic scales, while strategies emerge for regions at any geographic scale. In this section we consider the experiences of organizations and observations in literature on the spatial scale of strategy development for surface transportation and summarize the historical influence of technology in shaping geographic scale.

In the U.S., state governments and the federal government have historically been the dominant geographic scales of deliberate strategy development for highway transportation. In the early 20th century, the federal government undertook a national effort to define highway corridors, with substantial input from states, which ultimately became the Interstate highway system. Contemporary strategy development occurs largely at the scale of states and metropolitan areas, while operating agencies such as turnpike authorities and transit agencies also develop strategy for geographies coincident with their operating boundaries (Weiner, 1997). Statewide strategy development occurs through the transportation planning process at state DOTs. The "state" as the preferred geographic unit of strategy development in the U.S. is a product of both political and financial history. Traditionally, states have provided the greatest amount of transportation services. During the early decades of the national highway planning efforts, for example, the states dominated the federal government's efforts to determine highway locations, routes, and order of construction. Also, for most of the 20th century, states collected fuel taxes to fund transportation investments (TRB, 2006). As owners of fuel tax revenue streams, the states required a process by which to determine how to disburse revenues back to the transportation system. These factors can be understood as the historical influences that have led to the role of today's statewide organizations (largely state DOTs) as strong actors in the determination of transportation investments.

Despite the financial and political dominance of state DOTs, metropolitan strategy development has grown in importance in the latter part of the 20th century, facilitated partly by federal requirements for metropolitan planning. The origins of today's metropolitan planning efforts date to the technical studies of transportation demand in urban areas of the late 1950s, such as the Chicago and Detroit Metropolitan Area Transportation Studies. In addition to the analytical convenience of the metropolitan scale discussed in Section 3.2.2, planners appear to have been motivated by a belief that the metropolitan area was an important economic unit with dense, strong internal connectivity. Just as Porter would later recognize, the authors of the Chicago and Detroit studies argued that metropolitan regions "are, and will continually be, in competition with one another." Moreover:

> The productive strength of a metropolitan area is affected by the design and operation of its internal transport system. Once again there is great need to secure a more efficient transport system, and there will be great rewards for those areas which do so most effectively (CATS, 1962).

According to Meyer and Miller, the Chicago and Detroit studies, and their successors in the 1950s and 1960s "facilitated 'rational' decision making by developing comprehensive plans... 20 to 25 years into the future" (CATS, 1962). Comprehensive, in this context, refers to the metropolitan geographic scale. Boyce et al. (1970) observed that the metropolitan land use and transportation planning programs of the 1960s "evolved from the urban transportation study of the late 1950 to early 1960 period." The 1960s metropolitan planning programs were later codified by federal laws as the metropolitan planning process and carried out by MPOs (Weiner, 1997). Recent research by Porter and others in the regional science field reflect the motivations explicitly stated in the Chicago study and highlight the economic importance of "regions" as units of competition (e.g., Porter, 2001). For example, according to the Association of Metropolitan Planning Organizations (AMPO, 2010), U.S. metropolitan areas account for nearly 75% of the population, and "the quality of metropolitan transportation infrastructure ... is, therefore, a primary factor in American economic competitiveness."

Despite the clear economic importance of metropolitan areas, there is little empirical evidence to justify transportation infrastructure planning and governance at the metropolitan geographic scale. For example, the geographic scale suggested by Porter is not necessarily limited to the conventional metropolitan area; he suggests a broader regional perspective such as a sub-national region or even a nation. Even AMPO points out that efficient functioning of metropolitan transportation systems is key for American competitiveness, raising the question, if *American* competitiveness is the objective, why do we not plan at a national geographic scale? The CATS observation that a metropolitan area is "affected by the design and operation of its internal transport system" could likewise be applied to a wide range of other geographic scales, from neighborhoods to continents. In short, when we conclude that metropolitan geographic scales for transportation planning are appropriate simply because metropolitan areas are important economically, we are begging the question. Regardless of whether the objective is metropolitan transportation efficiency and economic competitiveness, national transportation efficiency and economic competitiveness, or efficiency and competitiveness at some other geographic scale, it does not follow that planning and strategy development must occur at that same geographic scale. There is a step missing from that logic. Hence, in this thesis we investigate the consequences of strategy development at other geographic scales in an attempt to complete the logic chain and to understand more completely the relationship between the geographic scale of strategy development and transportation system performance.

Strategy development also occurs at a variety of geographic scales in Portugal. As the dominant political unit with the greatest financial resources, the national government executes most of the strategy development at the national geographic scale through a political process. However, municipalities also develop strategies for transportation (e.g., municipal transportation plans) and operating agencies such as transit agencies develop strategies for their organizations. There have also been two recent efforts to conduct metropolitan planning, one "top-down" and another "bottom-up." The top-down approach has involved the European Union's designation of five regions within the country, and attempts to develop development plans, including transportation plans, for those five regions. The bottom-up approach has involved several collections of two or more municipalities with dense transportation or other mutual economic linkages attempting to coordinate municipal transportation investments and to raise awareness of transportation needs corresponding to their multi-municipality metropolitan areas. For example, several municipalities in the Lisbon metropolitan area have attempted this tactic (Nelson, 2008).

There are three general ways in which technology has influenced the spatial scale of strategy development for surface transportation. First, the technology of transportation itself (infrastructure and vehicles) has continually changed the spatial scales across which people can travel, which has led to continual changes to the scales which are viewed as important or appropriate for strategy development. Second, the types and methods of collecting data from the transportation system, together with analytical techniques and computational resources, have enabled transportation studies at a variety of spatial scales, including scales for which no formal organization or deliberate strategy exists. Finally, the types and methods of collecting revenues from and for the transportation system have empowered organizations of varying spatial scales with resources for allocation, and therefore power, over investment decision making.

Vehicle and infrastructure technology. Many researchers have examined the relationships between demand for travel, vehicle technology, transportation infrastructure technology, land-use patterns, and organizations. Lay (1992), for instance, provides an broad survey of the co-evolution of vehicles and infrastructure in civilization dating back several thousand years. Mumford (1961) focuses specifically on urban settlements, providing a historical overview of the co-evolution of vehicle technology and urban spatial patterns. Early long-distance travel methods, from wagons to trains, enabled increasingly dispersed settlement patterns, while the automobile enabled suburbanization of cities. As the technology of surface transportation has changed, so have notions of what constitutes the spatial scale of a community. Today's surface transportation organizations are both modally oriented and spatially oriented, in that they tend to deal with one mode of travel covering a fixed geography, whether local, metropolitan/regional, state, or national in scale. The rise of "metropolitan" as an important scale for strategy development is a function of the transportation technologies (e.g., automobile and transit networks) that have allowed for metropolitan-scaled settlement, travel, and trade patterns. Likewise, increasing emphasis on larger scales (e.g., the Northeast corridor in the U.S. or the Lisbon-Porto corridor in Portugal) for strategy development can be traced in part to more broadly scaled transportation technologies such as high-speed, high-volume highway networks and high-speed rail. More recently, Sussman, et al. (2005) suggest that widespread deployment of ITS requires a regionally scaled perspective for strategic transportation planning.

Transportation system data. The geographic scale of strategy development has also been influenced by the availability of transportation system data, which is a function of the technology used to collect them and the techniques available for analyzing them. The origins of *metropolitan* planning date to the technical studies of transportation demand in urban areas of the late 1950s, such as the Chicago and Detroit Metropolitan Area Transportation Studies (e.g., CATS, 1962). The metropolitan scale was appropriate for the application of large-scale alternative future visions of a regional highway network and of the mathematical models that had been developed to estimate travel demand on urban highways (e.g., Meyer & Miller, 2001). The adoption of the metropolitan scale led to the need for metropolitan-wide data collection efforts—for example, traveler behavior surveys.

Revenue collection technology. Early highways were privately built with local financing secured by toll revenues. Even today, toll facilities in the U.S. tend to be operated by local entities, often with special jurisdictions. Notable examples include the Port Authority of New York and New Jersey, which owns and operates toll bridges and tunnels in the New York metropolitan area; North Texas Turnpike Authority, which owns and operates a network of tolled facilities in the Dallas-Fort Worth Metroplex; and the Massachusetts Turnpike, which owns and operates the fully tolled, 130-mile portion of Interstate 90 in Massachusetts. "Free" highway facilities financed by indirect user fees and general tax revenues, on the other hand, tend to be owned and operated by state governments in the U.S. Such anecdotal evidence corroborates the conclusions of Levinson (1997), whose theoretical work examined the relationship between the size of a jurisdiction and its choice of transportation infrastructure revenue sources. He concluded that the likelihood of financing highways through tolls increases as the size of jurisdictions decreases; likewise, the likelihood of financing highways through general taxes increases as the size of jurisdictions increases.

In Portugal, free and tolled highway facilities are owned by the national government and operated by a combination of state-owned and private companies through concessions. One notable exception is the A21 toll highway, which connects a major north-south Portuguese highway (A8) to the coastal town of Ericeira through the city of Mafra. A21 was the first highway project pursued entirely by a municipal government without central government approval or support (Mafra Regional, 2006) and was secured financially by borrowing against future toll revenues. Due to national regulations, ownership of the facility has reverted to the national government.

The linkage between revenue collection technology and geographic scale of ownership and operation of highway facilities (and therefore the authority over strategic decision making in them) is indirect but important. As the cost and efficiency of electronic revenue collection technologies improve, they enable more comprehensive tolling and pricing of motorists, whether on high-speed expressways or congested urban streets. A fundamental task for strategists is to reevaluate existing organizations and determine the appropriate geographic scales at which to administer increasingly comprehensive and complex pricing schemes.

Table 3-5 summarizes the various geographic scales at which strategy development can occur and suggests the placement of various existing organizations.

Table 3-5. Geographic scales for strategy development by organizations

Local	Metropolitan	State	National
U.S. towns, cities, and counties; Portuguese municipalities	U.S. MPOs; Portuguese CCDRs, multi-municipality compacts, transit operators	U.S. state DOTs; Portuguese central government agencies & SOEs	U.S. DOT; European Union

There is no consensus in the literature or in practice as to the "appropriate" geographic scale for strategy development in surface transportation. Municipal, metropolitan, statewide (or provincial), and national scales have all been proposed, with no clear preference, and often with nascent organizations to match proposed new scales struggling to take shape (e.g., MPOs in the U.S. and AMLs in Portugal). It is clear that technology, analytical methods, demographics, economics, politics, and even culture are factors affecting the spatial scale of strategy development. Moreover, as the range of spatial scales deemed important for transportation strategy expands, so does the need for an understanding of how strategies are likely to emerge, particularly in the absence of a corresponding organization.

3.2.4 Transportation lessons from the field of strategy

The dimensions of interest along which strategy development frameworks vary include institutional architectures, decision-making processes, and geographic scales. A variety of factors influence the alternatives available for selection along these dimensions, including demographic forces, the "inertia" of history (i.e., once an approach is adopted, it is difficult to change), natural geography (e.g., natural barriers such as bodies of water and mountainous terrain), political choices, and technology. We focus our interest on the influence of the political choices of various organizations ("agents") as well as the influence of technology.

- Institutional architecture: Deliberate strategies in transportation inherently span an organization. The size and scope of the organization are influenced by demographic forces, political choices, and vehicle and infrastructure technology.
- Decision-making process: The selection of types and quantities of revenue sources is a function of politics and the technology of revenue collection. Options for collecting revenues from surface transportation systems have expanded with the growth of ETC and farecard technology. Likewise, the range and quality of available system data to inform decision-making has grown with the deployment of transportation technologies. Again, politics and institutional context influence *how* data are used in the strategy development process, but technology-enabled sources of data offer the potential for reshaping decision-making processes.

- Geographic scale: Strategies may be developed to cover specific geographic scales (e.g., metropolitan, national). The selection of a particular geographic scale is influenced not only by political factors but also by vehicle and infrastructure technologies which define regions of interest, the quality of technology-dependent data and information for decision support, and the efficacy of revenue collection technologies at various geographic scales.

In this section we have drawn on strategy literature from the management field as well as transportation literature to characterize the key dimensions of transportation strategy development frameworks. In the following section, we survey the strategy development framework of the Portuguese context more deeply.

3.3 Transportation strategy in the Portuguese context

This section summarizes transportation strategy in the Portuguese context, focusing on the organizations that develop strategy in Portugal. We distinguish between geographically defined, general-purpose government agencies and functionally defined, task-specific agencies (the two principal classifications developed by Hooghe and Marks discussed earlier). General-purpose governments are responsible for a variety of services within a fixed, clearly defined geographic jurisdiction, such as a municipality. Task-specific agencies, on the other hand, have responsibility for a single function or type of service, but not necessarily within a geographic region that corresponds to a particular government. Urban public transit agencies, for instance, may cover all or part of multiple municipalities, with boundaries that are not permanently fixed. Transportation infrastructure and services in Portugal are provided by a combination of these two types of organizations, and we discuss the inter-relationships, decision-making processes, and geographic scales of each organization below.

3.3.1 General-purpose organizations

There are five layers of general-purpose government jurisdictions of relevance for Portugal: the European Union, the national government of Portugal, administrative regions, municipalities, and civil parishes. Each layer varies in its ownership of transportation infrastructure, responsibility for operating transportation services, authority to collect and disburse revenues, and control over transportation strategy development. In the following sections we will discuss each of these aspects for each level of government.

3.3.1.1 EU

The European Union (EU) is a governing body comprising 27 member nations, including Portugal, which acceded in 1986. The EU maintains some regulatory institutions; however, its most important role, measured by expenditures, is to provide for economic development of member states. Its primary mechanism for accomplishing this is to distribute funds to sectors (e.g., agriculture and transportation) and regions (e.g., Central and Eastern European countries).

EU revenues are collected from the governments of member nations. Each nation's contribution is computed based on the following tax mechanisms: duties (on agricultural production and customs), a uniform 0.3311% value added tax (VAT), and a payment proportional to gross national income (GNI). The GNI portion of revenues accounts for approximately 2/3 of total EU revenues, while duties and VAT each account for about 1/6. Portugal's contribution to the EU budget is modest relative to total EU revenues: Portugal contributed €1.55 billion in 2008, or

1.3% of total EU revenues. For financial year 2008, EU revenues totaled approximately €119 billion, up from €106 billion in 2007 and €101 billion in 2006 (EU, 2008).

The majority of EU budget is allocated to agricultural programs; however, a substantial portion of the remainder is devoted to economic development programs, including transportation. Funding for transportation is delivered through several programs. At the highest level, funding designated for the *Structural* and *Internal* "headings" can be applied to transportation. In 2006, €45 billion were distributed under the *Structural* heading. The *Structural* heading includes the Cohesion Fund, an annual program of approximately €6 billion specifically earmarked for transportation and energy infrastructure. Funds awarded to transportation projects through the *Structural* heading tend to be based on financial need of the applicant countries and the merits of each particular project relative to EU goals such as economic and social cohesion and inter-regional cooperation. The *Internal* heading provides funding to a wide variety of sectors such as education, environment, health, research, and transportation; transportation funds distributed under the *Internal* heading are devoted largely to the Trans-European Network. Member countries can propose projects for funding through these programs, and funding is typically awarded on the condition of a local funding match of as little as 15% for countries with per capita income below 90% of the EU average.

Although the EU provides funding for transportation projects, regulates some aspects of the sector, and supports research through its Directorate-General for Energy and Transport, explicit strategy development activities for infrastructure are very limited. The principal planning effort of the past two decades has been the designation of the Trans-European Network for Transportation (TEN-T). TEN-T is a network of roadways, railways, waterways, airports, seaports, and a satellite communications network (Galileo), first defined by the European Council in 1994 and adopted by European Parliament in 1996. Since then, TEN-T has been updated periodically based on the recommendations of the High Level Group, a special committee charged by the EU government with examining the TEN-T network. TEN-T today comprises a set of "30 priority axes" (e.g., rail corridors, motorway corridors, waterways, and airports) throughout Europe. The purpose of designating the network is to encourage investment of local, national, and EU resources in the axes, in order to support economic competitiveness, balanced and sustainable development, and economic and social cohesion. The EU's TEN-T program has historically provided a small amount of funding for TEN-T infrastructure (€600 million per year until 2004), but the EU expects to increase the amount of annual investment to €3 billion in the future. TEN-T funding supports up to 50% of "preparatory studies" and as much as 20% of construction costs. The remainder of TEN-T costs is covered by local matches and EU Cohesion funds.

In Portugal, applications for EU funding are managed by Quadro de Referência Estratégico Nacional (QREN), an agency of the national government responsible for managing applications with the EU and distributing funds from the EU to applicant agencies and organizations (Almeida, personal communication, 2008). In order for Portuguese transportation proposals to be awarded EU funding, applicants must meet certain criteria, such as demonstration of the international benefits of a project. QREN's role is to standardize and prioritize applications for EU funding from the various government agencies, companies, and other organizations in Portugal.

In addition to funding, the EU can use regulations and directives as means of expressing and implementing strategy. Regulations are effectively prescriptive laws that are binding and enforceable in all member EU states. Directives, by contrast, set results or standards which member states must achieve, but they can do so by means of their own choosing. For example, Directive 96/48 specifies an EU-wide definition for high speed rail, including such parameters as speeds and gauges, which influences how member states may choose to pursue rail investments (EU, 1996).

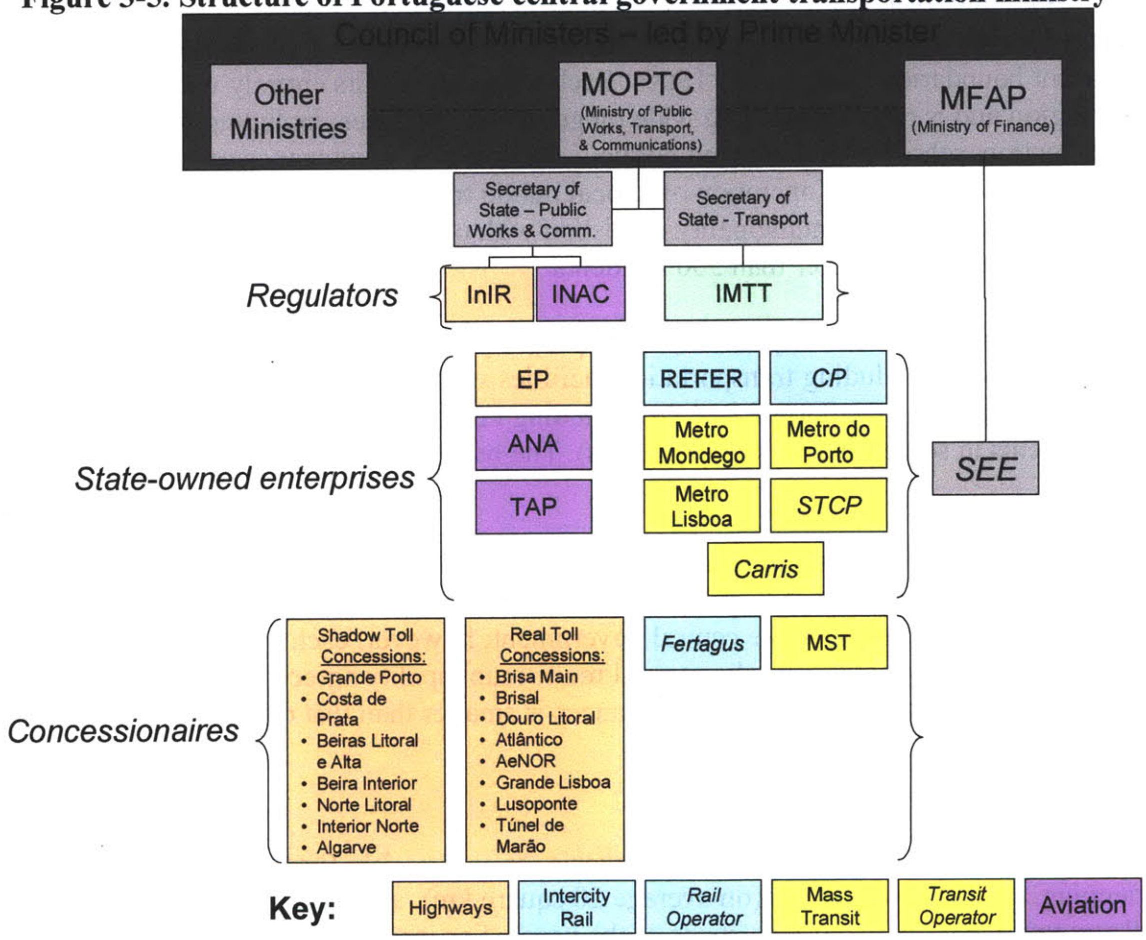
3.3.1.2 Portugal

The jurisdiction of the national, or central, government of Portugal covers the entire mainland of Portugal as well as the autonomous island territories of Madeira and Azores. Portugal was governed by the centralist authoritarian regime of António de Oliveira Salazar from 1933 until 1968. Salazar's successor, Marcelo Caetano, surrendered power in a coup d'état in April 1974, which marked the beginning of a several-year transition toward democracy. Owing in part to this recent dictatorial heritage, the central government of Portugal today is strong relative to the lower-level layers of general-purpose government jurisdictions. Also, many of the functionally defined organizations that provide transportation services, while in many cases technically private corporations, are owned by the Portuguese state and ultimately answer to boards of directors appointed by central government officials. These *state-owned enterprises* (SOEs) include the national highway company, the national rail infrastructure company, several transit operating companies, and others.

The central government collects revenues from a variety of sources, including personal and corporate income taxes, social security taxes, inheritance taxes, VAT, and excise taxes on alcohol, tobacco, automobiles and motor fuel. With the exception of a portion of motor fuel taxes, none of these revenues streams is dedicated to transportation. Instead, the government makes spending decisions on an annual basis for the variety of transportation agencies and state-owned enterprises which depend on grants and loans.

The cabinet agency with the most significant role in transportation strategy development is the Ministry of Public Works, Transportation, and Communications (Ministério das Obras Públicas, Transportes, e Comunicações, or MOPTC), but the Ministry of Finance and Public Administration (Ministério das Finanças e da Administração Pública, or MAFP) also plays a major oversight role, particularly for the state-owned enterprises. MOPTC comprises several regulatory agencies for each of the major "modes," including highways, rail and urban public transit, airports, air traffic control, maritime/ports, and telecommunications. Within each mode, the state owns one or several companies that build, manage, and/or operate transportation infrastructure and services. Each of these companies must report to and is subject to regulation by their corresponding MOPTC modal regulatory body and by the MAFP. Estradas de Portugal (EP), for instance, is the state-owned enterprise responsible for building and operating the national highway system; it reports to both the Road Infrastructure Institute (Instituto de Infra-estruturas Rodoviárias, or INIR) and the MFAP. In addition to state-owned enterprises, many private companies provide services to the national government under a variety of contractual arrangements ranging from management contracts (e.g., Groundforce, which provides luggage handling and other ground services at Portuguese airports) to full concession agreements (e.g., Brisa, which operates a substantial portion of the national highway network). Some of these contracts are between private companies and state-owned enterprises, while others are between private companies and the appropriate MOPTC modal regulatory body. Figure 3-5 summarizes the regulators, state-owned enterprises, and some of the private participants for highways, rail and urban public transit, and airports. Although the state-owned enterprises are technically owned by the national government, we treat them as "functional" agencies according to the Hooghe and Marks classification; as such, several key state-owned enterprises are discussed further in Section 3.3.2.

Figure 3-5. Structure of Portuguese central government transportation ministry



3.3.1.3 Regions

In the past, Portugal's central government divided the country into 18 administrative districts. However, these administrative districts are in the process of being replaced by a new sub-national designation in order to meet EU requirements. The new sub-national layer of government is the *region*, which meets standards set by the EU for statistical purposes as well as for delivering and administering Structural and Cohesion Funds. The national government is also beginning now to administer some national programs at the regional level. The EU's Nomenclature of Territorial Units for Statistics (NUTS) includes three levels: NUTS 1, NUTS 2, and NUTS 3. In Portugal, there are two NUTS 1 regions: the mainland and the island territories (Madeira and Azores). For NUTS 2, the mainland is divided into 5 regions, and the territories are divided into 2 regions, for a total of 7. Finally, there are a total of 30 NUTS 3 "subregions" covering the mainland and the island territories.

Regions have no independent revenue-generating authority; likewise, they do not control any funds for distribution. However, the regions do have an increasingly important role to play in transportation strategy development. Regional Coordinating and Development Commissions (Comissões de Cordenação e Desenvolvimento Regional, or CCDRs) produce regional plans, including transportation plans (Nelson, 2008).

3.3.1.4 Municipalities

Portugal is divided into 308 municipalities, the country's most stable sub-national jurisdiction, with current boundaries dating to the 1800s. Each municipality fits entirely within a single region and subregion and is responsible for a wide range of local services, including utilities such as waste collection, schools, libraries, and public works such as maintenance of local roads and sidewalks and in some cases operation of a local public transit service. Municipalities range in size, from the dense, urban municipality of Lisbon with over half a million residents, to the rural Corvo municipality with fewer than 500 residents.

Municipalities collect revenues primarily from property taxes. These revenues support all of the municipal activities, including transportation facilities such as streets and sidewalks, traffic lights, signs, and other operational features including ITS in some municipalities (e.g., access control systems in some Lisbon neighborhoods). The budgets are decided by the municipal councils.

Municipalities are required to produce municipal master plans (which may include transportation components, at the discretion of the municipality) and infrastructure development plans. The master plan is a requirement of the central government; however, each of these plans is primarily of local use. As discussed previously, several multi-municipality agreements for planning have formed, although the geography of these alliances is smaller than that of the regional designations of the EU.

3.3.1.5 Freguesias

The most local unit of government is the freguesia, or civil parish. Freguesias are non-overlapping, typically very small (on average 20 square km), and retain responsibility only for a small amount of services such as justices of the peace. For instance, there are 53 freguesias inside the Lisbon municipality. The geographic scale of the freguesia is an artifact of the Catholic parish system, and in many cases parishes and freguesias still share similar boundaries. However, the freguesia is a purely secular designation with purely secular responsibilities. It is uncommon for a freguesia to have responsibility for transportation issues; more commonly, they provide neighborhood amenities such as public restrooms, gardens, and kindergarten schools.

Freguesia activities are typically supported by funds from the freguesia's municipality. For example, there are 8 freguesias in the municipality of Porto. Each year, the municipality allocates approximately 3-5% of its total budget to the freguesias. Forty percent of the funds are divided equally among the 8 freguesias, while the remainder is divided based on population (30%) and geographic area (30%).

3.3.2 Task-specific jurisdictions

Cutting across the five geographically defined layers of government in Portugal are numerous task-specific organizations. The geographic boundaries of these organizations do not necessarily coincide with those of any general-purpose jurisdiction such as a municipality or region. Agencies and companies of this nature exist for a wide variety of types of services, including energy, water, economic development, and other utilities and services. For transportation, task-specific agencies tend to be defined modally in Portugal. That is, each agency or company deals, with few exceptions, with only one of the following: highways, rail infrastructure, rail operations, urban public transit, ports, and airports. Because of this organization, we will discuss task-specific Portuguese jurisdictions by mode in the sections that follow.

First, it is useful to consider the ownership structure of these largely modally defined, task-specific organizations. Task-specific transportation organizations in Portugal fall into one of three categories: state-owned enterprises, private companies, or agencies of municipal government.

- State-owned enterprises are regulated and funded by the State Enterprise Sector (Sector Empresarial do Estado, or SEE) an agency of the MFAP. Among the approximately one hundred state-owned enterprises, ten are involved in the provision of surface transportation infrastructure or operations: 1 highway provider, 2 rail infrastructure managers, 1 rail operator, and 6 urban public transit operators. Other state-owned enterprises include airport operators, telecommunications companies, banks, electric utilities, and hospitals (SEE, 2007).
- Private companies provide services under contract to agencies of one or more municipal governments and/or to the national government. Some private companies contract directly with state-owned enterprises, while others contract with regulatory bodies within the MOPTC. The type of contracts range from management contracts to long-term concession agreements.
- Finally, some municipal agencies provide public transit services. Municipal transportation *infrastructure* is often administered by a public works division of the municipal council, which also has a variety of other local infrastructure responsibilities. However, public transit operations are typically treated distinctly from the public works divisions and operated in many ways similarly to state-owned enterprises, although on a much smaller scale.

3.3.2.1 Highways

Highways in Portugal fall into two general categories: local roads and national roads. *Local* roads, sidewalks, bridges, and tunnels are owned, operated, and maintained by the municipalities in which they are located, typically by a public works department. All *national* roadways and associated facilities, on the other hand, are owned, operated, and maintained by a variety of concessionaires under contracts managed by the national government's Road Infrastructure Institute (Instituto de Infra-Estruturas Rodoviárias, or InIR).

Concessionaires vary in size and type of concession contract. By far the largest concessionaire to InIR is Estradas de Portugal (EP), which until recently was the highways agency of the national government, but now is a state-owned enterprise. The decision to convert EP into a state-owned enterprise was taken in 2007, purportedly to realize the same efficiencies available to the highway sector that have been achieved by private concessionaires. EP's concession contract covers all intercity highways in Portugal, which it can sub-concession to private companies or maintain using its own revenues, which are derived in part from fuel taxes (EP receives 16% of the national motor fuel tax revenues, amounting to about €600 million per year) and in part from borrowings against future anticipated toll revenues. EP's status as a concession is unusual, as concessions typically are made with private companies and are backed by user fees (i.e., tolls, whether "real" or "shadow"). EP, however, will maintain responsibility for the majority of the national highway network.

The largest private concessionaires are Brisa (which itself was a state-owned enterprise until the 1980s) and Lusoponte; approximately one dozen additional private concessionaires are responsible for highways and bridges. There are two types of private concession contracts: real tolls and shadow tolls. Under a real toll concession agreement, the operator sets toll rates (according to provisions in the contract) and collects tolls directly from motorists. Under a shadow toll agreement, the central government, through INIR, makes transfer payments to concessionaires based on the amount and mix of traffic recorded on their segments of the roadway network. Information is critical to the successful execution of concession contracts between the state and private operators. To that end, the government and concessionaires have deployed an extensive network of advanced devices to monitor traffic. The information collected supports the enforcement of contract provisions such as:

- Computing shadow toll transfer payments to concessionaires is based on the number and mix of vehicles using a facility.
- In many contracts, the government requires the concessionaire to expand a facility (e.g., from 2 to 3 lanes or 3 to 4 lanes in each direction) once average daily traffic (ADT) exceeds certain thresholds based on the data collected from monitoring devices.

Strategy development in the highway sector occurs at several levels. At the highest level, the national government has partly articulated a national highway strategy through its National Roadway Plan (Plano Rodoviária Nacional, PRN). The first PRN was finalized in 1948, with updates in 1985 and more recently in 1998. The 1998 update was developed and approved by the national assembly after consultations with the MOPTC, municipalities, and engineering organizations. It designates a variety of route types, including the location, length, and characteristics of roadways, many of which are already complete. Of course, "lines on maps" do not necessarily constitute a complete strategy. Other elements of the national strategy have emerged through negotiation in government over the past decades, including the decision to concession major elements of the road network to private operators and the decision to privatize EP. As private companies, highway concessionaires, including EP, pursue deliberate strategies of their own. Likewise, at the local level, each municipality pursues a road transportation strategy of its own. These "local" strategies may be quite diverse, but generally subservient to the conditions and requirements of the national government.

In summary, the institutional context of the highway mode in Portugal consists of a national regulator (INIR), numerous concessionaires (including EP, the former state highways agency, which is now a state-owned enterprise), and municipal government public works departments. Strategy development occurs at the national level in the government and is executed by INIR. Concessionaires take strategic positions of their own, but they compete *for* the market rather than in the market. Meanwhile, municipal governments develop independent strategies, while also reacting to any regulatory and financial constraints imposed by the national government.

3.3.2.2 Public transit

The institutional context of public transit in Portugal varies from region to region. In small municipalities and rural areas, local bus transit services are funded by municipalities. The service itself is operated either directly by a separate agency of the municipality or by a private company under contract to the municipality. In the Lisbon, Porto, and Coimbra metropolitan areas, transit service is provided by a combination of locally operated agencies, state-owned enterprises, and private operators under contract to the national and/or municipal governments.

Nelson (2008) provides a useful discussion of the financial and organizational aspects of transit agencies in Portugal, including the major operators in the Lisbon, Porto, and Coimbra metropolitan areas. The following are the state-owned enterprises providing public transit services in Portugal:

- Lisbon subway: Metropolitano de Lisboa (Metro)
- Lisbon buses, light rail, and trolley: Carris
- Lisbon ferry: Transtejo
- Porto buses and tram: Sociedade de Transportes Colectives do Porto (STCP)
- Porto light rail: Metro do Porto (MP)
- Coimbra light rail: Metro Mondego (MM)
- Lisbon and Porto commuter rail: Comboios de Portugal (CP)

In addition to these state-owned enterprises, there are approximately 14 private bus operators in the Lisbon metropolitan area, 30 in the Porto region, and numerous other companies operating under contract to various municipalities (e.g., the municipalities of Faro and Lagos). Also, Metro Sul do Tejo (MST) is a private company that constructed and is currently operating a light rail line south of Lisbon under contract to the national government. In Coimbra, Braga, and several smaller municipalities, bus service is funded and operated by an agency of the municipal government.

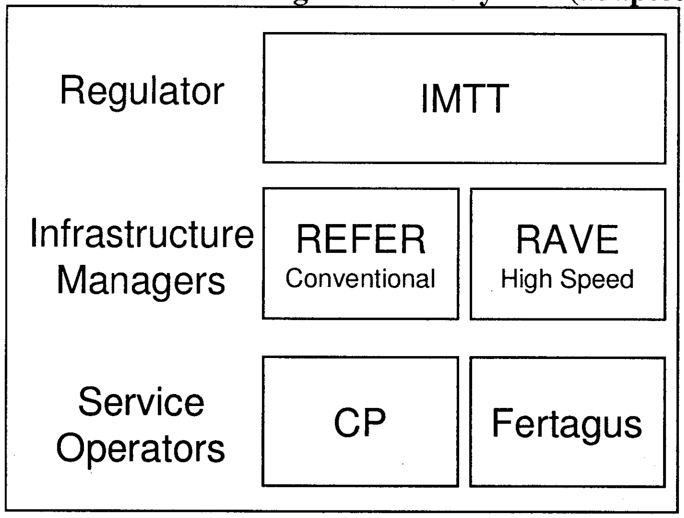
State-owned enterprises and private companies operate under contract with the national government are regulated by the Institute of Mobility and Surface Transportation (Instituto da Mobilidade e dos Transportes Terrestres, or IMTT), which determines fares, sets operating boundaries, and provides operating licenses to the various agencies for both public transit and intercity rail. IMTT does not have jurisdiction, however, over municipally operated bus transit.

Some elements of a national strategy for urban public transit are formulated by IMTT. However, the majority of strategy development occurs within each of the state-owned enterprises, private companies, and municipal agencies that operate the services as more or less autonomous entities.

3.3.2.3 Intercity rail

Intercity rail infrastructure and services are provided by a combination of state-owned enterprises at the national level. Figure 3-6, adapted from Nelson (2008), summarizes the institutional structure for inter-city rail in Portugal.

Figure 3-6. Institutional Context of Portuguese Intercity Rail (adapted from Nelson, 2008)



As mentioned previously, IMTT is the regulator for both urban public transit and rail. The two national rail infrastructure managers are state-owned enterprises. National Rail Network (Rede Ferroviária Nacional, or REFER) owns and manages the national conventional rail infrastructure for both passenger and freight, while High Speed Rail Network (Rede Ferroviária de Alta Velocidade, or RAVE) is responsible for planning and developing the national high-speed rail network. Meanwhile, service operators include CP, a state-owned enterprise, and private concessionaires. As mentioned previously, in addition to its national passenger and freight rail service, CP operates commuter rail services in the Lisbon and Porto region. At this time, the only private concessionaire providing rail service in Portugal is Fertagus.

3.3.3 Regions without corresponding jurisdictions

In addition to formal organizations defined both jurisdictionally (e.g., national government agencies and municipalities) and functionally (e.g., state-owned enterprises and private companies for highways, rail, and urban public transit), there are hypothetical regions of various sizes lacking any corresponding formal organizations. These include, for instance, urban neighborhoods, metropolitan areas, and other sub-national regions.

Neighborhoods can be defined in many ways. In Portugal, freguesias (or parishes), as previously discussed, are formal governing bodies that approximate representation at the neighborhood scale and present an opportunity to develop strategy at that scale; however, there are many other conceivable designations of neighborhoods for which there is no formal corresponding organization. Similarly, there are no formal corresponding organizations with real authority at the metropolitan and sub-national scales, despite recent attempts to formalize such agencies by the national government and attempts to create multi-municipality compacts.

3.4 Summary

Given the importance of strategy both to organizations and to regions (whether defined as metropolitan regions, nations, or some other scale), this chapter identified several ways to conceive of strategy and the dimensions of a strategy development framework which we can use to describe the context within which deliberate strategies are developed and from which emergent strategies emerge. At the same time, recognizing the importance of context, this chapter described the Portuguese context for surface transportation strategy development. In the next chapter, we construct a series of alternative frameworks, and in the following chapters we evaluate the performance of these alternative frameworks.

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4 Characterization of Strategy Development Frameworks

This chapter presents the experimental design for evaluating alternative strategy development frameworks in the context of Portugal's surface transportation infrastructure system. We provide a brief summary of prior efforts to describe and evaluate complex systems, define the term *strategy development framework*, and present a systematic approach for characterizing a variety of possible frameworks for exploration within our context. Using this approach, we can characterize both the existing framework observed in practice in Portugal and new, alternative frameworks enabled by advances in technology and new viewpoints. Together, the existing and alternative frameworks represent an "explorable solution space."

4.1 Prior complex systems research

Our identification, definition, decomposition, and characterization of "strategy development framework" draws on relatively recent research efforts aimed at understanding complex systems. Although complexity has long been present in natural and engineering environments, scientific study of complexity began only in the mid-20th century. Simon (1962), in one of the early works on complexity theory, defined a complex system as one "made up a number of parts that interact in a non-simple way" such that "it is not a trivial matter to infer the properties of the whole." There is a perhaps natural tendency toward reductionist approaches for understanding and evaluating complex systems, but a key insight of complexity theory cautions that over-reliance on reductionism can compromise our understanding of the very complexity we seek to explain. Reductionist approaches, therefore, must maintain a holistic view of the system in question; we attempt to appreciate this balance in developing the methodology of this research.

One approach for addressing complex systems is enterprise architecting, defined by Nightingale and Rhodes (2007) as the application of "holistic thinking to conceptually design, evaluate, and select a preferred structure for a future state enterprise to realize its value proposition and desired behaviors." While there are several competing approaches for framing holistic thinking about complex enterprises, Nightingale and Rhodes offer a framework comprising eight "views": strategy, organization, information, knowledge, services, products, processes, and policy. Their framework specifies methods for evaluating an enterprise according to these views, and how to approach transitions to the architecture based on that evaluation in a coordinated, holistic way. Glazner (2008) operationalized the concept of enterprise architecting by constructing a hybrid simulation model of a real-world defense contractor; by mapping the eight views of the enterprise architecture framework into quantifiable sub-models, he was able to develop an integrated platform for predicting behavior of the enterprise.

In our terms, enterprise architecting aims to improve the linkage between deliberate and emergent strategies within a single organization. Tools such as the Glazner model can be used by organizations to design more robust deliberate strategies in the face of both internal and external complexities and uncertainties. Transportation systems, however, comprise many organizational and many stakeholders, features which introduce evaluative complexity (i.e., how can we confidently recommend actions when stakeholders have competing views of "good" system performance?) and nested complexity (i.e., how can we predict the impact of multi-organizational behaviors on performance of a physical system, and vice versa?). We seek a method which, like enterprise architecting, will improve our ability to relate deliberate strategies and emergent outcomes for complex socio-technical systems, but in the context of a multi-organizational environment.

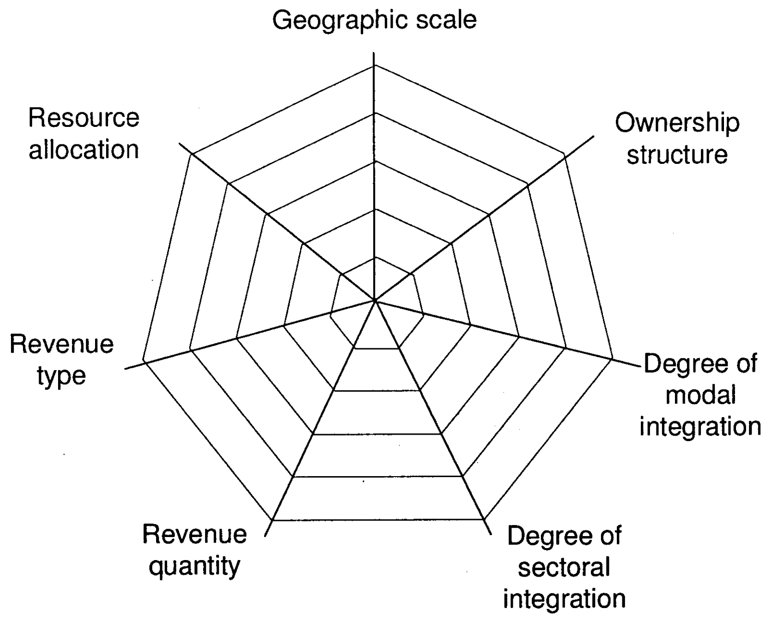
Sussman, et al. (2005) introduced the notion of Complex, Large-scale, Interconnected, Open, Socio-technical (CLIOS) systems, such as transportation infrastructure systems. CLIOS systems are characterized by several types of complexity, including the structural and behavioral complexity stressed by Simon, but also evaluative and nested complexity. These complexities complicate our ability to describe, analyze, or improve CLIOS systems using traditional analytical approaches. The CLIOS Process is an approach for representation, evaluation, and implementation of changes to CLIOS systems and has been applied to a number of contexts, including transportation systems. Although the CLIOS Process provides a framework for capturing various types of complexity, it does not suggest any particular qualitative or quantitative approaches. Instead, it allows for the construction of a unique methodological approach for representing and evaluating a system.

Our focus is on strategic decision-making for a complex system (transportation infrastructure). We are particularly interested in strategic investments in the physical infrastructure networks, but in recognition of the complexity inherent in the system we have created the notion of a *strategy development framework* as our lens for evaluating those decisions. A strategy development framework allows us to reduce our CLIOS system (Portugal's intercity surface transportation system) into discrete elements that are simpler to characterize, but we endeavor to analyze the system in an integrated—and not a reductionist—fashion.

4.2 The strategy development framework as the lens for complex systems evaluation

In Chapter 3 we introduced the notion of a strategy development framework, defining the term simply as "the environment which produces a strategy." To allow a more tractable, systematic description, we decomposed strategy development framework into several dimensions and sub-dimensions, as illustrated in Figure 4-1, and discussed the theoretical underpinnings and some examples from practice of each dimension. Characterization of a particular strategy development framework is accomplished by selecting values for each of the dimensions.

Figure 4-1. Strategy development framework solution space



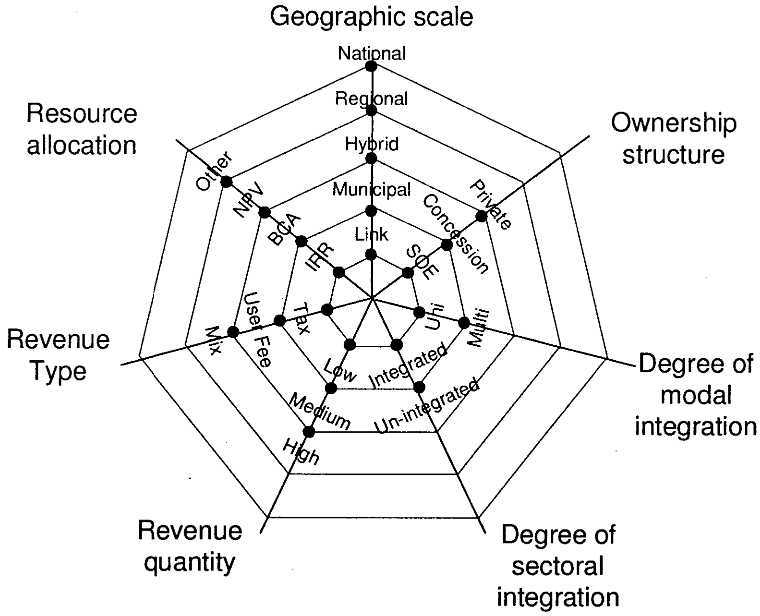
Next, we define the context: the surface transportation system of mainland Portugal. Others can be imagined—for example, the street network of Cambridge, MA; the transportation system of metropolitan New York City; or the railways of European Union countries. Defining the context is necessary in order to determine the range of values available for selection along each dimension.

Next, we define values available for selection along each of the dimensions. Figure 4-2 portrays these values along each dimension within the solution space. They are summarized as follows:

- Ownership structure: state-owned enterprise (SOE), concession, and private contracts
- Modal/sectoral linkages: uni-modal, multi-modal, and multi-sectoral
- Revenue sources: taxes, indirect user fees, and direct user fees
- Resource allocation: net present value analysis, benefit-cost analysis, and financial rate of return
- Geographic scale: link, municipal, hybrid, regional, and national
- Degree of modal integration: uni-modal and multi-modal
- Degree of sectoral integration: integrated and unintegrated

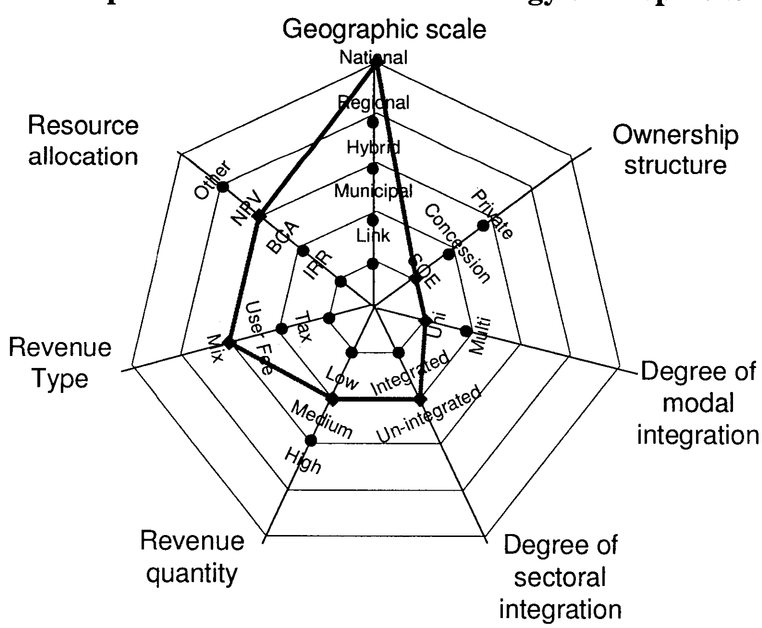
A mixture of choices along each dimension could also be selected. For example, the Portuguese highway system combines elements of concession and state-owned enterprise approaches to ownership structure.

Figure 4-2. Solution space with values



Finally, we can characterize a range of strategy development frameworks for our context by selecting specific values for each of the dimensions. For example, Figure 4-3 portrays a strategy development framework that involves a nationally scaled, uni-modal, uni-sectoral state-owned enterprises which derives resources from a mixture of taxes and revenues and makes resource allocation decisions using net present value analysis.

Figure 4-3. Example characterization of a strategy development framework



By combining all the possible values along each dimension (including mixtures of values along any single dimension such as state-owned *and* concession), it is possible to characterize many hundreds of alternative strategy development frameworks, even for the limited number of values available along just these five dimensions. We can characterize frameworks that approximate those observed in real contexts, such as Portugal; however, many of the frameworks we can characterize are hypothetical, while some are altogether infeasible, either logically or technologically.

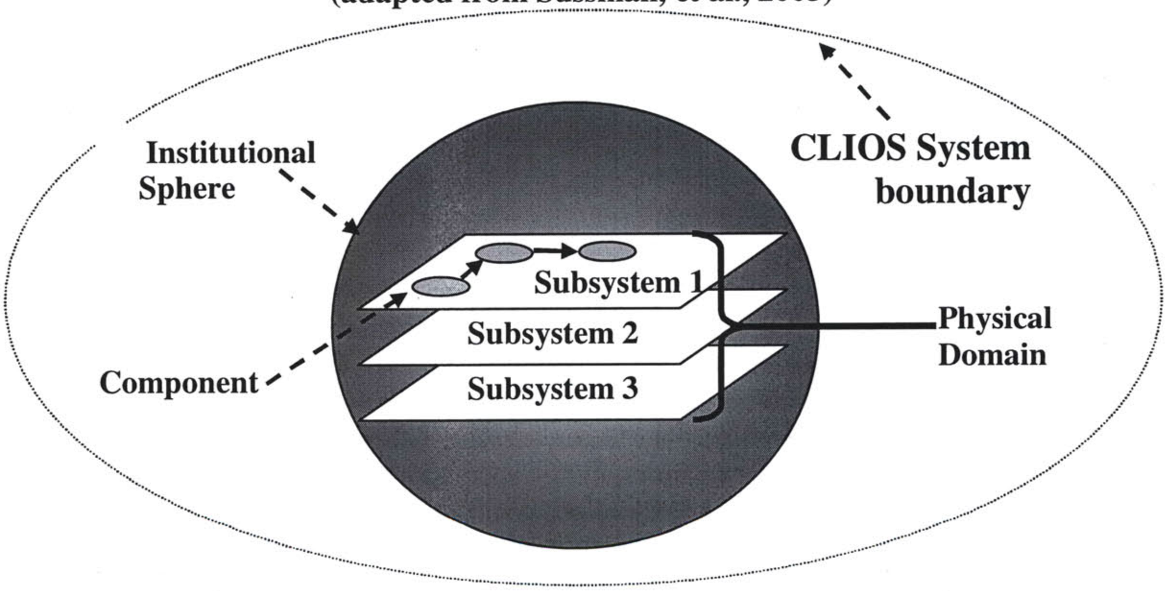
4.3 Assigning values to strategy development framework dimensions

In this section, we discuss the values available for selection along each of the five dimensions for our context as depicted in Figure 4-2 and Figure 4-3.

4.3.1 Institutional architecture

Institutional architecture refers to the organizations that oversee the physical transportation infrastructure systems and their relationships with one another. Drawing on the characterization of *nested complexity* by Sussman et al. (2005), we conceive of institutional architecture as a sphere surrounding the physical transportation system, which is represented by a set of planes (see Figure 4-4). As described above, we are interested specifically in two sub-dimensions of institutional architecture: ownership structure and modal/sectoral linkages.

Figure 4-4. Nested complexity: physical systems embedded within an institutional sphere (adapted from Sussman, et al., 2005)



4.3.1.1 Ownership structure

Infrastructure invites governmental participation because of unique characteristics—durable, immobile investments and economies of scale—which make it a natural monopoly. There are many approaches for dealing with natural monopolies; Gómez-Ibáñez (2003) identifies a continuum of alternative institutional architectures, ranging essentially from private to public: private ownership, concessions, discretionary regulation, and public enterprise.

- Private ownership. Under this approach, infrastructure is owned privately. Decisions relating to the supply of infrastructure are determined by private owners who contract directly with their customers (users and/or beneficiaries of the infrastructure). In a purely private context, customers would include individuals and privately organized, voluntary associations of individuals. Such an arrangement is difficult to achieve in practice for transportation infrastructure due largely to the immobility of assets, which increases risks such as obsolescence and expropriation and driving away potential investors. Even where private contracts could work, the economics of infrastructure would lead to an emphasis on profitable links, making extensive connectivity to high-cost and/or low-volume territories unlikely.

- Concessions. Concessions are conceptually similar to private ownership, except that governments are the customers, acting on behalf of their constituents. The key distinction here is that membership in the "association of individuals" is not voluntary. Infrastructure demand is determined collectively by government rather than by individual customers, but the private sector still must deliver the infrastructure product(s). Market influences are relatively strong because governments must rely on a willing private participant to supply the infrastructure. Private investors are more willing to participate in concessions than private contracts due to the reduction of risks such as expropriation.
- Discretionary regulation. Here the government's role includes regulation of standards of service, but provision of infrastructure is still left to private contractors. This approach is particularly useful for maintenance and operations of transportation infrastructure. When used for provision of new infrastructure, discretionary regulation requires that the government determine key parameters such as capacity (supply), alignments, and other factors, rather than leaving these determinations to the private sector supplier. Discretionary regulation is not a common approach for supplying infrastructure, but is relatively more common for operations (e.g., for urban public transit and intercity rail).
- Public enterprise. Under this approach, the government itself supplies the infrastructure. Government can still employ private contractors in the delivery of the work, but with contracts that are "limited in scope or duration" compared with concessions or discretionary regulation.

A scan of transportation infrastructure throughout the world reveals all four of these approaches, with contrasting preference from region to region. For any given context, then, ownership structures can (and often do) include combinations of the four basic alternatives described above. In the U.S., for example, almost all highways are owned and operated by state agencies or state-owned enterprises. In Portugal, on the other hand, over 70% of the motorway network (the highest grade of intercity highway) was built and/or is operated by private concessionaires, with the remainder built by government agencies and state-owned enterprises (Nelson, 2008).

4.3.1.2 Modal linkages

Another sub-dimension of institutional architecture is the diversity of the "portfolio" of the organizations within transportation, here termed "modal linkages."

- Uni-modal. Under this approach, the organizations responsible for transportation infrastructure own, manage, operate, and/or regulate particular modes of travel distinctly. For example, this is generally the case in Portugal, where distinct state-owned enterprises are responsible intercity highways, intercity railways, urban/metropolitan subways, and urban/metropolitan light rail systems.
- Multi-modal. An alternative to the uni-modal approach is for a single organization to take joint responsibility for the ownership, management, operation, and/or regulation of various modes of infrastructure, such as highways and railways.

4.3.1.3 Sectoral linkages

Related to modal linkages is the notion of sectoral linkages. In addition to considering integrated strategy development across modes, one can conceive of strategy development across sectors related to transportation such as land-use, economic development, and the environment.

- Uni-sectoral. This approach is by far the most common in practice. Organizations responsible for transportation infrastructure have little or no responsibility to other policy areas and only informal linkages to other sectors. The key implication of uni-sectoral strategy development is that the transportation sector owns its own resources or receives an allocation from a higher authority with little or no cross-modal competition.
- Multi-sectoral. By contrast, under a multi-sectoral approach, organizations responsible for transportation infrastructure would also take responsibility for a range of activities beyond transportation, including, for example, land-use, environmental, and economic development regulation, requiring that resource allocation decisions be made across these areas of activity.

4.3.2 Decision-making process

As with the institutional architecture dimension, we further decompose the decision-making process dimension into two sub-dimensions: revenue sources and resource allocation. There are three broad categories of revenues sources: direct user fees, indirect user fees, and general taxation. Meanwhile, there are numerous methods of allocating revenues; we focus our discussion on several "rational" techniques and contrast them with politically negotiated techniques.

4.3.2.1 Revenue sources

The choice of the type and quantity of revenue sources impacts the decision-making process in important ways, most importantly by determining the amount of resources available to organizations for investment in the transportation infrastructure system. The choice of type of revenues also directly impacts the *allocation* of revenues, as various types of revenues imply various levels of information about infrastructure utilization and needs. For example, direct user fees can simultaneously meter usage of infrastructure spatially and temporally, while general taxes cannot. Three broad types of revenues are available for transportation infrastructure:

- Direct user fees. Direct user fees include tolls charged to vehicles and fares charged to rail and urban public transit passengers. Electronic toll collection technology increasingly enables direct tolling, with price differentiation by location, time-of-day, type of facility, type of vehicle, and other factors.
- Indirect user fees. Indirect user fees include such mechanisms as fuel taxes, vehicle registration and licensing fees, and other usage-based charges. While these user fees attempt to allocate the cost of infrastructure to the users and beneficiaries, the ability to match actual consumption rates with payments is less straightforward. For example, an individual's fuel tax payments are a function of not only the distance traveled but also the fuel efficiency of the vehicle. Two motorists with the same consumption of infrastructure but different levels of fuel efficiency would not pay the same amount.
- General taxation. General taxation is not directly tied to infrastructure consumption. Forms of general taxation include taxes levied sales and income. Property and land-value capture taxes, on the other hand, are forms of indirect beneficiary taxes.

- Mixed. In practice, the revenue sources for infrastructure typically combine user fees and general taxation. The proportion derived from each varies from context to context. Other revenues, such as debt and private equity, constitute financing mechanisms, not sources of revenue. Ultimately both debt and equity must be repaid with revenues derived from user fees and/or taxation.

In Portugal, the principal source of revenue for the surface transportation sector historically has been the general fund of the central government, whose source in turn is a variety of general taxes: value-added, income, property, and excise taxes on such products as fuel.[10] Beginning in 2007, the government restructured the organizations participating in the transportation sector, devolving greater revenue-generating responsibilities and authorities to newly privatized state-owned enterprises such as EP (highways) and REFER (intercity rail). These entities now raise revenues almost exclusively from user fees; however, they have expanded authority to raise private capital through public-private partnerships and to borrow funds.

- Rail infrastructure in Portugal is owned and managed exclusively by the state-owned enterprise REFER. In 2007, prior to the privatization of REFER, it had expenditures of €836 million in 2007, much of it related to debt service. Of the total amount, 12% was covered by user fees and other operations-generated income, 17% by subsides (derived from general taxes of a variety of levels of government, predominantly Portugal and the EU), and 71% from new borrowing. Excluding debt service payments, REFER was able to cover 21% of its operations and investment expenses from user fees and 30% with direct subsidies, with the remaining 49% from new borrowing (REFER, 2007). Since the privatization of REFER in 2007, it no longer received direct subsides from the state, and the proportion of spending funded through user fees and borrowing have increased. However, especially given the implicit loan guarantees made to lenders by the state, it is likely that some form of general tax-funded subsidies will be necessary in the future to service the over €3 billion in debt currently held by REFER.
- EP, the newly privatized SOE[11] that operates all of the intercity highway infrastructure in Portugal, incurred total expenditures of €1,855 million in 2008, about 60% of it related to new highway investments and 26% related to debt service. Of the total amount, 49% was covered by loans, with the remainder derived from the new dedicated fuel tax (26%), payments from concessionaires (20%), and subsidies (5%) (EP, 2008). In 2008, highway concessionaires collected €722 million in direct user fees (toll), while spending €437 for upgrades and capacity expansions (APCAP, 2008). If the tolls collected by real-toll concessionaires are added to the revenues of EP and the payments by concessionaries to EP are removed, then the revenue split looks as follows: 41% loans, 22% indirect user fees (fuel tax), 33% direct user fees (tolls), and 4% subsidies.

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[10] In 2007, the government dedicated 15% of fuel tax receipts to the highway SOE (EP), such that fuel taxes can now be considered indirect user fees, at least partially.

[11] The "privatization" of EP means that, although 100% owned by the state, the company is governed by an independent board of directors (appointed by the government) and receives no direct subsidies from the government. Instead, it relies on own-source revenues which include a portion of motor fuel tax receipts, toll receipts, concessionaire fees, and fees for other user service. The majority of its revenues, however, are derived from borrowing against its own balance sheet. The government provides no direct guarantees for any loans; thus, the annual deficits and total debt of EP and other SOEs are not counted toward the government deficit and debt as reported to the EU for enforcement of EU-zone budget standards. Implicitly, however, because the SOEs provide public services, there is an expectation that the state would intervene to some extent in the event of a loan default.

Despite the fact that the central government has recently reduced its direct subsidies to the transportation sector, the ultimate sources of funding for highways, intercity rail, and urban transit remain direct user fees, indirect user fees, and transfers from general tax revenues. As indebtedness in the sector continues to grow, including via Borrowing (debt) and private sources (equity) serve not as revenues but rather as financing mechanisms to be repaid through future user fees and central government transfers.

4.3.2.2 Resource allocation

At the heart of strategy development is resource allocation decision-making. Much of the literature summarized in Chapter 3 focuses on resource allocation decisions as the essence of deliberate strategy development. Methods for making resource allocation decisions range from the highly analytical and "rational" to the chaotic, perhaps even random. Drawing an analogy to the range of approaches for strategy development discussed in Chapter 3, resource allocation decisions may be highly deliberative, based on planning, positioning, or design techniques; they can be cooperative, drawing on consensus-building and negotiation approaches; they can be centralized, influenced principally by the vision or entrepreneurship of a single leader or small group of leaders; or they can be coordinated by larger collections of individuals and groups, informed to varying degrees by information and experience.

We summarize resource allocation decision-making into two broad categories (rational and negotiated), but in order to gain analytical traction, particularly for quantitative modeling, we focus on the rational approaches.

- <u>Rational</u>. The term "rational" captures a broad range of approaches for resource allocation decision-making sharing in common that they follow standard processes and tend to be relatively more quantitative in nature than other approaches. Rational approaches are based on collection and application of data to standardized analytical techniques that incorporate computation of benefits, costs, and other effects and impacts of potential investment decisions. For transportation infrastructure, approaches are drawn largely from the project evaluation field. Commonly used examples that we will adopt in our simulation model include **benefit-cost analysis**, **net present value analysis**, and **financial rate of return**. A variety of "mixed-method" approaches that combine quantifiable scores such as benefit-cost ratios along with other measurable characteristics in order to rank alternatives are also common.
- <u>Negotiation</u>. Negotiated resource allocation decision-making processes are non-standard. Typically they play out in a political environment—for example, within legislative bodies or among elected and appointed legislative and executive leaders.

In reality, resource allocation decisions in most contexts combine rational and negotiated elements. For example, organizations may use rational approaches to recommend resource allocation decisions that are subject to negotiation and approval by political entities. Likewise, political entities may stipulate that decisions be made according to a rational process that is itself chosen through political negotiation, perhaps subject to politically motivated constraints. For example, resource allocations may be made based on a ranked score that combines measurable, "rational" inputs such as benefit-cost ratios but also politically determined distributional mechanisms such as minimum investment levels for particular, politically sensitive districts.

4.3.3 The geographic scale dimension

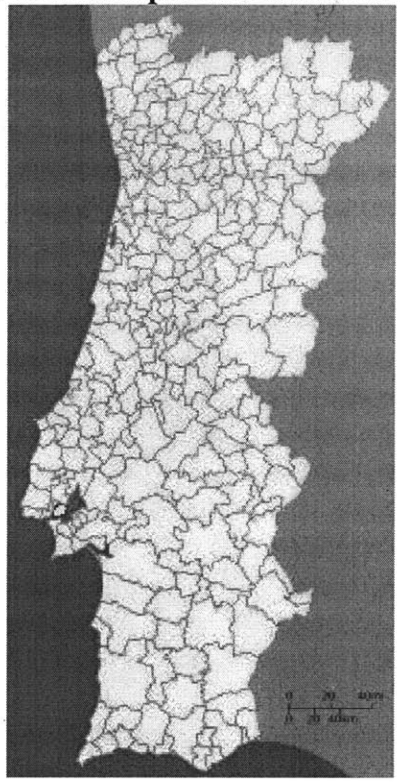
The organizations in our context span a variety of geographic scales. If we define our context as "all surface transportation infrastructure in Portugal," from residential sidewalks to high-speed intercity railways and expressways, then the organizations in our context would likewise range in geography from neighborhood associations to the European Commission. We include the following five geographic scales in our strategy development framework solution space:

- Portugal. Organizations at this scale correspond with the territory of mainland Portugal. Most of the activity related to transportation in Portugal, in fact, corresponds with this geography, including intercity highways, intercity railways, and major urban transit systems.
- Regional. This scale corresponds with the boundaries of the five EU-designated regions in mainland Portugal: North, Central, Alentejo, Lisbon, and Algarve (see Figure 4-5).

Figure 4-5. Regional boundaries of Portugal

- Municipal. For this scale, we refer to the boundaries of the 278 coterminous municipalities of mainland Portugal.

Figure 4-6. Municipal boundaries of Portugal

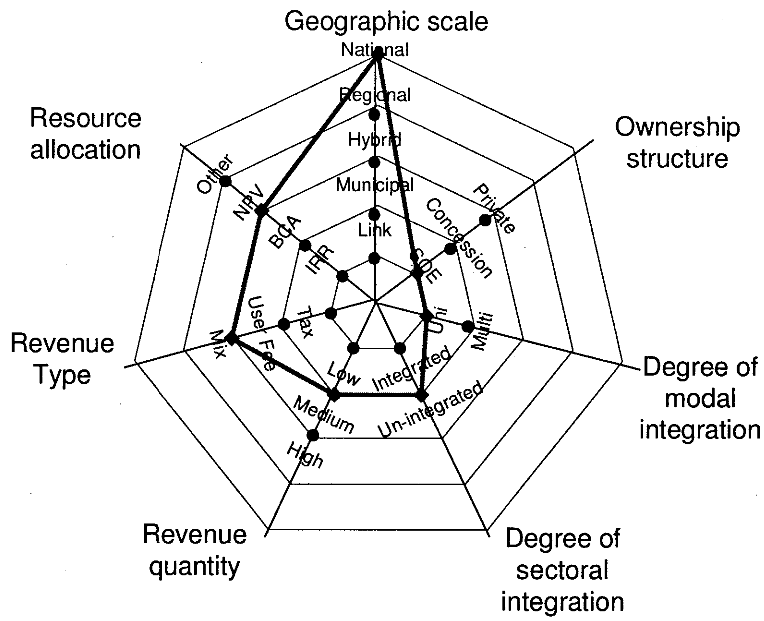


- Link. "Link-based" refers to the links of the infrastructure network itself. To achieve this geographic scale, we decompose the network into segments of highway or railway (e.g., a segment connecting two cities) and treat each link as an autonomous unit or organization.
- National-municipal hybrid. As with the other dimensions of strategy development framework, we recognize the possibility of frameworks with multiple organizations at a variety of geographic scales (national, regional, municipal, and link) described above. We explicitly include one such combination: a hybrid "national-municipal" approach.

4.4 Characterization of existing strategy development frameworks in Portugal

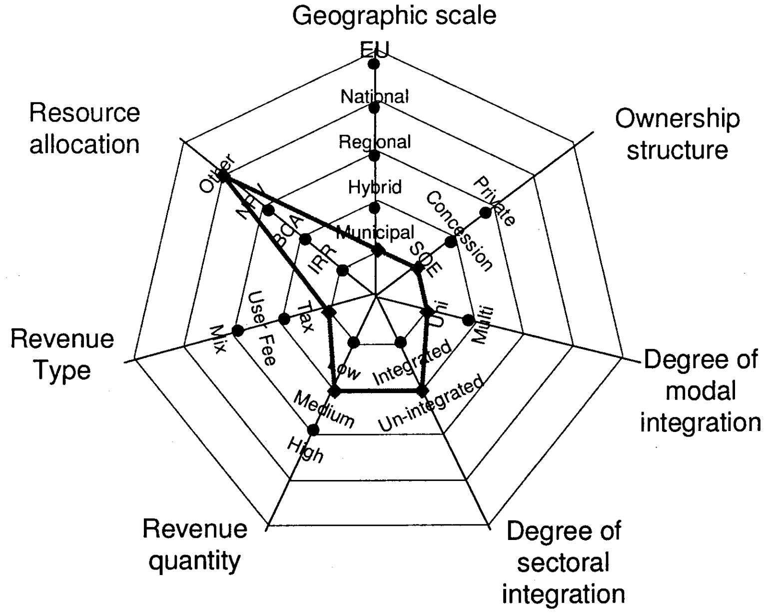
The existing strategy development framework for Portugal's intercity highways and railways is approximated by Figure 4-7. For highways, the state-owned enterprise EP is a nationally scaled, uni-modal entity deriving its revenues from a mixture of direct user fees, indirect user fees, and (at least implicitly) general taxes. The figure shows ownership structure as an SOE, although in reality there is a mixture of SOEs and concessions. Almost all of the intercity highways of "motorway" quality (limited-access, multi-lane, high-speed expressways) are provided as concessions, some through "real tolling," whereby motorists make payments directly to the operating concessionaire, and others through "shadow tolling," whereby the state makes payments to concessionaires based on traffic levels. Real toll concessions are used for the major, heavily traveled intercity and metropolitan motorways along the coast, while shadow tolls are predominantly located in the interior of the country. Under shadow tolling, the state often retains more of the traffic risk than under real tolling by guaranteeing a minimum level of payments to the concessionaire based on availability; for this reason, shadow tolling can be viewed as a "hybrid" SOE and concession approach. The remainder of the intercity highway network is operated by EP as an SOE. For railways, the state-owned enterprise REFER is a nationally scaled, uni-modal entity deriving its revenues from a mixture of direct user fees and (at least implicitly) general taxes. Investments in infrastructure in Portugal are driven by elected and appointed political leaders; this is true for both highways and railways.

Figure 4-7. Existing strategy development framework for intercity transportation infrastructure in Portugal



By contrast, Figure 4-8 approximates the strategy development framework for local road infrastructure. Local roads are all owned, operated, and maintained by municipalities effectively as state-owned enterprises (e.g., by the public works departments of the municipal government). Revenues to support local streets are derived from general municipal taxes (income and property). While some municipalities manage local roads multi-modally (e.g., in concert with local bus service, pedestrian facilities, or bicycle facilities), most municipalities treat local roads uni-modally. Resource allocation decisions combine rational elements with negotiated, politically driven decision-making (represented in the chart as "other").

Figure 4-8. Strategy development framework for local streets in Portugal



The frameworks in Figure 4-7 and Figure 4-8 reflect the approximate strategy development frameworks of two contexts: intercity and local transportation infrastructure in Portugal. However, we can select various combinations of values along each dimension to construct alternative frameworks. For example, along the revenue sources dimension we can alter the mix of reliance on user fees versus taxes. Along the ownership structure dimension, we can select among concession contracts, private contracts, and state-owned enterprises, while along the geographic scale dimension we can select organizations of a variety of sizes.

While some of these alternative strategy development frameworks remain hypothetical, recent advances in technology have made many of them feasible. For example, the improving efficiency of electronic toll collection (and declining costs) make possible the application of direct user fees across a broad range of transportation infrastructure. Collection of extensive system data from recently deployed sensors networks can be used to support a variety of increasingly rational approaches to decision-making. Likewise, improvements in available system data and more flexible, dynamic revenue collection mechanisms can empower jurisdictions at a variety of geographic scales to exert greater control than in the past. For a more detailed discussion of the technologies available and the mechanisms by which they can influence strategy development frameworks, refer to Appendix 1.

4.5 Summary: constructing and evaluating strategy development frameworks

Decomposing the strategy development framework into discrete dimensions gives us analytical traction; we can begin to see the ways in which a framework can change. Moreover, by populating each dimension with discrete values, we can construct detailed representations of strategy development frameworks, both existing and hypothetical. The factors that influence the selection of particular values along each dimension for a given context (e.g., Portugal) are numerous: political choices, demographics, natural topography, the "inertia of history" (i.e., once a value is selected, it is difficult to change), and technology. Of these factors, the two that strategists can influence most easily are political choices and technology. We explicitly recognize the influence of technology in enabling us to assemble alternative strategy development frameworks (refer to Appendix 1 for an extended discussion).

The fact that we *can* pursue any of a wide variety of strategy development frameworks for our transportation infrastructure systems does not necessarily mean that we *should*. Making a change to a strategy development framework along any of the dimensions presented here would be challenging, likely facing opposition from entrenched status quo interests as well as, in many costs, large financial costs. Before suggesting any changes, then, we must first develop a method for understanding and evaluating the full range of consequences. In the remaining chapters, we describe such a method and present the results of our evaluation of a variety of alternative strategy development frameworks within the context of Portugal. The method combines a quantitative simulation model of the evolution of a highway infrastructure network (Chapter 5 and 6) with qualitative analysis of empirical cases and stakeholder dynamics (Chapter 7).

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5 Simulation of Alternative Strategy Development Frameworks

In Chapter 4, we explained our adoption of the strategy development framework as a lens for evaluating the Portugal's transportation infrastructure as a complex system. However, the extent to which we can evaluate strategy development frameworks in isolation is rather limited; a framework is static, unengaged in any activities that produce measurable outcomes. Instead, we are interested in the outcomes that emerge from it. In this chapter, we describe a model that simulates the development and emergence of investments over time for a transportation infrastructure network. In Chapter 6, we present the results of the simulation and evaluate them, while in Chapter 7 we present a qualitative analysis of the alternative frameworks.

5.1 Transportation simulation modeling: background and assumptions

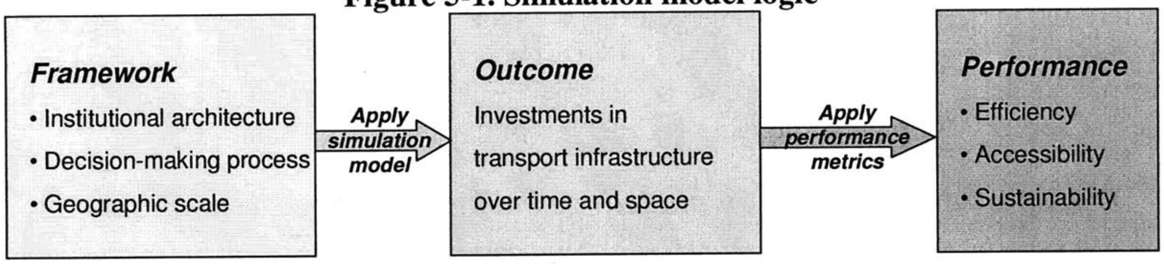
There is no shortage of simulation models with applications to transportation infrastructure. Typically, the purpose is to simulate the impacts of potential investments and policies in order to inform decision-making. Modelers commonly study the impacts of decisions on outcomes of interest such as safety, traffic and congestion, land-use patterns, revenues, economic development, and environmental impact. Research in transportation simulation modeling has focused on improving the mathematical representation of empirical observations of the contexts being modeled, by expanding the number of phenomena captured by the model, enhancing the mathematical methods used to describe observed phenomena, and improving the speed and reducing the cost of using models.

Many transportation models recognize the individual as the fundamental unit of decision-making. Individual choices relating to transportation include where to live, where to work, where and how often to travel, how to travel (by which means and by which routes), how much money to spend on travel, and so forth. Discrete choice analysis offers a means of modeling these individual choices and predicting how individuals will respond to infrastructure investment and policy decisions (e.g., altering the characteristics of transportation networks such as travel speeds, capacity, and prices will lead to new choices) (Ben-Akiva and Lerman, 1985). These individual choices can be aggregated in order to observe emergent behavior of larger populations, such as travel patterns. The focus of research in this type of transportation modeling is on individual behavior and understanding and modeling more accurately how choices are made. By predicting more accurately how consumers will react (both individually and collectively) to strategic investments and policies, decision-makers can make better-informed decisions.

The purpose of the model described in this chapter is distinct from transportation models based on individual choices and activities. Rather than simulating individual decisions in order to *inform* strategic infrastructure decisions, we are interested in simulating the strategic infrastructure decisions themselves. To do so, we focus on simulating the decisions of *organizations*. These decisions are informed by the organization's deliberate strategy and, over time, produce outcomes (investments) that reveal an emergent strategy.

The inputs to our simulation model are a strategy development framework and a context, or environment, which includes a physical transportation infrastructure system and its users. The outputs of the simulation include investment decisions in the infrastructure network which over time produce investments and reveal emergent investment strategies. We can evaluate these investment decisions (the outputs of the simulation model) according to a range of performance metrics such as efficiency, accessibility, and sustainability. Figure 5-1 summarizes this logic: beginning with a framework, we apply the simulation model to produce an outcome, then evaluate that outcome according to externally defined performance metrics.

Figure 5-1. Simulation model logic



The central assumptions of the simulation model are the following: (1) a particular strategy development framework will lead to a distinct outcome, from which we can infer an emergent strategy, (2) we can predict that distinct emergent strategy based on the characteristics of the strategy development framework, and (3) the quality of a strategy relates directly to the quality of the strategy development framework; that is, a "good" outcome indicates a "good" emergent strategy, which in turn is an indicator that the strategy development framework is likewise "good."

In short, we characterize traditional transportation models vis-à-vis our model as follows:

- Traditional approach: modelers develop alternative deliberate strategies, run simulations to predict the outcomes of those strategies, and evaluate the outcomes in order to determine which strategy is preferred.
- Our approach: develop alternative strategy development *frameworks*, run simulations to predict what strategies will emerge from those frameworks, and evaluate the outcomes associated with those strategies in order to determine which strategy development framework is preferred.

Our approach is conceptually not without precedent. As described in Chapter 5, Glazner (2009) developed a hybrid simulation model to evaluate alternative "enterprise architectures" of a corporation. By varying key parameters of the architecture, he could simulate the strategy that resulted and, ultimately evaluate the performance of the company according to a key metric of interest: profits. In the transportation arena, Xie and Levinson developed a model of infrastructure network evolution (2009) that has a similar structure as the model presented here. They view the infrastructure network as an emergent outcome of a variety of interactions of a complex system that includes individual users as well as organizations interacting based on economic and political forces. Xie and Levinson observed the long-term evolution of an infrastructure network under various frameworks, but considered principally changes in the level of centralization of investment decision control. Here, in addition to geographic scale, we simulate a variety of types and quantities of revenues, methods of investment decision-making, and ownership structures. Moreover, while Xie and Levinson evaluated a hypothetical network initially populated by only a few links, our simulation model is applied to a real network (Portugal), many of whose links already exist.

Xie and Levinson (2009b) also provide a comprehensive review of past efforts to understand and model networks. Many past transportation planning applications were built on the assumption that a planner could rationally determine "good" outcomes and implement them deliberately. By contrast, relatively recent efforts focus on the emergent properties of networks such as transportation infrastructure—this somewhat fatalistic view asserts that there are forces (e.g., demographic, economic, and topological forces) of the complex system beyond the control of any individual manager. The preferred tool to analyze such systems is agent-based modeling, which allows for the observation of self-organizing phenomena among numerous agents interacting in a complex environment.

5.2 Simulation model structure

We adopt an agent-based structure for this simulation. Agent-based models allow for simulation of complex systems by decomposing the problem space into smaller elements (agents) whose individual actions aggregate into emergent collective behaviors and patterns. Agent-based modeling has been used as the conceptual basis for simulation models in a many fields, including biology, physics, economics, transportation, and more (Resnick, 1994). In transportation, agent-based models have been as the basis for studying driver behavior (e.g., Hidas, 2002), traffic flow (e.g., Dia, 2002), vehicle routing (Kikuchi et al., 2002), and travel demand modeling (Zhang and Levinson, 2004). Agent-based modeling is also the basis of most microscopic traffic simulations, with individual vehicles represented as agents interacting within the environment of a highway facility. Agent-based modeling applied to the simulated evolution of infrastructure networks has been studied extensively by Zhang and Levinson (e.g., 2005). A recent twist on this line of research involves the study of slime mold as the "planner" of road networks. Single-celled organisms are placed in an experimental space with "food" chosen to replicate major population centers; in separate experiments, the decentralized growth patterns of these organisms have been shown to replicate closely the London motorway network (Adamatzky and Jones, 2009) and the Tokyo metro network (Tero et al, 2010).

An agent-based model comprises four components: agents, an environment, rules, and outputs (Gilbert, 2008). We summarize each components of our model below:

- **Agents** are infrastructure "customers" and "suppliers." The number and size of each agent will vary depending on the geographic scale and institutional architecture of the strategy development framework under consideration.
- The **environment** comprises mainland Portugal, passenger travel demand between municipalities, and the set of existing and proposed intercity highway links between municipalities (each municipality is represented as a node in this environment).
- **Rules** control agent behavior, guiding interactions between agents and their environment and interactions among agents. These rules vary from strategy development framework to framework.
- **Outputs** are investments in the highway infrastructure network over space and time—investments from which we can infer strategies and whose performance we can measure.

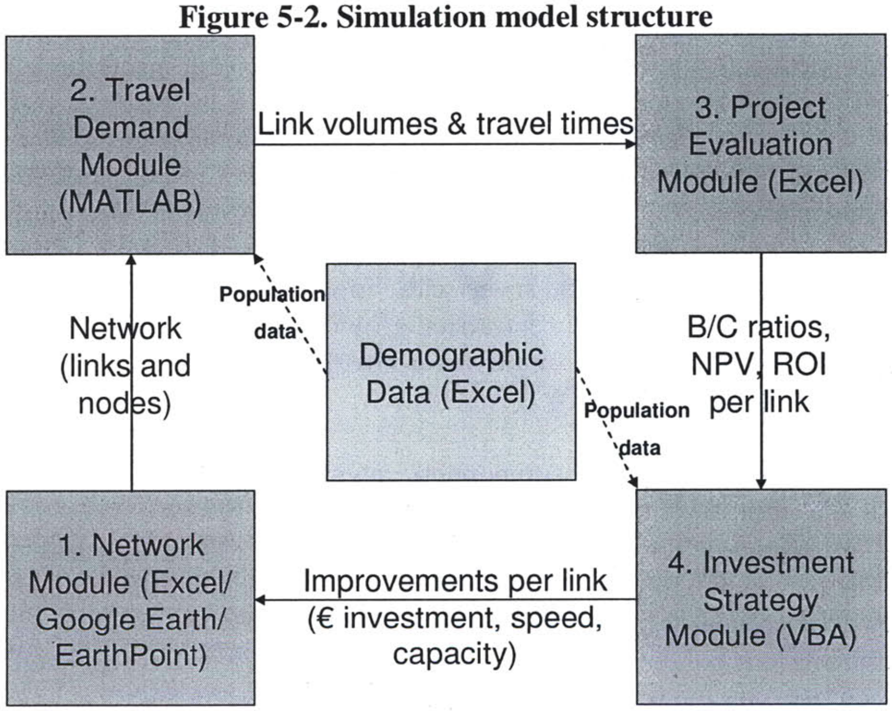
The simulation comprises five modules as illustrated in Figure 5-2. The flow of the simulation is as follows:

1. The **demographic module** contains population data for each municipality in mainland Portugal for the years 1995-2008.

2. The **network module** is a collection of links and nodes describing the intercity highway network in Portugal.
3. The **travel demand module** assigns trips to each link in the network based on the definition of the network from the network module and population information from the demographic module.
4. The **project evaluation module** determines the benefits, costs, and other impacts associated with various proposed projects based on inputs from the travel demand module.
5. The **investment strategy module** uses information from project evaluation module together with budget constraints to select projects for implementation.

In agent-based modeling terms, the **environment** is represented by modules 1-3 (demographics, network, and travel demand), **rules** are reflected in modules 4-5 (project evaluation and investment strategy), **agents** are defined in module 5 (investment strategy), and **outputs** are represented in module 1 (network).

Figure 5-2. Simulation model structure



Each run through these modules represents one year in time. Although the simulation could run for any number of years, we conduct scenarios for 15 years. In the following subsections, we discuss each module in detail.

5.2.1 Demographic module

The demographic module contains population data for each municipality in mainland Portugal for the years 1995-2008. Data were obtained from Portugal's National Statistics Institute, which maintains census data as well as annual population estimates (INE, 2009).

In 2008, there were 278 municipalities in mainland Portugal ranging in population from 1,714 (Barrancos) to 494,631 (Lisbon). The average population was 36,443, and the median population was 16,369. In addition to Lisbon, there were 3 municipalities with populations exceeding 200,000, 19 with populations between 100,000 and 200,000, and 94 with populations under 10,000 (see Table 5-1).

Table 5-1. Population distribution of municipalities in mainland Portugal

Population Range	Number of Municipalities
0 – 10,000	94
10,000 – 20,000	64
20,000 – 50,000	63
50,000 – 100,000	34
100,000 – 200,000	19
200,000 +	4
All	278

For modeling purposes, we merged some municipalities. For example, one important combination was Porto and Vila Nova de Gaia, the two centrally located municipalities within the Porto metropolitan area. Porto is the second largest metropolitan area in Portugal, with a total population of 1.5 million. However, the municipality of Porto in 2008 had a population of just 218,940, while the adjacent municipality of Vila Nova de Gaia had a population of 311, 414. Meanwhile, Porto has an area of only 40 square kilometers and Vila Nova de Gaia has an area of 168 square kilometers; both are far below the national average for municipalities of 320 square kilometers. The two municipalities are separated by the Douro River but have numerous bridges connecting them, including two motorways and three major urban surface streets, pedestrian crossings, and a tramway. There is also water taxi service across the river. Given the number of connections between these two municipalities, we consider them as a single node on our inter-city network. Other municipalities in the metropolitan region are treated as separate nodes due to the longer travel distances between their major population concentrations. Similar combinations were made for similar reasons for a number of municipalities across the country. In some cases, remote and/or sparsely populated municipalities with little or no highway connections were also combined. In addition, we added 5 "external zones" representing municipalities across the border in Spain served by important highway links from Portugal. The population of these external zones was set equal to the population of the largest city along the highway within 150 km of the border.

After making these adjustments, the demographic module contains 232 municipalities, each with population data for each year from 1995-2008. Summary data for these 232 municipalities are presented below in Table 5-2 and Table 5-3, showing the distribution of the number of municipalities and population by type of land use and by geographic region, respectively. Some columns do not add to 100% due to rounding.

Table 5-2. Distribution of municipalities and population by type of land use

Land Use	Number of Municipalities	% of Total	Population	% of Total
Rural	145	63%	2,201,467	21%
Suburban	81	35%	6,403,361	62%
Urban	6	3%	1,691,156	16%
Total	232	100%	10,295,983	100%

Table 5-3. Distribution of municipalities and population by region

Region	Number of Municipalities	% of Total	Population	% of Total
1 (North)	66	28%	3,745,338	36%
2 (Central)	82	35%	2,390,148	23%
3 (Lisbon)	15	6%	2,811,812	27%
4 (Alentejo)	52	22%	753,451	7%
5 (Algarve)	12	5%	428,235	4%
External	5	2%	167,000	2%
Total	232	100%	10,295,983	100%

5.2.2 Network module

The network module is a database containing records that describe the characteristics of the intercity transportation infrastructure network in Portugal. This module has as its basis the highway network of Portugal, making it "uni-modal." We define the network as the collection of nodes (municipalities) and the links (highway segments) that connect them. It is possible to conceive of the links "a-modal," meaning that they represent any infrastructure technology, but for convenience and consistency we have chosen the physical, performance, and economic characteristics of highways to describe the links.

The database describes the Portuguese intercity highway network as it existed in 1995. Data were obtained from a variety of sources, including principally the National Roadway Plan (Plano Rodoviária Nacional, or PRN) (EP, 2000) and Google Maps (Google, 2009). The PRN defines three categories of intercity highways in Portugal: principal routes (itinerários principais, or IPs), complementary routes (itinerários complementares, or ICs), and national roads (estradas nacionais, or ENs). Each is defined in the PRN as follows:

- IP: routes of highest national interest, serving as the backbone of the entire national road network, and ensuring linkages among those major urban centers with "national influence" as well as urban centers containing significant ports, airports, or international connections. IPs are for vehicles only; pedestrians, bicycles, and animals are prohibited.
- IC: complementary routes that ensure linkages among urban centers with "regional influence;" these are routes of primarily regional interest as well as routes facilitating access in and around the Lisbon and Porto metropolitan areas.
- EN: Like ICs, ENs are complementary routes that ensure linkages among urban centers with "regional influence."

The PRN goes on to define 9 IPs, 34, ICs, and 170 ENs. It further designates all 9 IPs and portions of 25 of the ICs as motorways ("auto-estradas"). Motorways are defined as high-speed, limited-access, grade-separated highways with medians wherever possible.

All 9 IPS, all 34 ICs, and all or part of 90 ENs are included in the network module. Each of these highways is broken into segments, or links, drawn to connect municipal centers. In all, there are 375 links, 341 of which existed in 1995. The remaining 34 are in the PRN and are represented in the network module as "proposed" links. Each link is two-way (traffic can flow in both directions) and has the following characteristics.

- *Terrain.* Terrain takes one of the following values: flat, hilly, or mountainous. Of course, many links traverse diverse terrains; these values are intended to approximate the "average" terrain of any given link and reflect the costs associated with construction there.
- *Land Use.* Land use takes one of the following values: urban, suburban or rural (defined as the more developed of the two nodes which it connects).
- *Length.* Length of the path (travel distance) followed between two nodes, measured in kilometers.
- *Design speed.* Links can have a design speed of 60, 90, or 120 kilometers per hour (kph). Links with a design speed of 120 kph represent motorways; links with a design speed of 90 kph design represent non-motorway ICs; links with a design speed of 60 kph represent ENs (note that many of the roads designated as ICs in 2008 were classified as ENs in 1995 and are represented as such in the network module).
- *Number of lanes.* The number of lanes of any link is identical in both directions and takes a nonnegative integer value (proposed links have 0 lanes; existing links have 1 or more lanes).
- *Capacity.* The capacity of a link is reflected in passenger cars per hour per direction. Capacity is a function of the speed and number of lanes according to a relationship defined in the Highway Capacity Manual (TRB, 2000). Per-lane capacity values used in the network module are presented in Table 5-4.

Table 5-4. Relationship between design speed and capacity (TRB, 2000)

Design speed (kph)	Capacity (passenger cars per hour per lane)
60	1,600
90	2,250
120	2,400

Portugal joined the European Union in 1986 and began to receive financial support for infrastructure investment, including highways, in the early 1990s. At that time, the only completed motorway was the A1 (part of IP1) connecting Lisbon and Porto, which was constructed between 1961 and 1991 (Brisa, 2009). Most of the motorways now extant in Portugal were constructed in the latter part of the 1990s and in the 2000s, with many still under construction today. The starting point for the simulation model is 1995, at the beginning of this era of major infrastructure upgrades in Portugal and several years prior to the publication of the PRN in 1998. Constructing an accurate representation of the highway system as it existed in 1995 requires careful review of contemporary maps, historical maps, satellite imagery, and official documentation of highway investments from EP and concessionaires. Table 5-5 summarizes the number of centerline-km of highways by classification in 1995 as represented in the model. Note, however, that the links behind many of these classifications are not fully developed. For example, many of the links designated as IPs and ICs in the PRN were low-speed, 1-lane links in 1995, and they are represented as such in the model. Other information pertaining to each link, however, including travel distance, nodes connected, terrain, and land use, is consistent with the PRN.

Table 5-5. Summary of roadway by type in simulation model, 1995

Designated **type of Roadway**	**Centerline-km (*built* as of 1995)**	**Centerline-km (*proposed* but not yet *built* as of 1995)**	**Total centerline-km**
IP	2,534	357	2,891
IC	2,525	574	3,099
EN	3,538	15	3,553
Total	8,597	947	9,543

Figure 5-3 illustrates the Portuguese intercity highway network as represented in the simulation model in 1995. The links in the image, although drawn as straight lines, represent facilities whose actual alignments are not straight. Moreover, links are drawn to connect nodes when, in reality, the highway links they represent pass near the node. For example, many of the data points in the network module use motorway exit locations to approximate locations of nearby municipalities. Links are color-coded as follows:

- White: proposed
- Blue: 60 kph design speed
- Yellow: 90 kph design speed
- Red: 120 kph design speed

The thickness of the links in Figure 5-3 represents the number of lanes. The only continuous high-speed corridor (red) is between Lisbon and Porto. This corridor represents the A1 motorway, which as stated previously was completed in 1991. Other partially completed corridors are visible, including the A23, which passes through Castelo Branco in the interior of the country; the A6, which connects Lisbon, Evora, and the Spanish border; and the A5 from Aveiro to Viseu and Guarda. There is also a considerable number of high-speed, high-capacity links in the metropolitan areas of Lisbon and Porto.

Figure 5-3. Illustration of 1995 Portuguese highway network used in simulation model (232 nodes, 375 links)

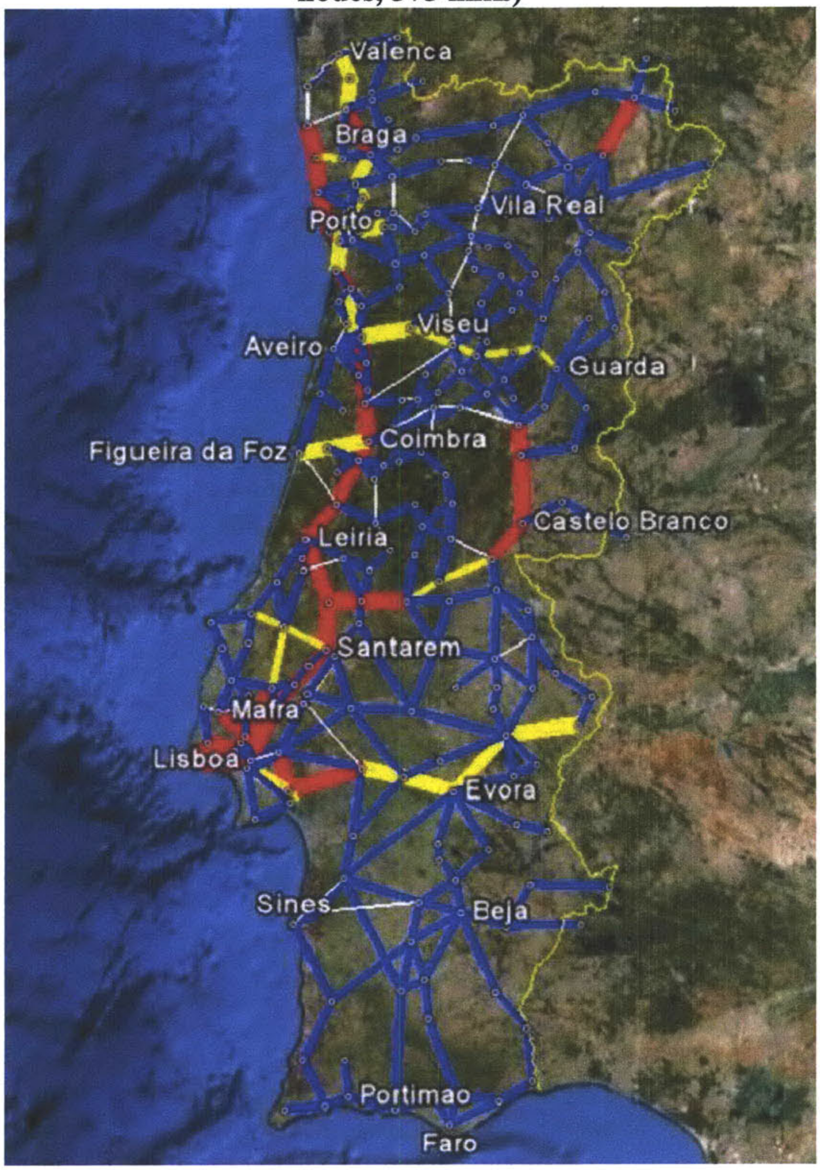


Table 5-6 summarizes the number and length of links by number of lanes. Note that the table includes 34 proposed links which in 1995 had a combined distance of 947 km.

Table 5-6. Distribution of links and length by number of lanes

Number Of Lanes	Number of Links	% of Total	Length (km)	% of Total
0 (proposed)	34	9%	947	10%
1	277	74%	7,220	76%
2	46	12%	1,048	11%
3	16	4%	301	3%
4	1	0%	12	0%
5	1	0%	16	0%
Total	375	100%	9,543	100%

Table 5-7 summarizes number of links and length of the network (in both centerline-km and lane-km) by design speed.

Table 5-7. Network by design speed (excluding proposed links)

Design speed (kph)	Number of Links	Centerline-km	% of Total	Lane-km	% of Total
60	271	6,992	81%	7,072	68%
90	33	791	9%	1,322	13%
120	37	814	9%	1,954	19%
Total	341	8,597	100%	10,348	100%

Link lengths range from 5 to 80 km, with an average length of 25 km; 84% of links have a length between 10 and 40 km.

5.2.3 Travel demand module

The travel demand module predicts the volume of travel across the intercity highway network of Portugal, drawing on data from the network and demographic modules. This is accomplished using a partial 4-step model as described below.

Steps 1 and 2: trip generation and trip distribution. The trip table is a matrix detailing the number of trips between all nodes in the network. For intercity travel, we estimate the number of trips using a traditional gravity model. The gravity model has a long history in transportation analysis; its purpose is to allocate trips from all origins to all destinations in a network using known parameters that relate the origins and destinations. Its name is derived from its similarity to Newton's equation, which describes the gravitational force between two objects as a function of the their masses and the distance between them. By analogy, the parameters typically of interest in a transportation gravity model are population (substituting for mass) and generalized travel costs (substituting for distance). Our model takes the following form:

$T_{ij} = a\frac{P_i P_j}{C_{ij}^b}$, where

T_{ij} = total number of trips from node i to node j.
P_i = number of inhabitants of municipality i
P_j = number of inhabitants of municipality j

C_{ij} = shortest-path free-flow travel time between i and j in minutes
a and b are parameters

This form is commonly used for intercity travel demand models, particularly when only aggregate data such as population are available (Wirasinghe and Kumarage, 1998). Shortcomings of this formulation include the potential for large calibration errors, correlation between variables, and spatial non-transferability. More sophisticated modeling techniques reduce the likelihood of errors arising from these shortcomings by separating trip generation from trip distribution, relying on socioeconomic characteristics of individual households such as income and vehicle ownership to more accurately generate trips, and distributing trips using more sophisticated gravity functions. However, because our simulation depends on aggregate data (population), we rely on the relatively simpler gravity model presented above while acknowledging the likelihood of calibration errors, which will be explained after step 4.

Step 3: mode split. Mode split is typically the next step in a travel demand forecast. Inclusion of additional modes of travel in our simulation model would more accurately reflect the reality of intercity travel in Portugal, where highway-based travel is not the only choice. In particular, rail is an important competitor to highways in Portugal, particularly regional/commuter rail service in and around the metropolitan areas of Lisbon and Porto as well as long-distance conventional and high-speed ("alfa pendular") rail service in the Lisbon-Porto and Lisbon-Faro corridors. Commercial airlines also serve the Lisbon-Porto and Lisbon-Faro markets. There are plans to upgrade the high-speed rail service in Portugal by building a new high-speed network, with the first major segment connecting Lisbon to Madrid and the second connecting Lisbon to Porto.

However, our model omits and instead assigns all traffic predicted in steps 1 and 2 to the highway network for several reasons beyond the simplicity that uni-modal traffic assignment affords. Outside of the corridors mentioned above, the only intercity travel infrastructure available is highway. Moreover, even within the corridors where rail and air compete with highway, highway remains the dominant choice. Table 5-8 summarizes the top origin-destination pairs by travel volume within the coastal corridor. The penetration of rail in these markets is relatively small, peaking at 18% for Lisbon-Porto, with only 6% choosing rail across all ten markets (note that there is currently no direct rail service to Viseu or Leiria).

Table 5-8. Top ten intercity travel markets in Portugal coastal corridor (SDG, 2007)

Origin-destination pair		Distance (km)	Annual trips (millions)	Highway	Rail	Air
Lisbon	Porto	320	4.88	79	18	4
Porto	Aveiro	80	2.98	99	1	0
Lisbon	Santarem	85	2.96	99	1	0
Porto	Viana do Castelo	80	2.67	90	10	0
Lisbon	Leiria	150	2.19	100	0	0
Lisbon	Coimbra	200	2.00	86	14	0
Lisbon	Ourem	140	1.98	100	0	0
Porto	Coimbra	120	1.89	94	6	0
Porto	Viseu	130	1.59	100	0	0
Coimbra	Viseu	90	1.41	100	0	0
Total			**24.54**	**93**	**6**	**1**

Step 4: trip assignment. The final step in the traditional 4-step model is to assign trips to the links in the network. There are several approaches for trip assignment of varying degrees of complexity. The most straightforward approach is all-or-nothing traffic assignment, whereby all trips are assigned to the path offering the fastest free-flow travel time or the lowest free-flow travel cost. The most advanced approach is to assign trips in a manner that produces a "user equilibrium." This approach accounts for congested links in the network by rerouting trips and seeking a Pareto-optimal trip assignment in which no single user can improve his or her travel time by choosing a different route.

For this model, we chose all-or-nothing traffic assignment for several reasons. First, the all-or-nothing assignment allows us to see the "desired" routing of users, which is an important input for the project evaluation component. In addition, the model run time with a simple all-or-nothing assignment is much faster given the iterations required of an equilibrium approach. More pragmatically, however, our simulation represents intercity links with an average length of 25 km. Few motorists would in reality re-route on these long-distance trips in order to avoid congestion. To verify the appropriateness of this assumption, we compared the traffic loadings of the all-or-nothing trip assignment with an incremental trip assignment (which accounts for congestion). The results of the comparison were as follows:

- 40% of the links saw no change in traffic
- A further 55% of links saw a change in traffic volumes of less than 10%.
- Of the remaining 5% of links (17 links), only 11 saw a change in traffic volume of greater than 50%.
- Only 7 links saw a change in volume greater than 250 trips per day; all of these links are associated with a bottleneck in the Porto metropolitan area (the congested link representing the highway that connects Porto to the nearby suburban municipality of Maia). Re-assignment of all trips associated with this bottleneck occurred to other links within the metropolitan area.

Given the relative lack of influence of congestion feedback on the overall model outputs, all-or-nothing traffic assignment is used. Note that no trips are assigned to proposed links.

Calibration. Calibration of the parameters a and b from the gravity formula was conducted after all-or-nothing trip assignment. Link flows were compared to the actual flows measured on 45 of the 375 links in our network (the majority of the measured flows are from motorway links). These traffic count data were obtained from the EP's SICIT data collection system (EP, 2008). Fourteen successive approximations of the values for a and b were tested in order to improve the match between model-predicted and actual flows; the values selected were $a = 0.005$ and $b = 1.80$. While calibration of all links is impossible (the gravity model formulation constrains the number of variables we can alter), the total number of trips predicted versus measured across all 45 links was calibrated to within 1%. Link-by-link analysis reveals more variation. Predicted volumes ranging from 15% to 230% of actual volumes; half of the links have predicted travel volumes within 40% of measured values. The majority of links with predicted volumes higher than actual volumes are located in the central region of the country.

In the terminology of agent-based modeling, the three modules discussed above (demographic, network, and travel demand) together represent the **environment**. Next, we discuss the project evaluation module, which captures many of the **rules**.

5.2.4 Project evaluation module

The project evaluation module enumerates and evaluates each of the possible improvements to the national highway network. We assume there is exactly one project associated with each link in the network per year. Table 5-9 summarizes the projects available for any given link based on its design speed, number of lanes, and whether or not it is congested. The rules implicit in the table are as follows:

- The only project associated with any "proposed" link (i.e., to get from "nothing" to "something") is to construct one lane in each direction with a design speed of 60 kph.
- Existing links can *either* improve the design speed one level (i.e., from 60 to 90 kph or from 90 to 120 kph) *or* add one lane of capacity in each direction.
- Links may only consider adding a lane of capacity if peak or offpeak congestion reduces speeds by at least 1% below free-flow speeds.

Table 5-9. Link project definitions

Free-flow Design Speed	Number of Lanes	Congested?	Project
0	0	No	Build 1x1 lane (1 lane in each direction)
60	1	No	Improve design speed to 90 kph
60	1	Yes	Add 1x1 lane
60	>1	No	Improve design speed to 90 kph
60	>1	Yes	Improve design speed to 90 kph
90	1	No	Improve design speed to 120 kph
90	1	Yes	Add 1x1 lane
90	>1	No	Improve design speed to 120 kph
90	>1	Yes	Improve design speed to 120 kph
120	>0	No	Do nothing
120	>0	Yes	Add 1x1 lane

For example, a proposed link might evolve in the following manner:

- Step 1: build 1x1 lane to 60 kph
- Step 2: if there is congestion, add 1x1 lane; if not, improve the design speed to 90 kph.
- Step 3 (suppose the latter from step 2): if there is congestion, add 1x1 lane; if not, improve the design speed to 120 kph.
- And so forth.

Our model contains 375 links, so for any given time period there are 375 proposed projects (noting that for uncongested links with a design speed of 120 kph, the "project" is "do nothing"). The project evaluation module computes several pieces of information related to each of the proposed projects, broadly categorized as costs and benefits.

5.2.4.1 Costs

There are two types of project costs computed within the simulation model: construction costs and life-cycle costs. The baseline construction cost reflects the cost to build the proposed project, as summarized by type of project in Table 5-10; these baseline values are indexed based on the terrain and land use of the project location as summarized in Table 5-11. Values are in constant 2008 euros and are chosen based on the construction costs associated with approximately 2,000 km of proposed new highway construction in Portugal (MOPTC, 2009) and cross-checked against a Washington State DOT survey of construction costs in the U.S. (WSDOT, 2002). In addition, there are several "special purpose" facilities represented as links in the network whose construction costs for each type of project are four times the baseline:

- Vasco da Gama Bridge (proposed)
- Almeirim – Santarém Bridge
- April 25 Bridge
- Marão Tunnel

Table 5-10. Baseline construction costs (€2008)

Project description	Construction Cost (millions/km)
Construct new 1x1 facility (60 kph)	€3.5
Add 1x1 lane to a 120-kph facility	€3.0
Add 1x1 lane to a 90-kph facility	€2.5
Add 1x1 lane to a 60-kph facility	€2.0
Improve design speed from 90 to 120 kph	€1.5
Improve design speed from 60 to 90 kph	€1.0

Table 5-11. Construction cost factors

Land Use	Terrain	Cost Factor
Urban	Flat	1.00
Urban	Hilly	1.40
Urban	Mountainous	0.90
Suburban	Flat	1.26
Suburban	Hilly	2.70
Suburban	Mountainous	0.50
Rural	Flat	0.50
Rural	Hilly	0.70
Rural	Mountainous	1.50
n/a	Bridge or Tunnel	4.00

The present value of life-cycle cost is computed as the total discounted cost of ownership, including initial construction costs and discounted annual maintenance costs. Annual maintenance costs are computed as a flat percentage of construction costs. The cost of maintenance as a percentage of construction costs (10%), time horizon of the life cycle (15 years), and discount rate (5%) are all variables.

5.2.4.2 Benefits

Benefits of each project computed within the model include travel-time savings and, in some cases, revenues. The model projects travel-time savings associated with each proposed project over a 15-year horizon, matching the same temporal horizon as the life-cycle cost analysis. The 15-year horizon is broken into three periods, and a distinct design speed is assumed for each period. The projected travel time is compared to the current travel time in each of the three periods; the difference, if positive, is multiplied by the expected travel volume to arrive at an estimate of aggregate time savings across all users of the link.

First, we determine the proportion of traffic assigned to each link from the travel demand module that travels during the peak hour. This value, known as the "K" factor in the Highway Capacity Manual, is summarized by type of link in Table 5-12 (TRB, 2000). For example, 20% of all daily traffic on rural links is assumed to travel during the peak hour, while the remaining 80% is assumed to be split equally across the other 23 hours of the day.

Table 5-12. Allocation of daily traffic to peak hour ("K" factor)

Land Use	% of Daily Traffic in Peak Hour
Rural	20%
Suburban	13.5%
Urban	9.5%

Next, we use the peak and offpeak travel volumes to compute adjusted (congested) travel speeds for both the peak hour and for the offpeak. The relationship between adjusted speed, free-flow (design) speed, capacity, and volume is captured using the traditional relationship put forth by the Bureau of Public Roads in the 1965 Highway Capacity Manual (" the BPR curve"). Singh summarizes the shortcomings and some alternatives to this relationship (1999); nevertheless, the BPR curve persists even in planning studies today, commonly using the originally proposed values for c and d of 0.15 and 4, respectively:

$$S = \frac{FFS}{1 + c(V / C)^d}, \text{ where}$$

S = adjusted speed
FFS = free flow speed
V = hourly link volume
C = hourly link capacity
c and d are parameters

Travel times for each link are computed by dividing its length by its adjusted speed. We compute two speeds and travel times: one for the peak hour and another for the offpeak.

Next, the proposed free-flow and adjusted speeds are computed based on the type of project associated with the link. For example, if the proposed project is to add a lane, then capacity and congested travel speeds will increase, which in turn will reduce travel times. Proposed travel times are computed for three time periods as follows:

- In the first time period, we assume the free-flow travel speed of the link (design speed) will decrease by one level due to the disruption associated with construction. For example, a 90-kph link being upgraded either by increasing the design speed or adding a lane will have a free-flow travel speed of 60 kph (however, no lanes of travel are removed from service). The length of this time period in the simulation model is 2 years.
- In the second time period, we implement the proposed project and compute the travel time associated with making the design speed upgrade of lane addition. For example, a congested, 1-lane, 90-kph link will add a lane based on the project definition rules in Table 5-9. Travel times are computed based on this new capacity. The length of this time period in the simulation model is 8 years.
- In the third time period, we compute the travel time based on the assumption that the link is improved to the next highest design speed. Continuing the previous example, we would assume for the third time period that the link has a design speed of 120 kph. The length of this time period in the simulation model is 5 years. The total of all three time periods, 15 years, matches the time horizon used for computing life-cycle costs.

Travel time savings in year i are computed as the difference in travel times multiplied by the expected travel volume and the time value of money:

$$TravelTimeSavings_i = \left(\frac{D}{S_0} - \frac{D}{S_i} \right) \times V \times VOT, \text{ where}$$

D = link length
S_0 = travel speed at time 0
S_i = travel speed in year i
V_i = link volume in year i
VOT = time value of money

The time value of money used in the simulation model is €19.5 per hour; this is the survey-based value used in studies conducted for EP (e.g., Deloitte, 2009).

The other potential source of project benefits is toll revenues. Tolls typically represent an intra-jurisdictional transfer from users to the infrastructure provider and should not be treated as a benefit. However, in cases where non-local users are using the facility and contributing toll revenues, then toll revenues can be counted as benefits.

$$Benefits_i = TravelTimeSavings_i + NonLocalTollRevenues_i$$

The present value (PV) of benefits is computed by discounting the annual benefits for each year over the full 15-year time period. All values, both costs and benefits, are in 2008 euros. Although inflation is considered in order to adjust variables represented as money (e.g., value of time), inflation is ignored in the simulation model.

5.2.4.3 Project evaluation metrics

The computation of costs and benefits allows us to construct several metrics, including benefit-cost ratios and net present values. For each proposed project, these values are computed as follows:

- Benefit-cost ratio = PV(Benefits)/PV(Costs)
- Net present value = PV(Benefits) – PV(Costs)

In addition, we compute the financial internal rate of return (IRR) for each project, which is used to guide investment decision-making for concessionaires. For our purposes, return on investment represents the purely financial returns associated with the project. Revenues are derived from toll receipts, while costs are the same as the life-cycle costs discussed above. IRR is the rate which makes the net present value of the project cash flows equal to 0, and is solved for based on the following equation:

$$NPV = 0 = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n}, \text{ where}$$

C_n = cash flow in year n
r = IRR
N = number of years of project (we assume 30 years for concessions, APCAP, 2007)

5.2.5 Strategy development module

The fifth and final module is the strategy development module. The outputs of this module are investment decisions for the various proposed projects. These decisions are made by **agents** on the basis of the project evaluations performed in module 4 and executed subject to additional **rules**, including budget constraints and agent negotiation procedures. These rules and constraints reflect the dimensions of the strategy development framework as discussed below.

5.2.5.1 Institutional architecture

In Chapter 4, we discussed 3 sub-dimensions of institutional architecture: ownership structure, modal linkages, and sectoral linkages. Because the simulation model is uni-modal, we now consider only the ownership structure (the impact of modal and sectoral linkages will be discussed further in Chapter 7). Although in Chapter 4 we described three potential approaches for ownership of infrastructure (private contracts, concessions, and state-owned enterprises), fully private contracts are unheard-of in modern practice outside of small-scale networks such as neighborhood associations. This leaves state-owned enterprises and concessions as the two key alternatives to consider in the simulation model. These two alternatives are reflected as follows:

- State-owned enterprise (SOE). See Chapter 3 for a formal definition and more extensive discussion of SOEs. The key distinction is that SOEs are 100% owned by the state and act as both the customer and supplier of infrastructure. If the framework calls for a state-owned enterprise, the model makes investment decisions in the various projects on the basis of either their benefit-cost ratios or net present values. Agents representing the SOE will select projects with the highest benefit-cost ratio or net present value until the budget is exhausted.
- Concession. If, on the other hand, the framework calls for a concession-based approach, the model makes investment decisions in the various projects on the basis of their IRRs. The key distinction is that while the state is still the infrastructure customer, private entities are now the infrastructure suppliers. They will only supply infrastructure if they believe the investment will generate a minimum level of return. In our model, agents representing concessionaires will only select projects with IRR above 10% (Brisa, 2008).

5.2.5.2 Decision-making process

There are three sub-dimensions of decision-making process to capture in the simulation model: type of revenues, quantity of revenues, and resource allocation approach. For revenue type, following three alternatives are available:

- Tax. Under the "all tax" approach, the entire investment budget is derived from a per capita tax on all individuals in Portugal. The baseline rate is €65 per person.
- Toll. Under the "all toll" approach, the entire investment budget is derived from revenues collected from tolls across the entire highway network. The baseline rate is €0.028 per kilometer.
- Mixture. Under the "mixture" approach, the investment budget is derived from both tolls and taxes. The baseline rate calls for a 50/50 mixture, or a tax rate of €32.5 per person together with a toll rate of €0.014 per kilometer.

For revenue quantity, the model implements one of the following three alternatives:

- Medium. The medium revenue quantity scenario is based on the actual level of annual investment in Portugal's highway infrastructure from 2004-2008. The values expressed above are calibrated to produce a medium quantity of revenues in the first year of the simulation.
- High. The high revenue scenario is 40% higher than the medium scenario.
- Low. The low revenue scenario is 40% lower than the medium scenario.

For resource allocation, the model implements one of the following three approaches:

- Benefit-cost ratio. Projects are ranked highest to lowest by benefit-cost ratio. Note that this approach is only available for state-owned enterprises.
- Net present value. Projects are ranked highest to lowest by net present value. Note that this approach is only available for state-owned enterprises.
- Internal rate of return. Projects are ranked highest to lowest by IRR over a 30-year time horizon. Note that this approach is only available for concessionaires. Only those projects with IRR greater than 10% are selected.

5.2.5.3 Geographic scale

Finally, we define agents based on the geographic scale dimension of the alternative strategy development framework being simulated.

National. With a nationally scaled organization, there is one agent making investment decisions for all 375 links across the entire nation. For a state-owned enterprise agent, projects are selected on the basis of benefit-cost ratio or net present value until the available budget is exhausted. Budgets are derived from taxes on residents and/or tolls on highway users. If the next project in line for selection exceeds the available budget, then the project is denied and the remaining budget is rolled over into the next year's budget. For a concessionaire agent, projects are selected on the basis of internal rate of return as long as the rate exceeds 10%. There is no budget limit for concessionaires; however, they cannot count toll revenues used to justify one project toward another project later on the same link.

Regional. With regionally scaled organizations, there are 5 agents making investment decisions only for the links within their region. Each region has a budget corresponding to the tax collected from its residents and/or toll revenues collected from links within the region. Projects are selected in the same way as the national case.

Municipal. Under this approach, there are 232 agents with decision-making autonomy. Their budgets are limited to whatever they collect in tax revenues from their residents and in tolls from users of adjacent links. Since each link is shared by exactly two municipalities, any decision to invest in a link must result from a negotiation and agreement between the two municipalities that share it. The negotiation process used in the simulation model is described below:

1. Each municipality computes a *municipal budget.*
2. Each municipality submits a *bid* for each adjacent link. Bids represent the amount that the municipality is willing to pay for the project and is computed as the minimum of the project's local benefit, the project's cost, and the municipal budget. Local benefits are distinct from the global benefits computed for the national and regional case because they consider only those travel time savings that accrue to residents or visitors of the municipality as well as toll revenues contributed by nonresidents and nonvisitors.
3. Each link computes a *total bid* by adding together the bids of the two adjacent municipalities.
4. Each municipality calculates a *new bid* which reflects any overbidding on the link (*new bid = bid*cost/totalbid*), a *benefit-cost ratio* (*local benefit/new bid*), and computes its *commitment* (sum of all the new bids submitted for all adjacent links).

5. If the budget is greater than the commitment, then the municipality approves all of its bids. If, however, the budget is less than the commitment, then the municipality removes its bid for the link with the lowest benefit-cost ratio and provides tentative approval for all of its other bids.
6. Each link now has a measure of approval from both of its associated municipalities. If it has two approvals, then it implements the project and deducts the cost contributed by each municipality from its respective budget. If it has two disapprovals, then it removes itself from further consideration in the current year.
   - If one municipality approves and the other disapproves, then the link will implement the project only if the approving bid is greater then the cost. If the approving bid is less than the cost, then the link is removed from consideration.
   - If one or both municipalities provide tentative approvals, then the links will likewise remain in a tentative status.
7. This process continues until all projects are either built or out of consideration.

Hybrid. The hybrid approach is similar to the municipal approach, except that municipalities share a portion of their revenues equally. We simulate two levels of revenue sharing: 25% and 50%. The mechanism works as follows: municipalities collect revenues, but contribute a portion (25% or 50%) of their budgets to a national pool; the national pool is then distributed in equal portions to each of the 232 municipalities.

Link. This approach is perhaps the simplest. Under a link-based approach, the links themselves collect revenues. Toll revenues accrue to a link budget, while tax revenues are derived from the residents of neighboring municipalities. Links accumulate budgets and invest in projects whenever their budget is sufficient to cover the cost of the improvement.

5.2.6 Simulation process

One cycle through the five modules represents one year in time. At the end of the year, the model updates the network to reflect the new design speeds and number of lanes on each link; updates the budgets to reflect the amount of money invested as well as any unspent budget that can roll over into next year; and prepares the origin-destination matrix and free-flow travel times for the next year of the simulation. This process repeats for 15 cycles (15 years).

5.2.7 Summary

In summary, the 5 modules simulate the process of developing and implementing an investment strategy in a highway network over a 15-year period. At the end of this time period, the network reflects an outcome that we can evaluate. Definitions and assumptions include the following:

- An outcome is the set of investments made in the physical transportation infrastructure network over time and space, from which we can infer an emergent strategy.
- Each strategy development framework produces exactly one outcome.
- We can evaluate the performance of the outcome and, on the basis of that evaluation, infer the quality of the underlying strategy development framework.
- The "environment" is the collection of municipalities in mainland Portugal, represented as nodes of varying populations, and the Portuguese highway network, represented by 375 links of varying speeds and capacities.

Table 5-13 summarizes the variables employed in the various modules of the simulation model.

Table 5-13. Summary of variables in simulation model

Module	Variable	Value in model
General	Start Year	1995
	End Year	2009
Network	Design speed – low	60 kph
	Design speed – medium	90 kph
	Design speed – high	120 kph
	Capacity – low speed	1600 pcphpl
	Capacity – medium speed	2250 pcphpl
	Capacity – high speed	2400 pcphpl
Travel demand	a	0.005
	b	1.80
Project evaluation	Evaluation time horizon	15 years
	Evaluation time horizon – band #1	2 years
	Evaluation time horizon – band #2	8 years
	Evaluation time horizon – band #3	5 years
	Discount rate	5.0%
	Escalation rate (for value of time and maintenance costs)	1.4%
	Annual maintenance costs as % of construction costs	10%
	Passenger value of time	€19.5 / hour
	c	0.15
	d	4
	% of peak-hour traffic in peak direction	65%
	K factor – rural (% of traffic in peak hour)	20%
	K factor – suburban	13.5%
	K factor – urban	9.5%
Strategy development	Per capita tax rate – low	€39
	Per capita tax rate – medium	€65
	Per capita tax rate – high	€91
	Toll rate per km – low	€0.0166
	Toll rate per km – medium	€0.028
	Toll rate per km – high	€0.039

5.3 Alternative strategy development frameworks to simulate

A strategy development framework is characterized by selecting values along a variety of dimensions as discussed in Chapter 4. The simulation model can explicitly reflect alternative values along each of the following dimensions: institutional architecture (ownership structure), decision-making process (revenue type, revenue quantity, and resource allocation approach), and geographic scale. Table 5-14 summarizes the values available along each of these dimensions.

Table 5-14. Alternatives modeled for each strategy development framework dimension

Dimension	Values	Operationalized in model by:
Institutional architecture: ownership structure	SOE	Selecting NPV or BCA as resource allocation approach
	Concession	Selecting IRR as resource allocation approach
Decision-making process: revenue type	Tax	Setting toll rate to 0
	Toll	Setting tax rate to 0
	Mix	Setting positive tax and toll rates
Decision-making process: revenue quantity	High	Using a high rate of tax and/or toll
	Medium	Using a medium rate of tax and/or toll
	Low	Using a low rate of tax and/or toll
Decision-making process: resource allocation approach	NPV (SOE)	Ranking projects by NPV
	BCA (SOE)	Ranking projects by BCA
	IRR (Concession)	Ranking projects by IRR
Geographic scale	National	1 agent, 1 budget
	Regional	5 agents, 5 budgets
	Hybrid National-Municipal (50%)	232 agents, 232 budgets (50% shared), negotiated investment decisions
	Hybrid National-Municipal (25%)	232 agents, 232 budgets (25% shared), negotiated investment decisions
	Municipal	232 agents, 232 budgets, negotiated investment decisions
	Link	375 agents, 375 budgets

Table 5-15summarizes the values along each dimension again, however it has removed the institutional architecture dimension, recognizing that selection of a resource allocation process implies the ownership structure (i.e., benefit-cost analysis and net present value imply state-owned enterprises, while IRR implies a concession).

Table 5-15. Alternative strategy development frameworks

Geographic scale	Ownership structure/resource allocation	Resource collection: type	Resource collection: quantity
National Regional	Benefit-cost (SOE)	Tax	High
Hybrid – 50% Hybrid – 25%	NPV (SOE)	Toll	Medium
Municipal Link	IRR (Concession)	Mix	Low

Combining all of these values yields 6x3x3x3 = 162 frameworks. However, we reduce this number by specifying that concessions (IRR resource allocation) can only use toll revenues as the type of resource, and by considering only two geographic scales for concessions: national and link-based. Finally, the link-based approach requires no resource allocation process. These revisions reduce the number of alternative frameworks to 105. A complete summary of all 105 frameworks is provided in Appendix 2. Each simulation run corresponds to one of these frameworks, and in Chapter 6, we present evaluate the results of all 105 simulations.

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6 Simulation Results and Evaluation

In the preceding chapters, we described an approach for modeling a complex system. The model simulates the emergence of a transportation network as a function of its strategy development framework. In this chapter we present the outputs of the simulation, describe several techniques for evaluating the outputs, and summarize the results of the evaluation.

It should be noted at the outset that the model has many limitations. The simulation approach cannot capture "everything," and we endeavored in Chapter 5 to explain what is in the model, in some cases pointing out explicitly what is not in the model (e.g., other modes beyond highways, the effects of politics and political negotiation on strategic decisions, intra-city infrastructure), but otherwise leaving it to the reader to infer elements that are missing (e.g., population-infrastructure investment feedback loops, impacts on land use). The results obtained from the model and presented in this chapter are interpreted in light of the model's limitations. Moreover, we supplement the results with a qualitative analysis, presented in Chapter 7, which allows us to consider and predict the influence of many of the factors that the model does not capture.

6.1 Description and examples of simulation outputs

The outputs of the simulation model described in Chapter 5 are the following: predictions of the amount and type of investments made in a transportation infrastructure network (i.e., addition of lanes and/or improvement in design speed) over time and space. These outputs represent the emergence of a transportation network and reveal and underlying emergent strategy. We ran simulations for 7 "do-nothing" scenarios and 105 alternative strategy development frameworks. In Section 6.2 we summarize the complete results for all 105 frameworks. Meanwhile, in this section, to illustrate the outputs of the simulation, we present detailed results for the 7 do-nothing scenarios and 2 of the 105 alternative frameworks (labeled in this section as #1 and #2).

1. Do nothing. In the do-nothing scenario, the strategy is to make *no* improvements to the network. No investments are made in the intercity transportation infrastructure network of Portugal from 1995 through 2008, such that the physical characteristics of the network at the end of 2008 (design speeds, number of lanes, points connected) are identical to those of the network in 1995. However, travel demand evolves over this time period due to population growth, allowing measurement of outputs of interest such as congestion and travel times between points in the network at the end of the simulation period.
2. Alternative framework "1". This framework attempts to replicate the strategy development framework that was actually followed in Portugal from 1995-2008. We characterize the framework as a **nationally scaled state-owned enterprise** which makes resource allocation decisions based on **net present value** using a **mixture of tolls and general taxes** that generate the **medium** quantity of revenues.[12] The expectation is the outputs of simulating this framework will resemble the actual evolution of the Portuguese highway network over 1995-2008. In reality, many of the intercity highways in Portugal during this period were developed using a concession approach (thus not purely a "state-owned enterprise" ownership structure). However, the approximation of this framework as a state-owned enterprise is pursued for two reasons: (1) the majority of the intercity network (including motorways as well as less-developed, lesser-quality intercity links)

[12] "Medium" revenues are calibrated to approximate the actual annual amount invested in highway infrastructure in Portugal based on 2004-2008 highway budgets.

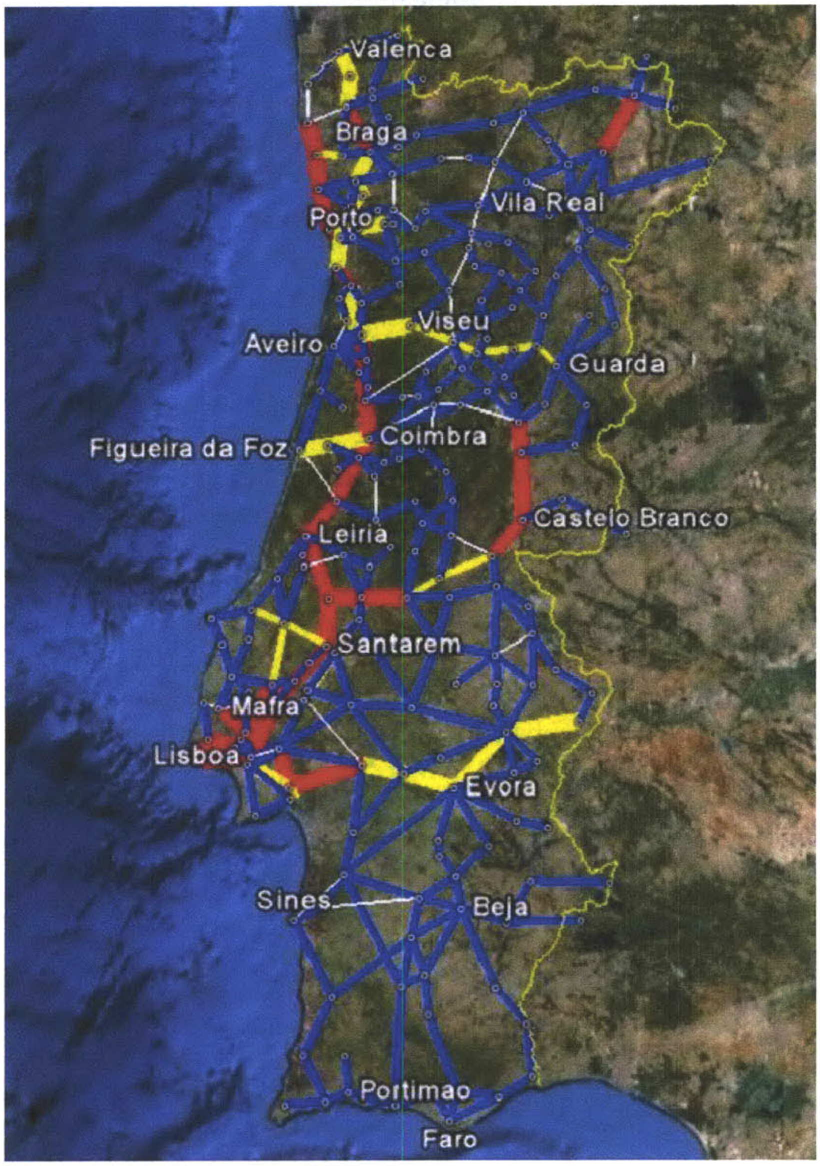
was owned, built, operated, and managed by a state-owned enterprise or government agency during the time period covered by the simulation and (2) all of the links that were constructed or improved during this time period as shadow-toll concessions had minimum revenue guarantees, meaning that the state retained demand risk in most cases; meanwhile, most of the links that were constructed as real-toll concessions have been renegotiated, a process that serves as a de facto ex-post minimum revenue guarantee.

3. Alternative framework "2". Alternative framework #2 calls for strategy development by **municipally scaled state-owned enterprises** which make resource allocation decisions based on **benefit-cost analysis** using **general taxes** that generate the **low** quantity of revenues. Although SOEs commonly make investment strategy for intercity transportation infrastructure using general tax revenues and benefit-cost analysis, it is uncommon to do so at the geographic scale of the municipality. In fact, in Portugal it is currently illegal for municipalities to participate in the decision-making, financing, improvement, or construction of intercity highways. However, we present the emergence of a network under this hypothetical alternative framework in order to explore the potential impacts of delivering intercity transportation infrastructure in entirely new ways.

6.1.1 Do-nothing scenario

The do-nothing scenario is presented as a baseline comparator for other strategy development frameworks. In the do-nothing scenario, no investments/improvements are made in the transportation infrastructure network from 1995-2008. However, since travel demand changes with population, the performance of the network changes over time. Figure 6-1 is a map of the links of the network as they existed in 1995; under the do-nothing scenario, this map looks the same in 2008. The colors of the links correspond to design speed as follows: green = 120 kph; blue = 90 kph; red = 60 kph. Meanwhile, thickness represents the number of lanes in each direction. Although at the altitude depicted in the map thickness is difficult to discern, almost all of the multi-lane facilities are located in the metropolitan areas of Lisbon and Porto and along the corridor between them. Note that in 1995 the only continuous, complete, long-distance, high-speed corridor is between Lisbon and Porto.

Figure 6-1. Representation of intercity highway network under do-nothing framework, 1995-2008



From 1995-2008, population in mainland Portugal grew at a modest annual rate of 0.5%, from 9.7 million to 10.3 million. However, the distribution of population in some particular areas changed at much higher rates. For example, the urban municipality of Lisbon shrank at a rate of 2% annually, shedding 140,000 inhabitants over the 13-year period and ending with a 2008 population of 494,000. Meanwhile, the suburban municipality of Sintra, near Lisbon, grew at a rate of 3% annually, gaining 140,000 inhabitants and ending with a population of 440,000 in 2008. The overall trend evident in these population shifts is that, although urban population is shrinking, suburban population is increasing and, as the territorial extent used to define "metropolitan areas" expands, total metropolitan population has grown. At the same time, the overall metropolitan densities have declined. In total, 148 of Portugal's municipalities (53%) lost population from 1995-2008; together, they lost 380,000 inhabitants, or an average of 2,550 per municipality. The other 130 municipalities (47%) gained 970,000 inhabitants, or an average of about 7,430 per municipality. As a consequence of these shifting populations (together with coincident changes in patterns of employment and industrial location), travel demand patterns changed. In addition to greater demand for travel within the major metropolitan areas of Lisbon and Porto (particularly for trips between suburban municipalities), demand for travel between the major metropolitan areas along the Lisbon-Porto corridor increased. Under the do-nothing scenario, these increasing travel demands resulted in increasing congestion.

We conducted 7 simulations of the do-nothing scenario, in each case assuming a distinct per-kilometer toll rate on all roads in the network. Because tolls add to generalized travel cost, they reduce demand for trips: the higher the toll, the lower the demand for travel. Tolls in the model are assessed per kilometer and, when present, are charged across the entire intercity network. While no investments are made in the intercity highway network under any of the 7 do-nothing scenarios, the travel demand patterns are distinct depending upon the toll rate levied on users.

Table 6-1summarizes several performance metrics relating to travel demand, speed, and congestion for the 7 do-nothing scenarios. For example, with no tolls on motorists (the "general tax only" case), the simulation predicts 25.7 billion vehicle-km of travel (VKT) in 2008, with average peak-hour and offpeak speeds of 72.6 kph and 95.2 kph, respectively. Meanwhile, there would be 221 million hours of congestion-related delay in 2008, most of it during peak hours, corresponding to about 22 hours per resident per year. By contrast, with high toll rates of €0.069 per km on all intercity highways (the "toll only – high" case), travel demand would be substantially curtailed, with only 14.7 billion VKT in 2008, higher average speeds, and less congestion-related delay.

Table 6-1. Performance metrics for 7 do-nothing scenarios (each representing a distinct toll rate)

Revenue category	Toll rate (€/km)	2008 VKT (billions)	Average speeds in 2008 (kph)		Hours delay in 2008 (millions)		
			Peak	Off-peak	Peak	Off-peak	Total
Tax only	0.00	25.7	72.6	95.2	208.2	13.1	221.2
Toll only – high rate	0.069	14.6	82.1	99.4	14.3	0.6	14.9
Toll only – medium rate	0.039	18.5	82.9	99.8	30.2	1.2	32.1
Toll only – low rate	0.020	21.6	78.7	97.5	84.0	5.3	89.3
Tax/toll mix – high rate	0.024	20.9	79.7	98.1	64.9	4.1	69.0
Tax/toll mix – medium rate	0.016	22.3	77.8	97.5	87.1	5.5	92.5
Tax/toll mix – low rate	0.009	23.7	75.8	96.9	117.5	7.4	124.8

Additional metrics related to performance are presented in Table 6-2 for the 7 do-nothing scenarios, including capacity utilization (a normalized measure of volume to available capacity), the number of VKT driven in "congested travel" (speeds under 45 kph), the total number of annual trips, and the average trip length. All of these values were measured for a single year, 2008, at the end of the simulation period.

In addition, the metric "average weighted accessibility" measures the relative ease of access between all points in the network, weighted by the amount of travel between them. Unweighted accessibility for any given node i is computed as follows:

$$Accessibility_i = \sum_{j \in J} TC_{ij} \text{, where}$$

TC = generalized travel cost between node i and node j

Moreover, we can compute the weighted accessibility of a node by incorporating the volume of trips between i and j.

$$WeightedAccessibility_i = \frac{\sum_{j \in J} (TC_{ij} * F_{ij})}{\sum_{j \in J} F_{ij}} \text{, where}$$

F = annual flow in trips between node i and node j

From this we can compute a variety of network accessibility measures, such as the sum, average, standard deviation, maximum and minimum across all nodes i of both the unweighted and weighted accessibility measures. We report the sum of all nodes' weighted accessibility measures across the network. Lower scores reflect higher levels of accessibility. For example, in Table 6-2, scenarios with higher toll rates have lower scores, indicating higher levels of accessibility, due to the reduction in congestion that follows imposition of direct tolls, allowing for easier access between all nodes in the network. Accessibility as a measure, even when weighted, does not account for the total *number* of trips, so it must be considered together with other metrics.

Table 6-2. Additional performance metrics for 7 do-nothing scenario (2008)

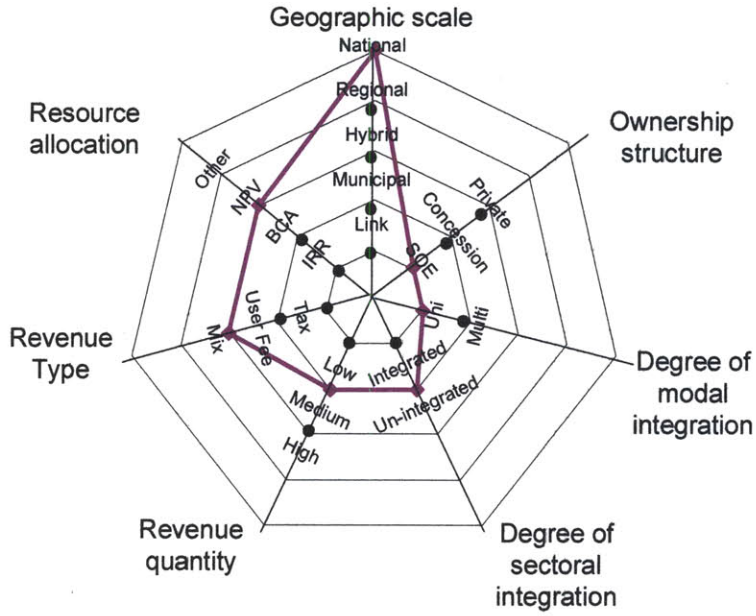
Revenue category	Toll rate (€/km)	Capacity utilization		VKT < 45 kph (millions)	Number of trips (millions)	Average trip length (km)	Sum of weighted accessibility (2008)
		Peak	Off-peak				
Tax only	0.00	141%	45%	1,077	785	32.8	25,306
Toll only – high	0.069	83%	25%	234	446	32.8	23,484
Toll only - medium	0.039	96%	31%	171	555	33.3	23,954
Toll only – low	0.020	117%	37%	202	657	32.9	24,531
Tax/toll mix – high	0.024	112%	36%	195	633	33.0	24,401
Tax/toll mix – medium	0.016	119%	38%	205	675	33.0	24,679
Tax/toll mix – low	0.009	127%	40%	218	719	33.0	24,953

Alone the do-nothing scenarios offer no opportunity for normative judgments or conclusions. However, we can compare metrics from the various alternative frameworks to the metrics of the 7 do-nothing scenarios in order to determine their relative performance.

6.1.2 Alternative framework #1

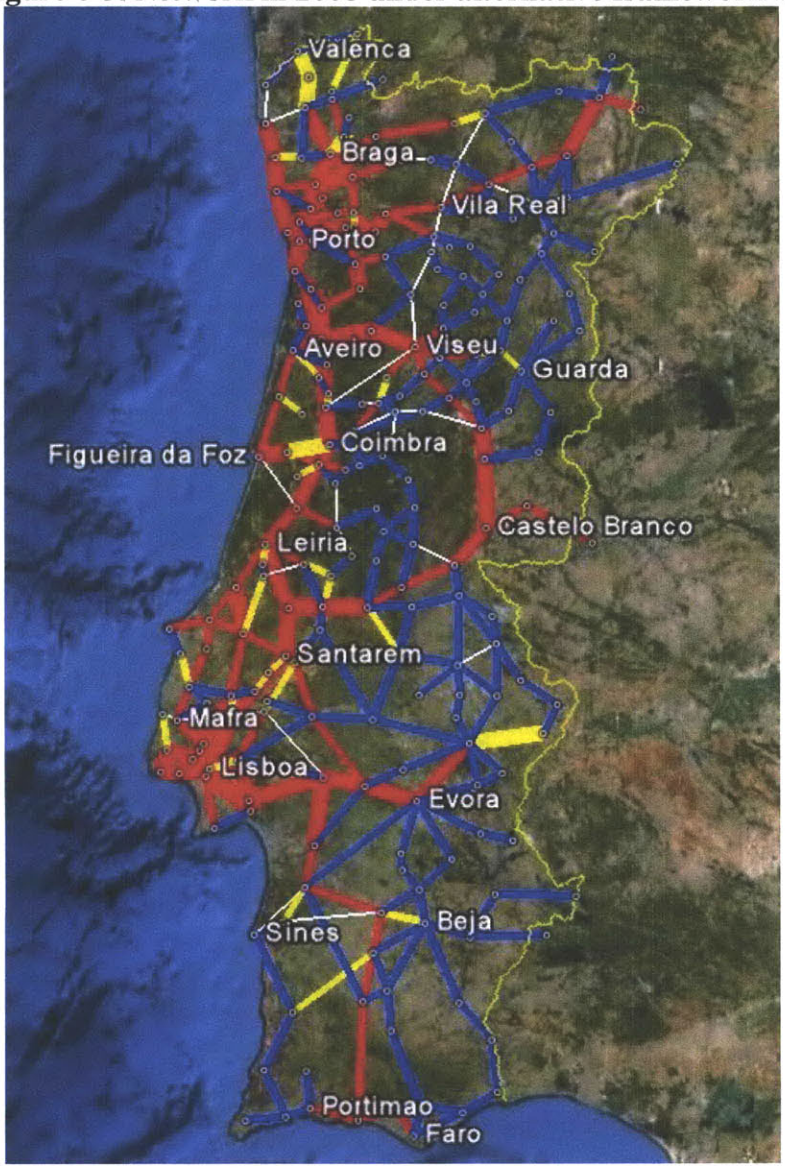
The first alternative framework considered (framework #1) is an approximation of the actual strategy development framework observed in Portugal from 1995-2008. Recall that for purposes of the simulation we characterize each strategy development framework along 7 dimensions: geographic scale, ownership structure, resource allocation approach, type of revenues, quantity of revenues, degree of modal integration, and degree of sectoral integration. However, in this chapter, we consider only uni-modal, uni-sectoral frameworks (that is, we hold the dimensions of modal and sectoral linkages constant). Alternative framework #1 is characterized as a nationally scaled state-owned enterprise making net present value allocations with a medium quantity of revenues derived from a mixture of direct user fees and general taxes (refer to radar chart in Figure 6-2 for an illustration).

Figure 6-2. Alternative framework #1



The simulation makes and records investments for each year from 1995-2008 based on the parameters for alternative framework #1. The network that emerges from this simulation is shown in Figure 6-3. Several results are observable by visual inspection. First, one of the most striking differences between the network in 1995 (refer to Figure 6-1) and the network in 2008 (Figure 6-3) is the number of high-speed links. Several high-speed corridors emerged, including a new parallel high-speed route between Lisbon and Porto, a complete high-speed corridor from Lisbon to the Algarve (visible on the map as the red links connecting Lisbon and Faro), as well as several corridors in the northern interior, one linking Porto to the east with Spain, one linking Aveiro with Viseu, a third extending from Santarém through Castelo Branco to Spain. In reality, each of these corridors was improved to high-speed quality between 1995 and 2008, validating (visually) the appropriateness of this framework as an approximate representation of reality. Several corridors proposed for construction (which did not exist in 1995) failed to appear in the simulation, including a north-south linkage in the north-central portion of the country; in reality, this corridor is still under construction as of 2010. In addition, there were numerous capacity expansions in the Lisbon and Porto metropolitan areas as well as in and around the various smaller metropolitan agglomerations between Lisbon and Porto, including Aveiro, Coimbra, and Leiria. Finally, between 1998-2000 the simulation constructed a second crossing of the Tagus River (a high-speed link with 2 lanes in each direction), connecting Lisbon with the suburbs to the south in Alcochete/Montijo. This link represents the Vasco da Gama Bridge, which in reality was completed in 1998. Overall, 86% of the links predicted in the simulation by 2009 conform with the links observed in reality.

Figure 6-3. Network in 2008 under alternative framework #1



In addition to visual inspection and measurement of the network "shape" (speed and capacity), we can measure a variety of performance metrics related to the emergent network. Table 6-3 summarizes 21 such metrics, including financial metrics (total spending, annual spending); traffic metrics in 2008 at the end of the simulation (total VKT, average peak and offpeak speeds, delay due to congestion); system performance metrics (spending per delay reduction, capacity utilization); equity (spending relative to population by land use); and others. In addition, we can compare these metrics with the metrics for the corresponding do-nothing scenario (recall there are 7 do-nothing scenarios, and the appropriate comparator is the "tax/toll mix – medium" framework, which has an equivalent per-km toll rate). For example, under alternative framework #1, there were 32.6 billion VKT in 2008, a 46% increase over the do-nothing scenario. Depending upon one's viewpoint, this could be a positive or negative change; these competing viewpoints are discussed further in Section 6.3.

Table 6-3. Alternative framework #1 metrics

Performance metric		Value	Change from do-nothing
Total spending, 1995-2008 (€ billions)		10.7	n/a
Average annual spending (€ millions)		761	n/a
Total VKT in 2008 (billions)		32.6	+46%
Lane-km built, 1995-2008		714	n/a
Average peak speed, 2008		100.6	+29%
Average offpeak speed, 2008		118.1	+21%
Total delay (millions hours), 2008		10.7	-88%
€ spent per hour reduction in delay, 1995-2008		130	n/a
€ spent per delay reduction per VKT, 1995-2008		2,790	n/a
Total spending relative to population, 1995-2008	Urban	-9.7%	n/a
	Suburban	-2.0%	n/a
	Rural	+11.7%	n/a
Peak capacity utilization, 2008		88%	-31
Offpeak capacity utilization, 2008		24%	-14
VKT < 45 kph (millions), 2008		220	+7%
Year-to-year spending stability, 1995-2008		10%	n/a
Number of trips (millions), 2008		957	+42%
Average trip length (km), 2008		34.1	+3%
Average peak trip travel time (minutes), 2008		20.3	-20%
Average offpeak trip travel time (minutes), 2008		17.3	-15%
Sum of weighted accessibility, 2008		18,151	-26%

In addition to comparing metrics such as those presented above to the do-nothing scenario, metrics can be compared to the other 104 alternative frameworks. To illustrate such a comparison, the next section presents the results of simulating alternative framework #2.

6.1.3 Alternative framework #2

Next we present the results of a second alternative framework that is substantially different from the first alternative framework. The only change between alternative framework #1 and alternative framework #2 is to alter the geographic scale from national to municipal. Framework #2 calls for municipally scaled state-owned enterprises that generate a medium quantity of revenues from a mixture of taxes and tolls and allocate them using net present value analysis (see Figure 6-4).

Figure 6-4. Alternative framework #2

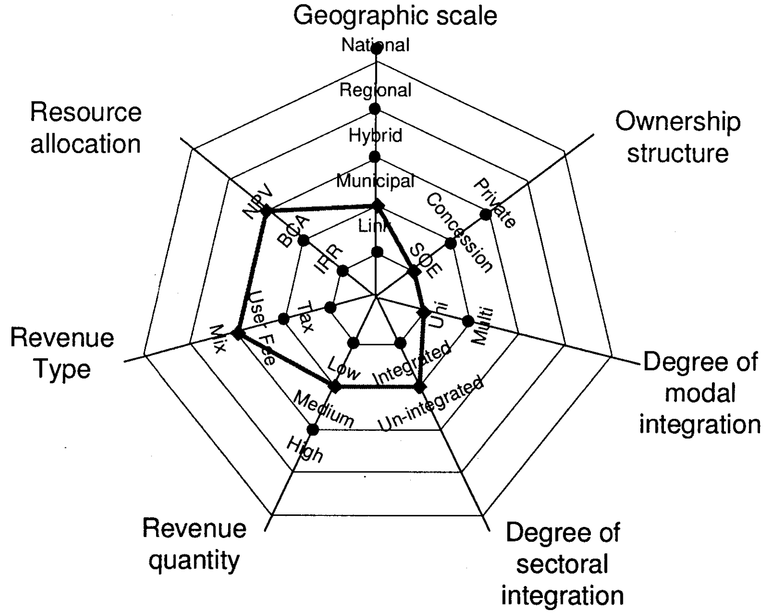
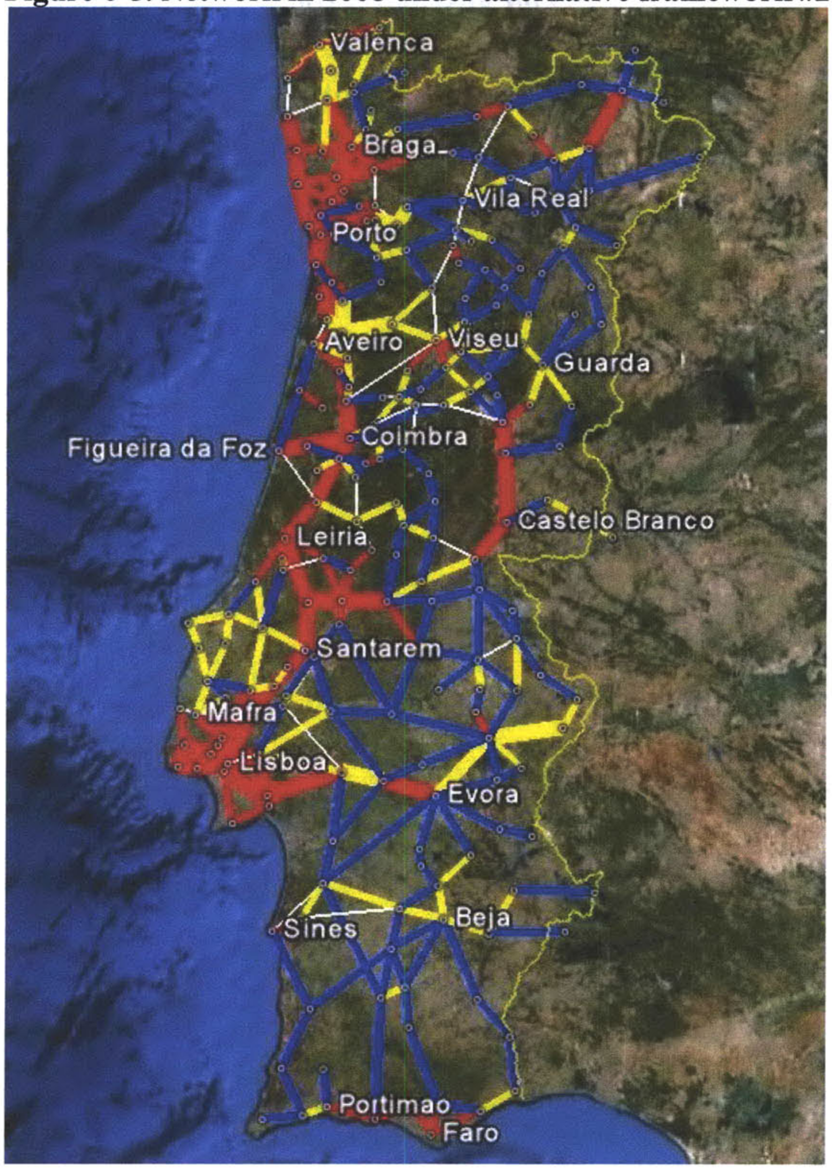


Figure 6-5 depicts the Portuguese network in 2008 following a simulation run under the conditions specified for alternative framework #2. From this map we can observe several results. First, the development of high-speed corridors outside of Lisbon-Porto is absent. Under alternative framework #1, continuous high-speed corridors emerged from Lisbon-Faro, Porto-Spain, and across several interior regions. Under framework #2, these corridors did not emerge. Moreover, the second Tagus River crossing in the Lisbon metropolitan area was not built until much later in the simulation period (2006 in framework #2 vs. 1997 in framework #1). Although there are some improvements in the speeds and capacities of various highway links in the interior of the country, the majority of investment is concentrated in and around the Lisbon and Porto metropolitan areas as well as along the corridor connecting them. Development of infrastructure in other regions of the country is more localized and fails to form long-distance corridors. For example, there are medium- and high-speed links connecting several municipalities along the southern coast in the Algarve, an area with a relatively dense concentration of inhabitants. However, there are no high-speed links connecting the Algarve to other regions of the country. Another example is in the far north of the country, where the municipalities of Bragança and Maceido de Cavaleiros are connected by a high-speed, multi-lane highway; however, there are no other high-speed links connecting these two municipalities to other areas of the country.

Figure 6-5. Network in 2008 under alternative framework #2



As with alternative framework #1, we can measure a variety of performance characteristics from the outputs of the simulation. These are summarized in Table 6-4, which also contains for comparison the values for alternative framework #1. Note that the do-nothing scenario that corresponds to framework #1 is different from the do-nothing scenario that corresponds to framework #2, due to the fact that the toll rates used in the two frameworks are different from one another (€0.016/km in framework #1 versus €0 in framework #2).

Table 6-4. Metrics for alternative frameworks #1 and #2

Performance metric		Framework #1: Value (Change from do-nothing, where applicable)	Framework #2: Value (Change from do-nothing, where applicable)
Total spending, 1995-2008 (€ billions)		10.7	4.7
Average annual spending (€ millions)		761	336
Total VKT in 2008 (billions)		32.6 (+46%)	28.6 (+28%)
Lane-km built, 1995-2008		714	365
Average peak speed, 2008		100.6 (+29%)	91.2 (+17%)
Average offpeak speed, 2008		118.1 (+21%)	114.4 (+17%)
Total delay (millions hours), 2008		10.7 (-88%)	29.1 (-69%)
€ spent/hours delay reduced, 1995-2008		130	74
€ spent/hour delay reduced per 1 billion VKT, 1995-2008		2,790	1,501
Total spending relative to population, 1995-2008	Urban	-9.7%	-0.8%
	Suburban	-2.0%	+2.2%
	Rural	+11.7%	-1.4%
Peak capacity utilization, 2008		88% (-31)	101% (-40)
Offpeak capacity utilization, 2008		24% (-14)	30% (-15)
VKT < 45 kph (millions), 2008		220 (+7%)	200 (+2%)
Year-to-year spending stability, 1995-2008		10%	45%
Number of trips (millions), 2008		957 (+42%)	908 (+34%)
Average trip length (km), 2008		34.1 (+3%)	31.5 (-5%)
Average peak trip travel time (minutes), 2008		20.3 (-20%)	20.7 (-19%)
Average offpeak trip travel time (minutes), 2008		17.3 (-15%)	16.5 (-19%)
Sum of weighted accessibility, 2008		18,151 (-26%)	21,229 (-14%)

Framework #1 resulted in higher levels of spending than framework #2 (€10.7 billion compared with €4.7 billion) over the 14-year simulation period. Not surprisingly, framework #1 also resulted in a network with less delay in 2008 relative to framework #2 (10.7 million hours vs. 29.1 million hours), higher peak and offpeak speeds, more stable spending year to year (10% relative standard error vs. 45%), and higher levels of accessibility both in constant terms and relative to the do-nothing scenarios. On the other hand, framework #2 provides more cost-effective delay reductions (€1,501 per hour of delay reduced per billion VKT, compared with €2,790 in framework #1), a closer match of spending relative to population, and a smaller increase in low-speed VKT relative to the do-nothing (2%, compared with a 7% increase under framework 1).

The results of these 2 simulations underscore the challenge of evaluation. Complex systems not only behave in ways that are difficult to predict or understand, but they also exhibit numerous characteristics that are difficult to measure in an integrated way. Even across just these two frameworks, there are measurable outputs across many dimensions that are important to decision-makers which reveal trade-offs. This lack of clarity over which framework is "preferable" is further compounded by the evaluative complexity of varying stakeholder perspectives. In the next section we attempt to illuminate some of the trade-offs among the various frameworks and categories of frameworks by presenting a more complete set of results from the 105 simulated alternative frameworks.

6.2 Complete results

The results presented in Section 6.1 illustrate the types of measurable outputs of the simulation of alternative strategy development frameworks, using as illustrations the 7 do-nothing scenarios and 2 alternative frameworks. A total of 105 alternative frameworks were simulated, however, covering a broad range of combinations of values along each of the five dimensions depicted in the radar charts in Figure 6-2 and Figure 6-4. In this section we present a summary of results from the simulation of all 105 frameworks. First, we present the results of the frameworks that call for a state-owned enterprise ownership structure (SOEs accounted for 99 of the 105 alternative frameworks simulated), followed by the results of the 6 concession-based frameworks.[13]

By presenting the full set of results we can begin to understand the range of trade-offs resulting from the various alternative frameworks. One of the fundamental assumptions of this approach is that we can conclude, based on the quality of the investment strategies that emerges from the simulation, whether the strategy development frameworks are "good." Again, the interpretation of "good" depends on one's viewpoint, a problem which we will explore further in Section 6.3; for now, we simply present the results.

6.2.1 State-owned enterprise frameworks

This section summarizes the performance of the alternative frameworks with a state-owned enterprise (SOE) ownership structure. In all, 99 SOE frameworks were simulated, but for purposes of presentation, we show only the results for frameworks with **medium** revenues that use the **NPV** resource allocation approach, thus leaving only the geographic scale and revenue type dimensions to compare. The reason for selecting NPV for resource allocation to present is that the results are nearly identical to the results for frameworks using BCA as the basis for resource allocation, with the only distinction being a slight, systematic shift in allocation of resources from rural to urban and suburban areas. Each of the 15 charts in Figure 6-6 through Figure 6-20 illustrates the outputs of the simulation for 18 SOE frameworks for a single performance metric.

[13] Recall that the number of concession frameworks is more limited due to the restriction that revenues can only be derived from tolls and must be allocated using financial rate of return as the primary criterion; moreover, we consider only two geographic scales for concession (national and link-based).

Figure 6-6. Average total investment, 1995-2008 (SOE, medium revenue quantity, NPV resource allocation)

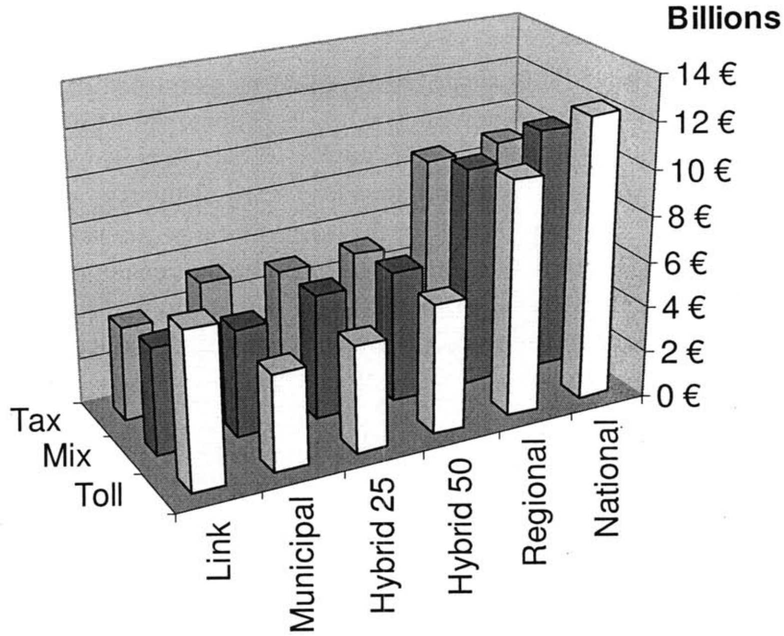


Figure 6-6 summarizes average total investment for 18 alternative SOE frameworks that vary along two dimensions: geographic scale and type of revenues. A key trend evident from this chart is that, as geographic scale shrinks, the total amount of spending declines. This is due in part to the inability of smaller geographic scales to aggregate funding and overcome high capital investment requirements. Specifically, small municipalities with smaller tax bases and/or municipalities that are adjacent to highway links with low travel volumes generate modest revenues. Even over a 15-year time period, with these modest revenues they are often unable to fund improvements which require substantial up-front capital investments. Also, relatively wealthier municipalities complete the portion of the network adjacent to them in the early years of the simulation, but continue to accumulate revenues in later years without any projects to which they can be allocated. Hybrid frameworks are able to spend slightly more than municipal frameworks due to revenue sharing among municipalities, and regional frameworks are able to spend more than municipal and hybrid frameworks due to the larger geographic scales they encompass. Overall, however, national frameworks are able to allocate the most revenues. In non-national frameworks, over the course of the simulation, organizations leave substantial funds unspent, making them available for other uses or as savings for future transportation investments.

Figure 6-7 shows total vehicle-kilometers of travel (VKT) on the entire network in 2008. VKT trends along the geographic scale dimension roughly match the spending trends: more spending increases speeds, attracting new trips, which increases total VKT. However, the relative difference in VKT for various geographic scales is not as large as the relative difference in spending. Moreover, there is a decline in VKT for frameworks with higher toll rates, due to the financial hardship that direct tolling imposes on motorists, thus reducing the demand for travel.

Figure 6-7. 2008 VKT

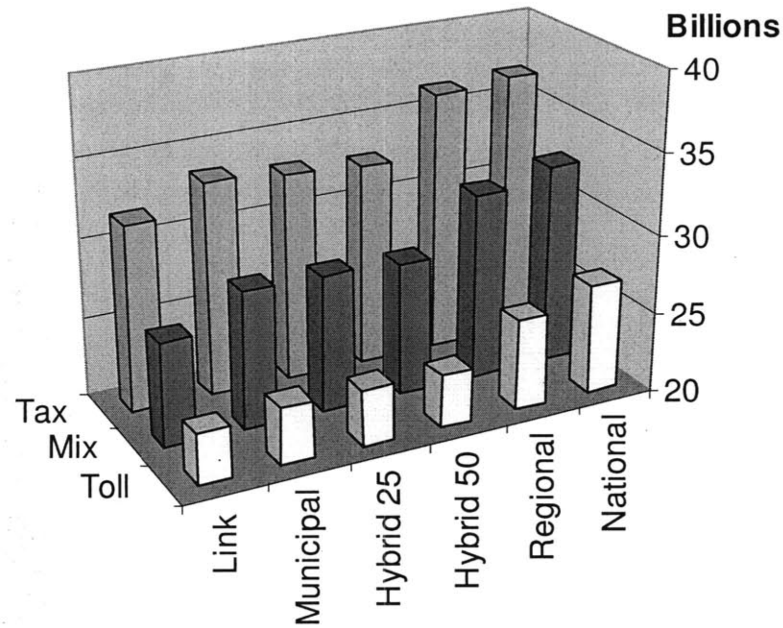


Figure 6-8 shows weighted average peak-period speeds in kilometers per hour (kph). Overall speeds are higher with higher toll rates due to the suppression of travel demand and concomitant reduction in congestion. Also, the same trend evident from earlier charts is evident here: larger geographic scales enable higher levels of spending, which reduce congestion and create higher design speeds over a greater portion of the national network, resulting in higher average peak speeds. The notable exceptions are frameworks with the smallest geographic scale (link-based), which have speeds that are equal to or higher than the peak speeds of the regional and national frameworks. Although they invest less overall, the link-based frameworks invest directly in those facilities where congestion is most problematic, nearly eliminating delay altogether, and improving peak speeds substantially. This is more pronounced for toll-based frameworks, which align revenues directly with travel volumes, thus enabling the links to invest more directly in congestion reduction. A similar trend is evident in Figure 6-9, which shows reduction in peak-period delays due to congestion.

Figure 6-8. Peak speed (kph)

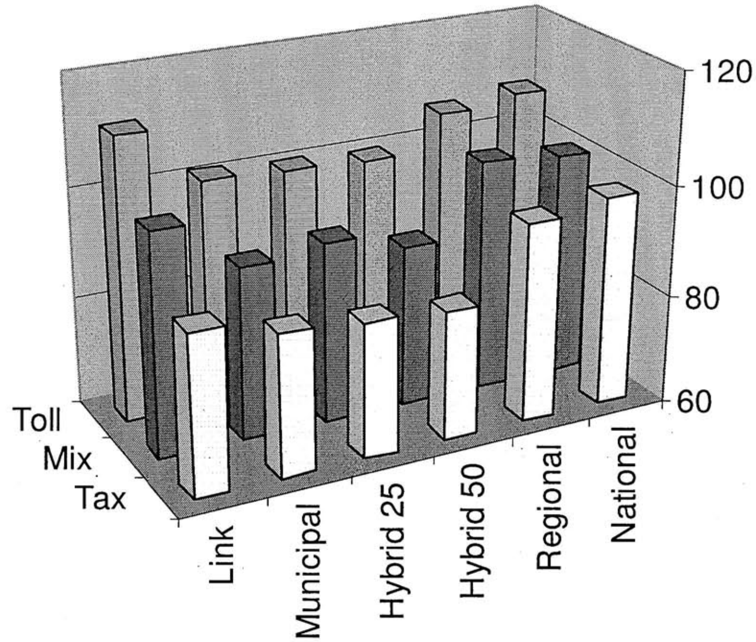
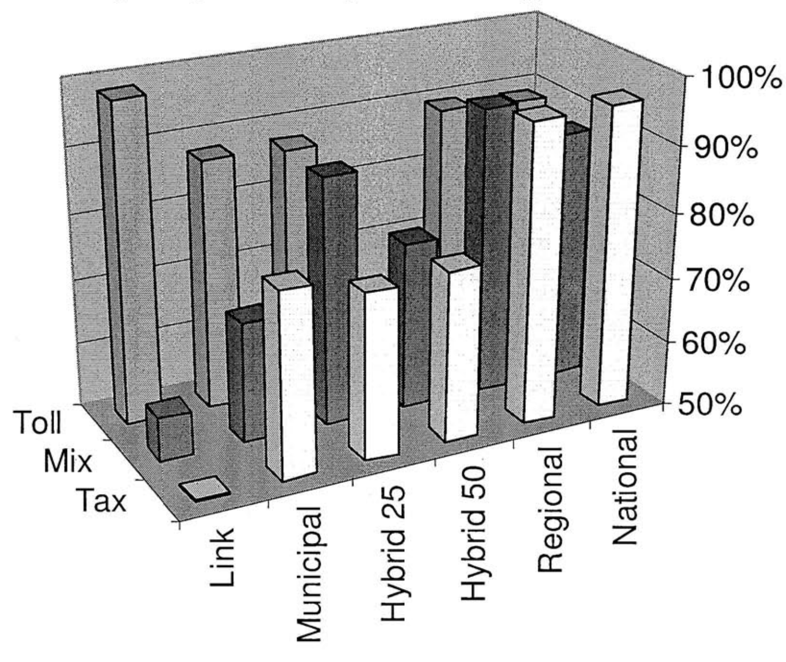


Figure 6-9. Reduction in peak-period delays due to congestion over do-nothing frameworks



As a measure of the cost-effectiveness of each framework, Figure 6-10 illustrates the cost per unit delay, normalized by VKT. The expression for this metric is as follows:

$$\frac{Investment}{\left(\frac{D_i}{VKT_i} - \frac{D_{dn,i}}{VKT_{dn,i}}\right)}, \text{ where}$$

Investment = total investment in the network, 1995-2008 in 2008 €
D_i = Hours delay of framework *i*
VKT_i = VKT of framework *i*
$D_{dn,i}$ = Hours delay of do-nothing framework corresponding to framework *i*
$VKT_{dn,i}$ = VKT of do-nothing framework corresponding to framework *i*

Clearly, cost-effectiveness increases as the toll rate declines. Because tolling suppresses travel demand, there are fewer opportunities for congestion and delay reduction in toll-based frameworks relative to frameworks with lower toll rates or no tolls whatsoever. In addition, cost-effectiveness increases as the geographic scale becomes smaller. This is due to the fact that, as the geographic scale gets larger, there is a greater ability and willingness to invest in low-volume links in rural areas with little or no congestion-reduction benefits.

Figure 6-10. Cost-effectiveness of congestion-related delay reduction over do-nothing framework (investment per reduction in hourly delay/VKT)

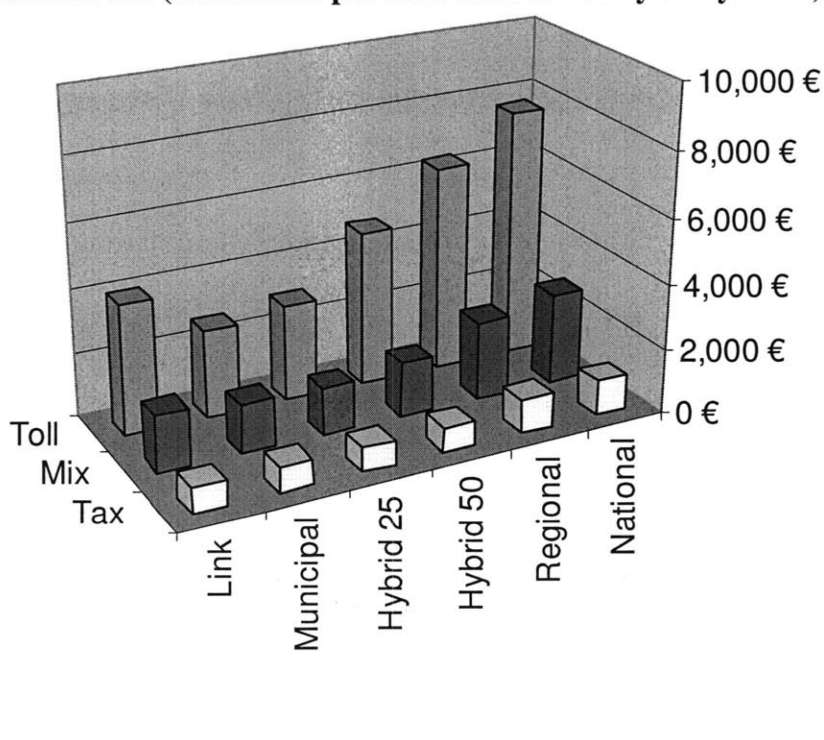


Figure 6-11, Figure 6-12, and Figure 6-13 illustrate the "variation" in spending for urban, suburban, and rural areas, respectively. Variation is defined as the difference between the relative proportion of population in an area and the relative proportion of investment in that area. For example, the investment in urban areas as a proportion of total investment is less than the proportion of urban population to total population in all frameworks except for frameworks with a link-based geographic scale. The inequity for urban areas is most pronounced in the national and hybrid 50% frameworks. Suburban areas receive more than their share of population in investment only under municipal frameworks, while rural areas receive disproportionately high investments under all frameworks except for municipal and link-based frameworks, in some cases significantly more than their population share would suggest (e.g., 20% more in the national-toll and hybrid 50%-tax frameworks).

Figure 6-11. Variation in investment relative to population - urban

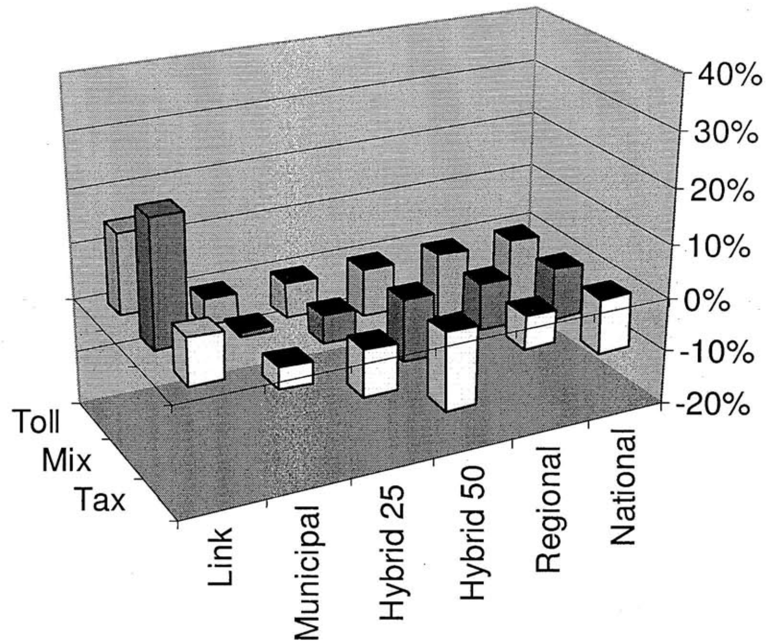


Figure 6-12. Variation in investment relative to population - suburban

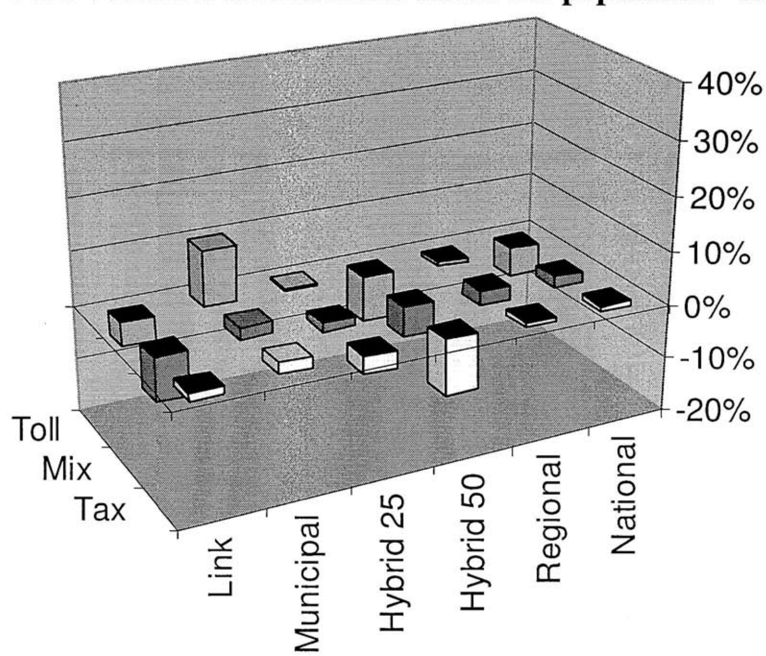
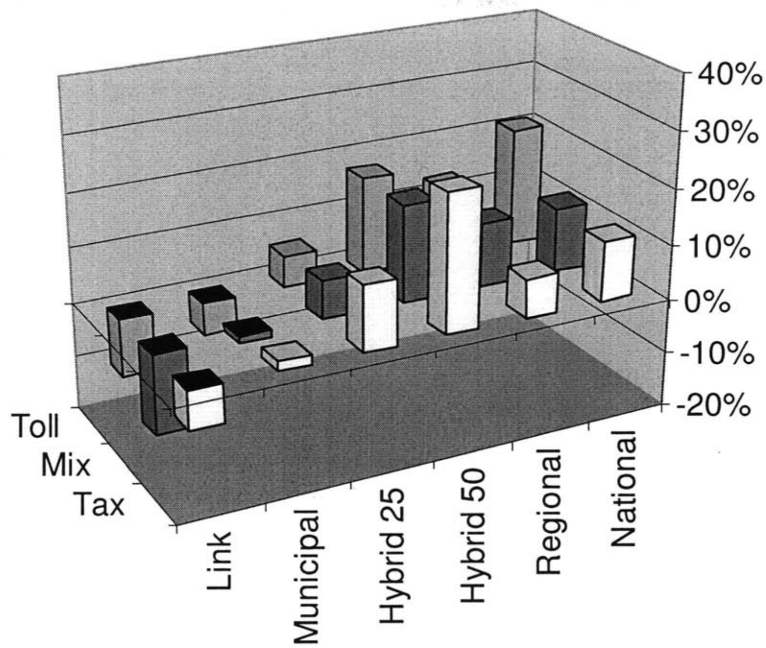


Figure 6-13. Variation in investment relative to population - rural



Capacity utilization measures the volume to capacity ratio across the entire network. This metric is weighted by volume according to the following expression:

$$\frac{\sum_{\forall i} (V_i / C_i) \times V_i}{\sum_{\forall i} V_i},$$

where V_i = volume on link i (peak or offpeak)
C_i = capacity on link i

Ideally, peak-period capacity utilization will fall below 100%. Utilization values above 100% indicate congestion, while utilization values below but near 100% indicate unstable flows. On the other hand, low utilizations indicate over-investment in capacity. Figure 6-14 illustrates capacity utilization for the peak hour, while Figure 6-15 illustrates capacity utilization for the offpeak. Both charts have the same shape, but the values along the vertical axis are distinct, with peak-hour utilization being higher, in some cases exceeding 100%. Offpeak utilization is under 50% for all frameworks.

Figure 6-14. Peak capacity utilization

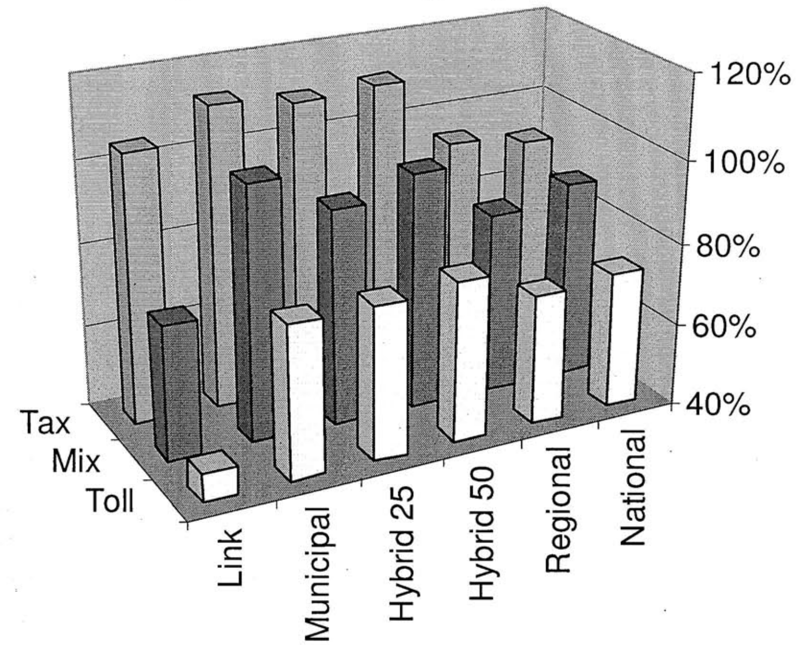


Figure 6-15. Offpeak capacity utilization

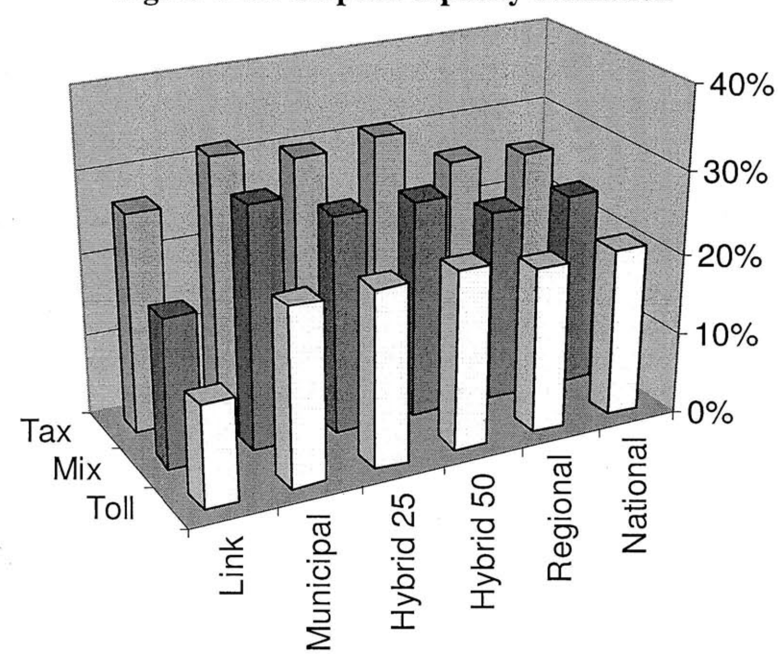


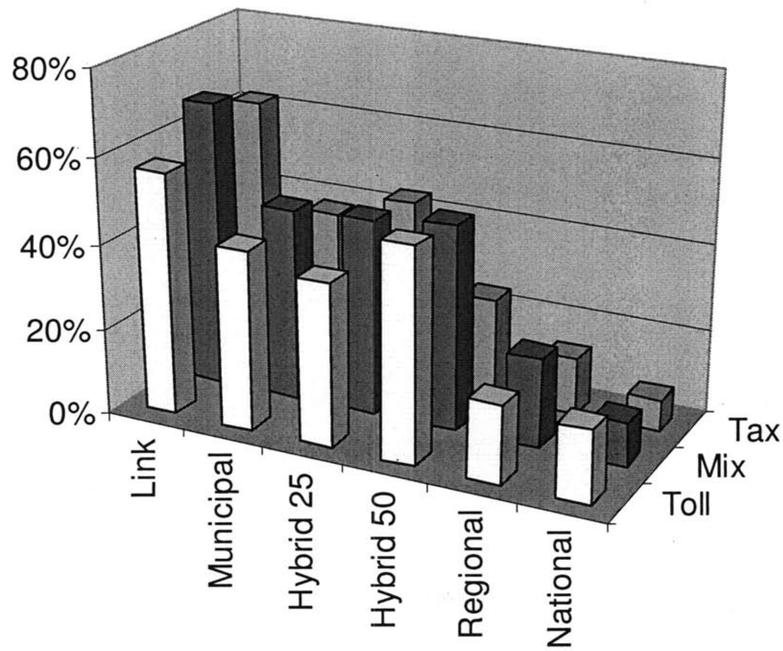
Figure 6-16 shows a measure of the "stability" of spending from year to year. Stability is measured as the relative standard error over the 14-year period 1995-2008 and computed as follows:

$$\frac{SE(M,i)}{Average(M,i)}, \text{where}$$

$SE(M,i)$ = standard error of the 14 annual investment values (M) for framework i
$Average\ (M,i)$ = average of the 14 annual investment values (M) for framework i

Lower values indicate more stable investments from year to year, and, as shown in the chart, larger geographic scales tend to have enjoy greater stability.

Figure 6-16. Year-to-year stability of spending



Trips are a measure of economic activity, and over time the number of trips that are "induced" by investment in an infrastructure network indicate economic growth. By the same token, they might simply reflect more dispersed land development patterns. In either case, they also indicate environmental degradation through greater consumption of energy and emissions. Figure 6-17 summarizes the average number of induced trips over the do-nothing framework for each category. As with total investment, speed, and delay reduction, there is a general trend toward more induced trips for more centralized geographic scales. However, there is much less variation in the percentage increase in induced trips based on the type of revenue. Meanwhile, Figure 6-18 provides a measure of the cost-effectiveness of induced trips (total investment per induced trip). Once again, the same general shape holds, with centralized and toll-based frameworks less cost-effective relative to decentralized and tax-based frameworks, with the exception of the link-toll framework.

Figure 6-17. Increase in induced trips over do-nothing

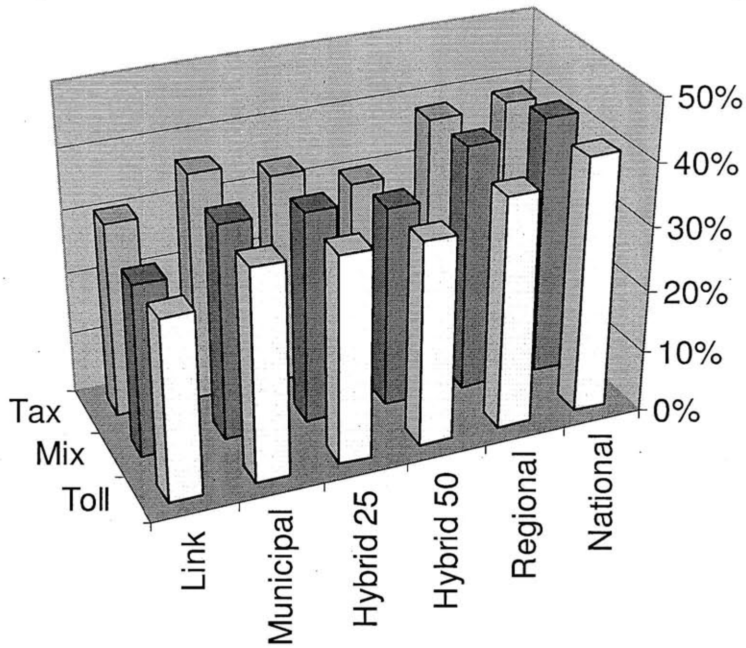
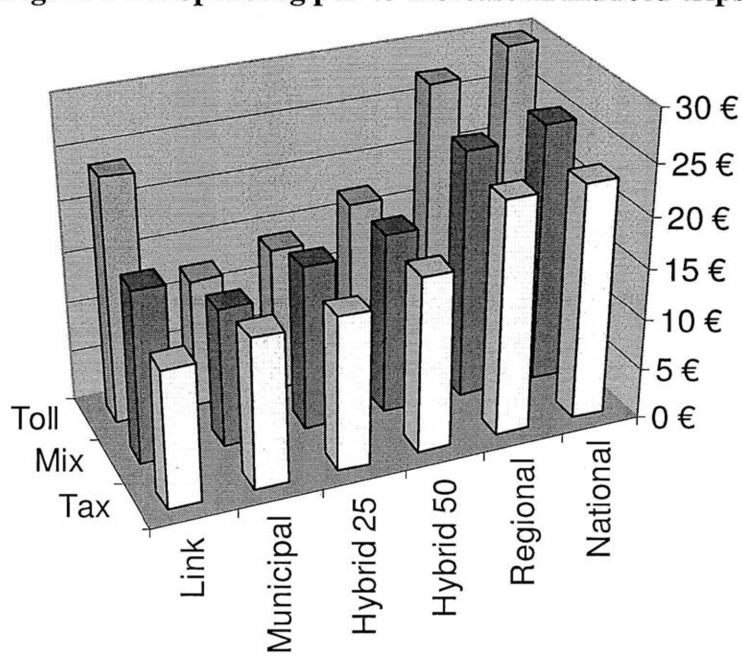


Figure 6-18. Spending per % increase in induced trips



Finally, Figure 6-19 and Figure 6-20 show unweighted and weighted measures of network accessibility, respectively, computed as follows:

$UnweightedAccessibility_i = \sum_{j \in J} TC_{ij}$, where

TC = generalized travel cost between node i and node j

$$WeightedAccessibility_i = \frac{\sum_{j \in J} (TC_{ij} * F_{ij})}{\sum_{j \in J} F_{ij}}, \text{ where}$$

F = annual flow in trips between node i and node j

Lower values indicate higher levels of accessibility, which, as shown in the figures for both unweighted and weighted measured of accessibility, are achieved at increasingly centralized geographic scales.

Figure 6-19. Unweighted accessibility

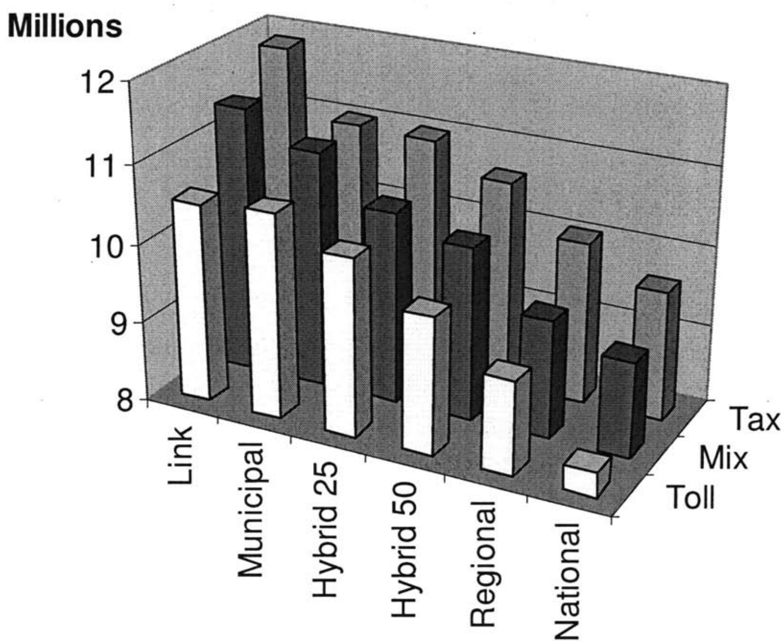
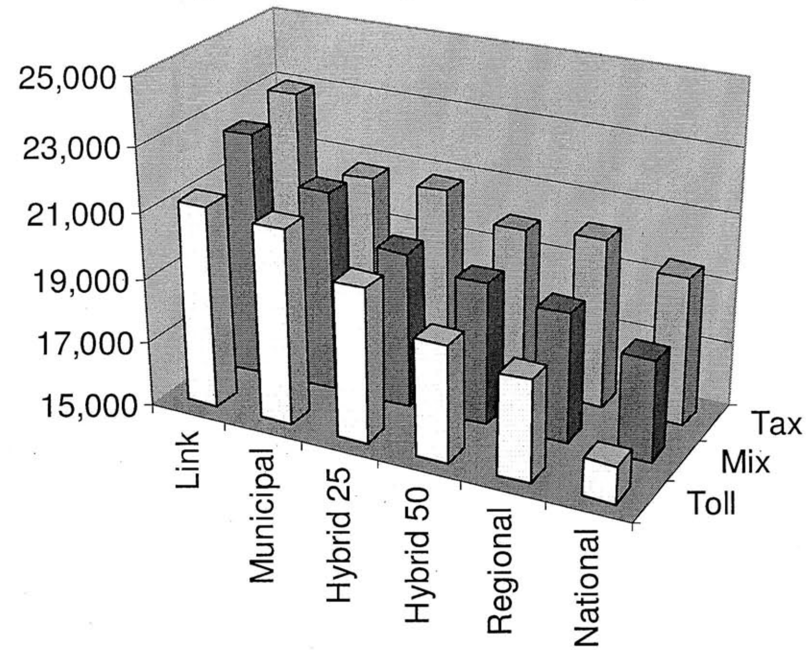


Figure 6-20. Weighted accessibility



6.2.2 Concession frameworks

The approach for simulating concessions is different from the approach for simulating state-owned enterprises in several important ways. The purpose of simulating a concession-based strategy development framework is to observe how the investments in the network would emerge over time subject to the typical constraints that private-sector participants impose on the system. These constraints are reflected in the simulation model as follows:

- Only toll revenues are available to fund investments. With a state-owned enterprise, the government can choose to use general tax revenues to support infrastructure investment. By contrast, one of the purposes of a concession approach is to use the revenue-generating capability of a facility to determine whether that facility merits investment. Although in practice some concession agreements involve direct and/or indirect subsides from the government, the theoretical basis of a concession is to rely on facility-generated revenues.
- Invest only in projects meeting a minimum acceptable internal rate of return (IRR). Computation of IRR depends on several parameters, including principally the length of the project, the initial investment required, and the expected revenues (which are a function of the toll rate). Although we can vary the length of the project and toll rate (the likelihood that a project will provide a sufficient IRR increases with increasing project length and toll rate), the fundamental relationship remains: projects are only pursued if they provide a sufficient financial return to the private owner.
- Links for which projects do not meet the minimum acceptable IRR remain under state ownership, but no investments are made in improving the link.
- Various combinations of projects are permissible under a concession framework depending on the geographic scale. Consider, for example, a nationally scaled concession. There may be several individual links that provide rates of return that are

much higher than the minimum acceptable threshold for the private investor. If this is the case, then the government can assemble a package of projects, some of which exceed the threshold and others which do not meet it, but whose overall IRR is acceptable to the private investor. By contrast, for smaller geographic scale, the government is limited in its ability to combine "winner" projects with "loser" projects. We consider two limiting cases in the simulation: a nationally scaled concession and a link-by-link approach to concessions.

In all cases, the length of the concession is 30 years and the minimum IRR is 10%. However, we consider 3 toll rates (high, medium, and low), and only collect tolls on those links for which a concession is pursued. Table 6-5 summarizes the performance of the 2 types of concession simulations (1 national concession versus independent link-based concessions), averaging the metrics across the 3 toll rate scenarios. For comparison, the metric values for alternative framework #1 are also shown. Recall that alternative framework #1 is a nationally scaled SOE making investment decisions with medium revenues derived from a mixture of taxes and tolls using net present value analysis. The values presented for the national and link-based concessions are likewise for medium revenues.

Table 6-5. Performance metrics for 3 frameworks for comparison: national concession, link-based concession, and alternative framework #1

Performance metric		Value (Change from do-nothing, where applicable)		
		1 National Concession (medium toll rate for revenue generation)	Link-based Concessions (medium toll rate for revenue generation)	Alternative framework #1 (national SOE, medium tax/toll rate, NPV)
Total spending, 1995-2008 (€ billions)		2.5	1.9	10.7
Average annual spending (€ millions)		175	133	761
Total VKT in 2008 (billions)		20.9 (+15%)	20.4 (+12%)	32.6 (+46%)
Lane-km built, 1995-2008		504	508	714
Average peak speed, 2008		98.9 (+22%)	98.9 (+22%)	100.6 (+29%)
Average offpeak speed, 2008		112.5 (+14%)	112.0 (+13%)	118.1 (+21%)
Total delay (millions hours), 2008		3.5 (-93%)	3.4 (-94%)	10.7 (-88%)
€ spent/hour delay reduced per 1 billion VKT, 1995-2008		1,985	1,500	2,790
Total spending relative to population, 1995-2008	Urban	+20.2%	+34.0%	-9.7%
	Suburban	-16.5%	-18.1%	-2.0%
	Rural	-3.7%	-15.9%	+11.7%
Peak capacity utilization, 2008		70% (-26)	67% (-29)	88% (-31)
Offpeak capacity utilization, 2008		20% (-11)	19% (-12)	24% (-14)
VKT < 45 kph (millions), 2008		28 (-86%)	32 (-84%)	220 (+7%)
Year-to-year spending stability, 1995-2008		147%	101%	10%
Number of trips (millions), 2008		662 (+20%)	649 (+17%)	957 (+42%)
Average trip length (km), 2008		31.6 (-4%)	31.5 (-4%)	34.1 (+3%)
Average peak trip travel time (minutes), 2008		19.3 (-21%)	19.3 (-21%)	20.3 (-20%)
Average offpeak trip travel time (minutes), 2008		16.9 (-16%)	16.9 (-16%)	17.3 (-15%)
Sum of weighted accessibility, 2008		21,977 (-8%)	23,309 (-3%)	18,151 (-26%)

Notably, the concession frameworks make much more modest investments than any of the SOE frameworks, investing under a national concession only €2.5 billion and under link-based concessions just €1.9 billion. Network-wide performance metrics such as average peak and offpeak speeds, reductions in delay, and cost-effectiveness of delay reductions compare favorable to SOE frameworks such as alternative framework #1. In fact, "congested travel" (number of VKT < 45 kph) is reduced substantially under the concession approach, although weighted accessibility does not improve as under alternative framework #1.

Under a concession approach, the government owner of the highway network is likely to lease those portions which generate revenue that can support a reasonable financial return for the private concessionaire. In some cases, they may also be able to lease less-profitable portions as part of a larger package that is, on the whole, attractive to private investors. In fact, the network leased and improved in the simulation model corresponds to a large portion of the actual concessioned network in Portugal. The simulation, however, ignores the rest of the network, while in practice the government is likely to make additional investments in those other portions of the network. However, it should be noted that the government in this situation cannot make widespread toll-financed improvements because the majority of the toll revenue streams of significance are owned by the concessionaire. Instead, the government would rely on general tax revenues for improvements to other portions of the network, resulting in a hybrid concession-SOE approach.

6.3 Evaluation

The results presented until now are descriptive, providing a summary of the measurable outcomes of simulations of 7 do-nothing scenarios and 105 alternative strategy development frameworks (of which 99 are SOE-based and 6 are concession-based). In this section we provide a more normative interpretation of these results by attaching value judgments to them.

Consider the case where the output of the simulation of a given strategy development framework is a single measurable value—for example, "profit." In such a case, determining the best framework from the 105 alternatives would be straightforward: it is the one which maximizes profit. Even if the estimation of profit is subject to uncertainty, one could determine which alternative framework maximizes the *expected* profit. However, when considering complex systems, single-objective decision-making is rare. Instead, we face not only a variety of metrics related to a variety of objectives, but also a variety of stakeholders who value each objective in distinct ways, increasing the potential for conflict. In order to evaluate a complex system, then, we must consider this *evaluative complexity* (Sussman, 2003). Judgment of the quality of any particular framework depends upon the values of the stakeholder through whose lenses the outcomes are viewed.

To produce normative judgments that are sensitive to evaluative complexity, the outcomes of the simulation model are combined in a variety of ways to reflect the diversity of viewpoints among stakeholders in Portugal. We begin by presenting a detailed list of the metrics to be used in this evaluation, followed by a description of the evaluation procedure and how it will be applied across a range of several scenarios, each representing a unique perspective.

6.3.1 Metrics

The metrics used to evaluate strategies produced by the simulation of the Portuguese highway system's evolution under alternative frameworks are summarized below.

- Investment:
    - Total amount invested. Total amount invested over the simulation period, 1995-2008, in the intercity transportation infrastructure network of Portugal.
    - Investment stability. Relative standard error of annual spending.
- New construction:
    - Urban construction. Total number of lane-kilometers of new urban highways.
    - Suburban construction. Total number of lane-kilometers of new suburban highways.
    - Rural construction. Total number of lane-kilometers of new rural highways.
- Travel:

- VKT. Total vehicle-kilometers of travel (VKT) in the year 2008.
    - Induced trips. Change in the total number of trips in 2008 relative to the do-nothing scenario's total number of 2008 trips.
    - Average trip length. Change in the average trip length relative to the do-nothing framework.
- Efficiency:
    - Speed. Improvement in weighted average speed over all links in the network (weighted by the volume on that link) during both the peak period and the offpeak relative to the do-nothing framework.
    - Delay. Reduction in congestion-related delay relative to the do-nothing framework.
    - Utilization. Ratio of volume to capacity during both the peak period and the offpeak.
    - Congested travel. Reduction in the number of VKT at speeds below 45 kph relative to the do-nothing framework.
- Cost-effectiveness:
    - Delay. Spending per unit reduction in delay relative to the do-nothing framework.
    - Trips. Spending per percentage increase in trips relative to the do-nothing framework.
    - Speed. Spending per improvement in peak and offpeak speeds relative to the do-nothing framework.
- Accessibility:
    - Free-flow accessibility. Sum of travel times from all nodes to all nodes (ignoring congestion). Lower values indicate higher accessibility.
    - Congested accessibility. Weighted sum of travel times from all nodes to all nodes taking into account peak-period congestion and weighted by peak travel volume. Lower values indicate higher accessibility.
- Fiscal equivalence:
    - Urban. Investment relative to population in urban areas.
    - Suburban. Investment relative to population in suburban areas.
    - Rural. Investment relative to population in rural areas.

Certainly other metrics could be imagined. For example, metrics explicitly considering environmental impact are not reported above. Instead, we use VKT and "congested travel" to approximate environmental impacts on air quality. The metrics summarized here represent a fairly broad cross-section of typical metrics considered in evaluating the performance of a transportation system: they describe the system in terms of its technical performance, financial performance, economic development potential, environmental impact, and fairness. For each performance metric, we rank all 105 frameworks from best to worst, noting that for some metrics "best" and "worst" are subjective. In the next section we describe a procedure for combining these metrics in a variety of ways in order to judge the relative value of each framework.

6.3.2 Multi-objective evaluation procedure

Determining which among the 105 alternative strategy development frameworks is "best" could be straightforward if we were interested in only a single metric, or if the views of only one stakeholder were important. For example, the framework which minimizes total congestion-related delay has a link-based geographic scale and a high toll rate. Alternately, we can combine more than one outcome of interest into a single metric. For example, the framework which provides the most *cost-effective* improvement in speed is a nationally scaled concession with low tolls.

In reality, infrastructure decision-makers are rarely able to make decisions driven by single objectives or a narrow view of stakeholder groups. Investment strategies reflect the combined interests of a range of individuals and stakeholder groups with diverse preferences. In order to reflect this multi-objective decision-making context, it is necessary to combine several metrics and measure the multi-dimensional performance of each framework. However, as already indicated, this approach is complicated by several factors:

- Stakeholders have distinct views about which metrics are important.
- Changes in some metrics can be viewed as positive or negative, depending on the viewpoint of the stakeholder. For example, increasing number of trips can be viewed positively for economic growth but negatively for environmental impacts.

In the face of this complexity, but with an interest in making normative judgments about the frameworks simulated, we create and present below 7 evaluation scenarios, each designed to reflect a unique stakeholder perspective. For each scenario, we present a unique weighted combination of the performance metrics summarized above and a summary of the top 20 frameworks. The 7 evaluation scenarios and their objectives are summarized as follows:

- *Mobility*. Facilitate intercity travel and trade within Portugal.
- *Environmental protection*. Preserve the environment by limiting travel and minimizing development.
- *Economic stimulus*. Invest in infrastructure as a means of providing jobs in the short-term and enabling economic growth in the long-term.
- *Territorial cohesion*. Provide broad access to high-speed intercity travel infrastructure.
- *Urbanization*. Relieve urban congestion by providing high-speed, high-capacity intra-metropolitan linkages to encourage metropolitan growth.
- *Fiscal equivalence*. Ensure a distribution of revenues that is equal in proportion to the population.
- *Fiscal austerity*. Reduce indebtedness by limiting spending in the infrastructure sector.

Following a simple rank-weighting approach demonstrated by Brusilovskiy and Hernandez for Conrail Corporation (1997), we develop a unified metric which weighs each of the performance metrics summarized in Section 6.3.1 in a unique way. First, we rank each of the 105 frameworks according to each metric. Next, we apply a weight to each metric with a value ranging from 0-10. Finally, we compute a weighted-sum ranking for each framework. For example, suppose we are interested in ranking alternative framework #1 for a scenario which values the metric "total VKT" with a weight of 10 and "peak-period speed improvement" with a value of 5. Alternative framework #1 ranks 7th in total VKT out of 105 and 34th in peak-period speed improvement. For this scenario, the weighted rank of alternative framework #1 is 16.0, a value for which it ranks 12th overall.

In the following sections, we present a description of each evaluation scenario, the rank weights employed, and the resulting top 20 frameworks.

6.3.2.1 *Mobility*

The first evaluation scenario, *mobility*, emphasizes travel. Under this scenario, we seek to improve the number and density of interactions among individuals across Portugal, while lowering impediments to travel by reducing congestion and improving speeds. We are also interested in making these improvements in a cost-effective manner. Table 6-6 summarizes the metrics and their weights as specified for this scenario to reflect the objectives described. Metrics not shown have a weight of 0. Based on these weights, Table 6-7 summarizes the top 20 alternative frameworks for this scenario.

Table 6-6. Performance metric weights for mobility scenario

Metric	Relative weight
Peak-hour speed improvement	10
Offpeak speed improvement	10
Peak-hour delay reduction	10
Offpeak delay reduction	10
Cost-effectiveness of speed improvements	5
Cost-effectiveness of delay reduction	5
Reduction in congested travel (<45 kph)	10
Increase in number of trips	10
Cost-effectiveness of induced trips	5
Weighted peak accessibility improvement	10
Unweighted accessibility improvement	10

Table 6-7. Framework rankings for mobility scenario

Rank	Ownership	Geographic Scale	Decision-Making Process		
			Resource Allocation	Resource Type	Resource Quantity
1	SOE	Regional	BCA	Tax Only	High
2	SOE	National	NPV	Tax Only	High
3	SOE	Regional	NPV	Tax Only	High
4	SOE	National	BCA	Tax Only	Medium
5	SOE	Regional	BCA	Tax Only	Medium
6	SOE	National	NPV	Tax Only	Medium
7	SOE	National	BCA	Tax-Toll Mix	High
8	SOE	National	BCA	Tax Only	High
9	SOE	Regional	NPV	Tax Only	Medium
10	SOE	National	NPV	Tax-Toll Mix	High
11	SOE	Regional	BCA	Tax-Toll Mix	High
12	SOE	National	BCA	Tax-Toll Mix	Medium
13	SOE	Regional	BCA	Tax Only	Low
14	SOE	Regional	NPV	Tax-Toll Mix	High
15	SOE	National	BCA	Tax Only	Low
16	SOE	Regional	BCA	Tax-Toll Mix	Medium
17	SOE	Regional	NPV	Tax-Toll Mix	Medium
18	SOE	National	BCA	Tax-Toll Mix	Low
19	SOE	National	BCA	Toll Only	High
20	SOE	National	NPV	Toll Only	High

All of the top 20 frameworks are either nationally or regionally scaled state-owned enterprises, and most call for revenues from general taxation. Toll-based frameworks tend to discourage travel relative to non-toll-based frameworks (even when both are compared to an appropriately tolled do-nothing scenario). Interestingly, only 10 of the top 20 frameworks call for high tax and/or toll rates. One might expect to see more, given that high revenue rates lead to greater investment in infrastructure. However, this is tempered by the inclusion of "cost-effectiveness" metrics in the scenario. Moreover, "medium" and "low" revenue rates often result in higher levels of investment when applied at a regional or national geographic scale than "high" rates at a municipal or hybrid scale.

6.3.2.2 Environmental protection

The environmental protection evaluation scenario emphasizes minimization of impacts on the built environment and minimization of travel, which leads to greater consumption of energy resources, contributes to degradation of air quality, and increases greenhouse gas emissions. Table 6-8 summarizes the metrics and weights for this scenario, while Table 6-9 presents the top 20 frameworks.

Table 6-8. Performance metric weights for environmental scenario

Metric	Relative weight
Increase in VKT relative to do-nothing	-10
Peak-hour speed improvement	2
Offpeak speed improvement	2
Total delay reduction	5
Cost-effectiveness of speed improvements	5
Cost-effectiveness of delay reduction	5
Peak capacity utilization	5
Offpeak capacity utilization	5
Reduction in congested travel (<45 kph)	10
Lane-km constructed in urban areas	-4
Lane-km constructed in suburban areas	-7
Lane-km constructed in rural areas	-10
Increase in number of trips	-10
Increase in average trip length	-5

Table 6-9. Framework rankings for environmental scenario

Rank	Ownership	Geographic Scale	Decision-Making Process		
			Resource Allocation	Resource Type	Resource Quantity
1	Concession	Link	ROI	Toll Only	Low
2	Concession	National	ROI	Toll Only	Low
3	SOE	Link	n/a	Tax-Toll Mix	Low
4	Concession	Link	ROI	Toll Only	Medium
5	Concession	National	ROI	Toll Only	Medium
6	SOE	Hybrid - 50%	NPV	Tax-Toll Mix	Low
7	Concession	Link	ROI	Toll Only	High
8	SOE	Municipal	NPV	Tax Only	Low
9	SOE	Municipal	BCA	Tax Only	Low
10	SOE	Link	n/a	Tax Only	Low
11	Concession	National	ROI	Toll Only	High
12	SOE	Link	n/a	Toll Only	Low
13	SOE	Regional	BCA	Tax Only	Low
14	SOE	Regional	NPV	Tax Only	Low
15	SOE	Hybrid - 25%	NPV	Toll Only	Low
16	SOE	Hybrid - 25%	BCA	Toll Only	Low
17	SOE	National	BCA	Tax Only	Low
18	SOE	Hybrid - 50%	BCA	Tax-Toll Mix	Low
19	SOE	Municipal	NPV	Toll Only	High
20	SOE	Hybrid - 50%	BCA	Toll Only	Low

Interestingly, the more decentralized and market-based (concession) approaches dominate the top 20 for the environmental protection scenario. In this sense, the top-performing frameworks for the environmental scenario are the "opposite" of the top frameworks for the mobility scenario. The reasons for these results were discussed in Section 6.2: decentralized frameworks and concession-based frameworks simply build less infrastructure, thereby inducing less travel relative to the more centralized frameworks. Although the metrics adopted for this scenario reflect important environmental protection objectives, they could also be characterized as "travel minimization," and they directly conflict with the objectives of the mobility scenario.

6.3.2.3 Economic stimulus

The objective of the economic stimulus scenario is to maximize spending on infrastructure for short-term job creation as well as to build an extensive network that will facilitate long-term economic growth via enhanced mobility. We are still concerned with cost-effectiveness, but to a lesser extent, as the weights in Table 6-10 reflect. The top 20 frameworks are summarized in Table 6-11.

Table 6-10. Performance metric weights for stimulus scenario

Metric	Relative weight
Total spending	10
Total lane-km constructed	10
Peak-hour speed improvement	3
Offpeak speed improvement	3
Peak-hour delay reduction	3
Offpeak delay reduction	3
Cost-effectiveness of speed improvements	2
Cost-effectiveness of delay reduction	2
Reduction in congested travel (<45 kph)	10
Year-to-year stability of spending	3
Increase in number of trips	10
Cost-effectiveness of induced trips	2
Weighted peak accessibility improvement	10
Unweighted accessibility improvement	10

Table 6-11. Framework rankings for stimulus scenario

Rank	Ownership	Geographic Scale	Decision-Making Process		
			Resource Allocation	Resource Type	Resource Quantity
1	SOE	National	NPV	Tax Only	High
2	SOE	Regional	BCA	Tax Only	High
3	SOE	Regional	NPV	Tax Only	High
4	SOE	National	BCA	Tax-Toll Mix	High
5	SOE	National	NPV	Tax-Toll Mix	High
6	SOE	National	BCA	Tax Only	High
7	SOE	National	BCA	Tax Only	Medium
8	SOE	Regional	NPV	Tax-Toll Mix	High
9	SOE	Regional	BCA	Tax-Toll Mix	High
10	SOE	Regional	BCA	Tax Only	Medium
11	SOE	National	BCA	Toll Only	High
12	SOE	National	NPV	Toll Only	High
13	SOE	National	NPV	Tax Only	Medium
14	SOE	Regional	BCA	Toll Only	High
15	SOE	Regional	NPV	Toll Only	High
16	SOE	National	BCA	Tax-Toll Mix	Medium
17	SOE	Regional	BCA	Tax-Toll Mix	Medium
18	SOE	Regional	NPV	Tax Only	Medium
19	SOE	National	BCA	Toll Only	Medium
20	SOE	National	NPV	Toll Only	Medium

As with the mobility scenario, the majority (11 out of 20) of the top-performing frameworks for the stimulus scenario are nationally scaled state-owned enterprises, and in this case all of them have medium or high revenue rates. Again, this makes sense, as the national scenarios allow for agglomeration of resources to invest broadly, rather than dispersion of resources over distributed organizations which then have difficulty assembling them to meet the financial requirements of capital-intensive infrastructure projects.

6.3.2.4 Territorial cohesion

The territorial cohesion scenario emphasizes investment in the interior, predominantly rural areas of Portugal, as reflected in the performance metrics in Table 6-12. The top frameworks for the scenario are summarized in Table 6-13.

Table 6-12. Performance metric weights for cohesion scenario

Metric	Relative weight
Investment surplus relative to population in rural areas	10
Lane-km constructed in rural areas	10
Increase in number of trips	5
Cost-effectiveness of induced trips	5
Unweighted accessibility improvement	10

Table 6-13. Framework rankings for cohesion scenario

Rank	Ownership	Geographic Scale	Decision-Making Process		
			Resource Allocation	Resource Type	Resource Quantity
1	SOE	National	NPV	Toll Only	High
2	SOE	National	NPV	Tax-Toll Mix	High
3	SOE	National	BCA	Tax-Toll Mix	High
4	SOE	Regional	BCA	Toll Only	High
5	SOE	National	BCA	Tax Only	High
6	SOE	National	NPV	Tax Only	High
7	SOE	Regional	BCA	Tax-Toll Mix	High
8	SOE	Regional	NPV	Toll Only	High
9	SOE	National	BCA	Toll Only	High
10	SOE	Regional	NPV	Tax-Toll Mix	High
11	SOE	National	BCA	Tax Only	Medium
12	SOE	National	BCA	Toll Only	Medium
13	SOE	National	NPV	Toll Only	Medium
14	SOE	National	BCA	Tax-Toll Mix	Medium
15	SOE	Regional	BCA	Tax Only	High
16	SOE	Hybrid - 50%	NPV	Tax Only	High
17	SOE	Hybrid - 25%	BCA	Tax Only	High
18	SOE	Hybrid - 50%	BCA	Tax Only	High
19	SOE	Regional	NPV	Tax Only	High
20	SOE	Hybrid - 25%	NPV	Tax Only	High

Six of the top 10 and 10 of the top 20 frameworks are nationally scaled. The others are regional and hybrid. This, once again, reflects the problem that less-populated areas in the interior face when left to their own devices: they lack sufficient local resources to build infrastructure connections to other areas, relying instead on cross subsidies that can only be delivered either through a nationally or regionally scaled infrastructure-supplying organization or through direct transfers of resources via a "hybrid" approach. One caveat of this conclusion is to note the resource quantities of the top 20 frameworks. Sixteen of the top 20 require a high level of revenues. The explanation is that resources are directed first to populated areas with high levels of benefit; when there are few investment opportunities remaining in urban and suburban areas, the focus shifts to less-populated interior regions. A consequence of this phenomenon is that, under relatively more centralized regimes or programs that allow for cross subsidies, the interior regions will only receive investments for development during periods of overall high spending.

6.3.2.5 Urbanization

The urbanization evaluation scenario is, in some ways, the opposite of the territorial cohesion scenario. In this scenario, we seek to focus investments in the congested metropolitan areas and to relieve congestion in a cost-effective way. The metrics and weights for these objectives are summarized in Table 6-14, and the resulting top-performing frameworks in Table 6-15.

Table 6-14. Performance metric weights for urbanization scenario

Metric	Relative weight
Cost-effectiveness of peak speed improvements	10
Cost-effectiveness of offpeak speed improvements	5
Cost-effectiveness of delay reduction	10
Investment surplus in urban areas relative to population	10
Investment surplus in suburban areas relative to population	5
Reduction in congested travel (<45 kph)	5
Lane-km constructed in urban areas	10
Lane-km constructed in suburban areas	5
Weighted peak accessibility improvement	5

Table 6-15. Framework rankings for urbanization scenario

Rank	Ownership	Geographic Scale	Decision-Making Process		
			Resource Allocation	Resource Type	Resource Quantity
1	SOE	Link	n/a	Toll Only	Low
2	SOE	Link	n/a	Tax-Toll Mix	Low
3	Concession	Link	ROI	Toll Only	Medium
4	Concession	Link	ROI	Toll Only	High
5	Concession	National	ROI	Toll Only	Medium
6	Concession	National	ROI	Toll Only	High
7	Concession	Link	ROI	Toll Only	Low
8	Concession	National	ROI	Toll Only	Low
9	SOE	Link	n/a	Tax-Toll Mix	Medium
10	SOE	Link	n/a	Toll Only	High
11	SOE	National	BCA	Tax Only	Medium
12	SOE	Link	n/a	Toll Only	Medium
13	SOE	Regional	BCA	Tax Only	High
14	SOE	National	BCA	Tax Only	Low
15	SOE	Regional	BCA	Tax Only	Low
16	SOE	National	NPV	Tax Only	Medium
17	SOE	National	NPV	Tax Only	High
18	SOE	Municipal	NPV	Tax Only	Low
19	SOE	Regional	NPV	Tax Only	High
20	SOE	Link	n/a	Tax Only	Medium

In contrast to the territorial cohesion scenario, the urbanization scenario is best achieved with concession frameworks and link-based SOEs. Moreover, only 6 of the top 20 frameworks call for high revenue rates, indicating that intercity infrastructure within metropolitan areas can provide cost-effective service with relatively lower investment levels, so long as those investments are delivered using a framework that concentrates them in the urban areas.

6.3.2.6 Fiscal equivalence

Fiscal equivalence is the notion that various levels of government should exist (geographically and/or functionally), and each unit of government should tax in proportion to the benefit that it delivers. We approximate fiscal equivalence by seeking the frameworks which most closely match revenues to investments by type of land-use (urban, suburban, and rural). Table 6-16 summarizes the metrics and weights, while Table 6-17 summarizes the top frameworks.

Table 6-16. Performance metric weights for fiscal equivalence scenario

Metric	Relative weight
Matches of urban investment and population	10
Matches of suburban investment and population	10
Matches of rural investment and population	10

Table 6-17. Framework rankings for fiscal equivalence scenario

Rank	Ownership	Geographic Scale	Decision-Making Process		
			Resource Allocation	Resource Type	Resource Quantity
1	SOE	Regional	NPV	Tax Only	Low
2	SOE	Hybrid - 25%	NPV	Toll Only	Low
3	SOE	Regional	BCA	Tax Only	Low
4	SOE	Hybrid - 25%	BCA	Toll Only	Low
5	SOE	Municipal	NPV	Tax-Toll Mix	Medium
6	SOE	Regional	BCA	Toll Only	Low
7	SOE	National	NPV	Tax Only	Low
8	SOE	Regional	BCA	Tax-Toll Mix	Low
9	SOE	Municipal	NPV	Tax Only	Medium
10	SOE	Hybrid - 25%	BCA	Tax-Toll Mix	Low
10	SOE	Hybrid - 25%	NPV	Tax-Toll Mix	Low
12	SOE	Hybrid - 25%	NPV	Toll Only	Medium
13	SOE	Municipal	BCA	Tax Only	Medium
14	SOE	Regional	NPV	Tax-Toll Mix	Low
15	SOE	Municipal	NPV	Tax-Toll Mix	Low
16	SOE	Regional	NPV	Tax Only	Medium
16	SOE	Hybrid - 25%	NPV	Tax-Toll Mix	Medium
18	SOE	Municipal	NPV	Tax Only	High
19	SOE	Municipal	BCA	Tax-Toll Mix	Low
20	SOE	Hybrid - 25%	BCA	Tax-Toll Mix	Medium

Intuitively, the more decentralized frameworks (link-based, municipal, and hybrid-25%) should ensure that revenues and investments are geographically balanced. Raising and spending resources locally ensures a better match of revenues and investments. This expectation is seen in the results above, as 13 of the top 20 frameworks are link-based, municipal, or hybrid-25%. However, somewhat surprisingly, regional frameworks performed relatively well, with 4 of the top 10 and 6 of the top 20.

Fiscal equivalence is typically associated with fairness. However, it is rarely the most important factor to consider in designing a strategy development framework (or in designing a deliberate strategy), and it is almost never the *only* consideration. So, while fiscal equivalence is certainly an important factor, it is interesting—and potentially controversial—to note that the frameworks that perform well under this scenario rarely rank as strong performers in the other evaluation scenarios.

6.3.2.7 *Fiscal austerity*

The final scenario considered is driven by current events. The Portuguese public sector's high level of indebtedness, much of it driven by infrastructure-related debt and ongoing infrastructure deficits, suggests the potential need in the near future to scale back on further infrastructure enhancements, particularly that will generate continuing maintenance burdens and exacerbate deficits. Table 6-18 summarizes the performance metrics used to generate a set of "fiscally austere" frameworks, which are presented in Table 6-19.

Table 6-18. Performance metric weights for austerity scenario

Metric	Relative weight
Total investment	-10
Cost-effectiveness of speed improvements	5
Cost-effectiveness of delay reduction	5
Cost-effectiveness of induced trips	5

Table 6-19. Framework rankings for austerity scenario

Rank	Ownership	Geographic Scale	Decision-Making Process		
			Resource Allocation	Resource Type	Resource Quantity
1	Concession	Link	ROI	Toll Only	Low
2	Concession	National	ROI	Toll Only	Low
3	SOE	Link	n/a	Tax-Toll Mix	Low
4	SOE	Link	n/a	Tax Only	Low
5	Concession	Link	ROI	Toll Only	Medium
6	SOE	Municipal	BCA	Tax Only	Low
7	SOE	Municipal	NPV	Tax Only	Low
8	SOE	Hybrid - 50%	NPV	Tax-Toll Mix	Low
9	SOE	Hybrid - 25%	BCA	Tax Only	Low
10	SOE	Hybrid - 50%	BCA	Tax Only	Low
10	SOE	Hybrid - 25%	NPV	Tax Only	Low
12	SOE	Hybrid - 50%	BCA	Tax-Toll Mix	Low
13	SOE	Hybrid - 50%	NPV	Tax Only	Low
14	SOE	Hybrid - 25%	NPV	Tax-Toll Mix	Low
15	Concession	National	ROI	Toll Only	Medium
16	SOE	Hybrid - 25%	NPV	Toll Only	Low
17	SOE	Hybrid - 25%	BCA	Tax-Toll Mix	Low
18	SOE	Municipal	BCA	Tax-Toll Mix	Low
19	SOE	Hybrid - 25%	BCA	Toll Only	Low
20	SOE	Municipal	NPV	Tax-Toll Mix	Low

Not surprisingly, fiscal austerity is facilitated by low revenues, as 18 of the top 20 frameworks call for low tax and/or toll rates. Also, none of the top 20 are nationally scaled SOEs. Instead, these results suggest that lower levels of spending are most feasible with concession-based approaches (assuming that the government *only* opts to invest in those facilities which the market will build under a concession approach and does not engage in investments elsewhere in the network) and more decentralized SOEs (link-based and municipal, with some hybrid scenarios allowing for cross subsidies).

6.3.2.8 *Top performers*

Finally, for an integrated view of the performance of the alternative frameworks, we compute the average rank of each framework across the 7 scenarios, and in Table 6-20 summarize the top 20 frameworks. Interestingly, only 2 of the top 20 call for tolls. Recalling that advanced toll-based revenue collection technologies were one of the principal motivations for this thesis, it seems that, at least broadly speaking across the scenarios explored here, the status-quo (tax only and tax/toll mix approaches) perform well. However, at the same time, 7 of the top 20 call for regionally scaled SOEs, 7 for nationally scaled SOEs, 4 for municipally scaled-SOEs, 1 for a national concession, and 1 for link-based SOEs. The strong performance of the regional SOEs is not surprising, given that they moderate the advantages and disadvantages inherent in both the more centralized and decentralized approaches.

Table 6-20. Top performers across 7 evaluation scenarios, by average rank

Avg. Rank	Ownership	Geographic Scale	Decision-Making Process			Low Rank	High Rank
			Resource Allocation	Resource Type	Resource Quantity		
23	SOE	National	BCA	Tax Only	Low	34	14
23	SOE	Regional	BCA	Tax Only	Low	66	3
32	SOE	Regional	BCA	Tax Only	Medium	70	5
34	SOE	National	NPV	Tax Only	Medium	79	6
34	SOE	Regional	NPV	Tax Only	Low	90	1
35	SOE	National	BCA	Tax-Toll Mix	Low	65	18
36	SOE	Regional	NPV	Tax Only	Medium	78	9
36	SOE	Regional	NPV	Tax Only	High	87	3
36	SOE	National	BCA	Tax Only	Medium	77	4
37	SOE	Regional	BCA	Tax Only	High	86	1
39	SOE	National	NPV	Tax Only	High	92	1
40	SOE	Municipal	NPV	Tax Only	High	56	18
41	SOE	Municipal	BCA	Tax Only	Low	82	6
42	SOE	Municipal	NPV	Tax Only	Low	84	7
43	SOE	National	BCA	Toll Only	Low	73	21
43	Concession	National	ROI	Toll Only	High	80	6
44	SOE	National	NPV	Tax Only	Low	94	7
44	SOE	Regional	BCA	Tax-Toll Mix	Low	100	8
44	SOE	Municipal	NPV	Tax-Toll Mix	High	62	32
45	SOE	Link	n/a	Tax-Toll Mix	Low	97	2

While average performance across the 7 scenarios is a useful way to determine strong performers, it may be important for some decision makers to select frameworks that perform well across all 7 or, said differently, to select frameworks that do not perform poorly in any of the 7 scenarios. To reflect this interest in "robustness," we present in the top 20 frameworks ranked by the best low rank. Notably, the top performer is the same under this method of ranking as in the average ranking: nationally-scaled SOE with a low quantity of tax revenues allocated by benefit-cost analysis.

Table 6-21. Top performers across 7 evaluation scenarios, by best lowest rank

Lowest Rank	Ownership	Geographic Scale	Decision-Making Process		
			Resource Allocation	Resource Type	Resource Quantity
34	SOE	National	BCA	Tax Only	Low
56	SOE	Municipal	NPV	Tax Only	High
57	SOE	Hybrid - 25%	NPV	Tax Only	Medium
60	SOE	National	NPV	Tax-Toll Mix	Low
62	SOE	Municipal	NPV	Tax-Toll Mix	High
64	SOE	Municipal	NPV	Tax Only	Medium
65	SOE	National	BCA	Tax-Toll Mix	Low
66	SOE	Regional	BCA	Tax Only	Low
67	SOE	Municipal	BCA	Tax Only	Medium
67	SOE	Link	n/a	Toll Only	High
70	SOE	Regional	BCA	Tax Only	Medium
71	SOE	National	NPV	Toll Only	Low
71	SOE	Hybrid - 25%	BCA	Tax-Toll Mix	High
72	SOE	Hybrid - 25%	NPV	Tax-Toll Mix	High
73	SOE	National	BCA	Toll Only	Low
75	SOE	Hybrid - 25%	NPV	Tax Only	High
76	SOE	Municipal	NPV	Toll Only	High
77	SOE	National	BCA	Tax Only	Medium
77	SOE	Hybrid - 25%	BCA	Tax Only	Medium
78	SOE	Regional	NPV	Tax Only	Medium

The relative merits of the top-performing frameworks for the various scenarios presented in this section are important, but at the same time, it should be emphasized that very few of the frameworks lack credibility outright. That is, none of the 105 frameworks are outliers unworthy of consideration altogether. For most, investment strategies and physical networks emerge that deliver benefits along dimensions that are important for at least some stakeholders and which would be appropriate for at least some contexts. Of course, the trade-offs along other dimensions exist in every framework and are often substantial. In the next section, we summarize the overall trends and findings of these results while highlighting some of the gaps that the simulation model is unable to capture.

6.4 Discussion

This chapter began by presenting descriptive results of the simulation of 105 alternative strategy development frameworks. Next, we presented a method for ascribing value judgments to those results along with normative interpretations for several evaluation scenarios. Each alternative framework simulated includes 5 dimensions with variable values, and here we discuss outcomes differed along the geographic scale, ownership structure, and revenue type dimensions.

6.4.1 Geographic scale

Overall, as the geographic scale shrinks (that is, toward smaller organizations), the level of total investment likewise shrinks. Concurrent with that lower level of investment are more modest improvements in such performance metrics as speed, congestion reduction, and accessibility. At the same time, however, the restricted investment of decentralized frameworks leads to a closer, fairer match of revenues with expenditures (geographically) as well as more cost-effective overall investment patterns with regard to congestion reduction, accessibility improvements, and travel time savings. Investments in the inter-urban and rural areas do not offer the same value along these metrics as investments concentrated in metropolitan areas.

For the more centralized frameworks (national and regional scales), increases in the toll and/or tax rates for revenues lead to a relatively substantial subsequent increase in transportation investment. By contrast, the more decentralized frameworks (link-based, municipal, and hybrid) are relatively insensitive to increases in toll and/or tax rates. Small, modestly capitalized jurisdictions are unable to overcome the high costs of infrastructure investment even with modest increases in revenues; meanwhile, relatively wealthy jurisdictions can afford to make all the improvements available to them with a substantial amount of revenues leftover. In other words, adding resources to the decentralized frameworks does not increase the amounts allocated to transportation proportionally. Interestingly, along these lines, strong performance among large geographically scaled frameworks (national and regional) is associated with a low rate of revenues, while strong performance among small geographically scaled frameworks (link, municipal, and hybrid) is associated with a high rate of revenues.

As rates are increased, more jurisdictions are able to accumulate the funds necessary to afford infrastructure investments. However, it is unlikely that small jurisdictions would be able to tolerate the political cost associated with the high tax rates necessary for local infrastructure in modestly populated areas, and the high toll rates necessary to generate revenues for infrastructure enhancement would drive away traffic and revenue. Indeed, remote jurisdictions with little pass-through traffic stand to benefit most from larger geographic scales, while highly populated jurisdictions will see a net transfer of revenues to other areas.

This raises an interesting dilemma for the urban and metropolitan portions of the network. Under more decentralized frameworks, urban and metropolitan regions are able to invest extensively in inter-urban connections, resulting in some long-distance corridors along heavily populated areas such as between Lisbon and Porto. However, because they do not have to share excess revenues with other regions, they have more revenues available to devote to other areas of need, including internal transportation systems such as high-capacity urban transit systems.

6.4.2 Ownership structure

Along the ownership structure dimension, substantial differences are observed between the SOE- and concession-based frameworks. Concession frameworks, by design, select only those projects with an acceptable predicted financial return for the investor (and only do so using direct user fees). Simulation of concession-based frameworks replicates major portions of the actual real-toll concessioned network in Portugal, particularly the Brisa concession, which is the largest and most important concession, but also the metropolitan concessions of Grande Lisboa and Grande Porto. If the government restricted itself to these investments, the network of motorways in

Portugal would be much smaller and more concentrated in and around the populated areas, with the only long-distance corridor connecting Lisbon, Porto, and points between, with a likely extension to the Algarve. SOE frameworks, on the other hand, aggregate revenues through direct user fees and general taxes to select projects with acceptable social benefits, regardless of financial return. Naturally, the SOE frameworks invest much more extensively than concession frameworks, across all geographic scales, due to the lower barrier that social (i.e., travel time savings) represent relative to the financial rate of return criteria during project evaluation.

6.4.3 Revenue type

The simulation results generally suggested that general tax represent a preferred method of revenue generation, contrary to our hypothesis that user fees would be preferred. There are several reasons for the emergence of general tax revenues as a preferred revenue mechanism. First, tolls discourage travel, thereby reducing aggregate travel demand between municipalities. This has the effect of reducing the total number of trips, which reflects poorly under evaluation scenarios driven by economic development). Moreover, since toll-based frameworks reduce travel and congestion, improvements to the highway network are less cost-effective with regard to congestion reduction (i.e., there is less congestion to reduce). That said, toll frameworks do perform well under several specific evaluation scenarios, including fiscal austerity, urbanization, and environmental protection. In part, its strong performance under these scenarios is due to the coupling of toll-only frameworks with concession-based ownership structures.

Given the caveats with which general tax revenues emerged as the preferred revenue source (namely that the baseline levels of congestion under toll frameworks were lower, which hindered the ability of toll frameworks to score well with regard to cost-effective congestion reduction), we can examine the performance of only toll-based frameworks. Suppose, for example, that tolling is pursued for operational reasons (i.e., to improve flow and reduce congestion). In Table 6-22 we summarize the top 10 performers among toll and tax-toll mix frameworks. The nationally-scaled, BCA-driven, low revenue quantity frameworks again emerge as the best performers.

Table 6-22. Top performers among toll and tax-toll mix frameworks

Avg. Rank	Ownership	Geographic Scale	Decision-Making Process		
			Resource Allocation	Resource Type	Resource Quantity
35.3	SOE	National	BCA	Tax-Toll Mix	Low
43.3	SOE	National	BCA	Toll Only	Low
43.3	Concession	National	ROI	Toll Only	High
44.0	SOE	Regional	BCA	Tax-Toll Mix	Low
44.1	SOE	Municipal	NPV	Tax-Toll Mix	High
45.3	SOE	Link	n/a	Tax-Toll Mix	Low
45.4	SOE	National	NPV	Tax-Toll Mix	Low
45.4	Concession	National	ROI	Toll Only	Medium
46.4	SOE	Hybrid-25%	BCA	Tax-Toll Mix	High
46.7	SOE	Regional	NPV	Tax-Toll Mix	Medium

6.4.4 Interaction of dimensions

The simulation model allows us to consider of a wide range of alternative strategy development frameworks, and for each framework it generates performance metrics that matter to decision-makers and stakeholders alike, such as financial impacts, cost-effectiveness of speed improvements and congestion reduction, accessibility, environmental impact, and others. We can quantify the trade-offs of these important metrics, and using a variety of evaluation scenarios, we can determine which frameworks offer the greatest promise for achieving system-wide objectives.

Nonetheless, the simulation model does not tell the entire story. It offers only a partial picture of the implications of approaching strategy development in innovative ways; there are important gaps that the model does not capture (e.g., multi-modal investments and explicit consideration of freight traffic) and some phenomena relating to framework design and system performance that cannot be quantified at all (e.g., politically negotiated investment decisions, competency of organizations at varying scales to participate in infrastructure strategy development at all). In Chapter 7, we add these considerations through qualitative discussion of the alternative strategy development frameworks, exploring their implications through case studies and stakeholder analysis.

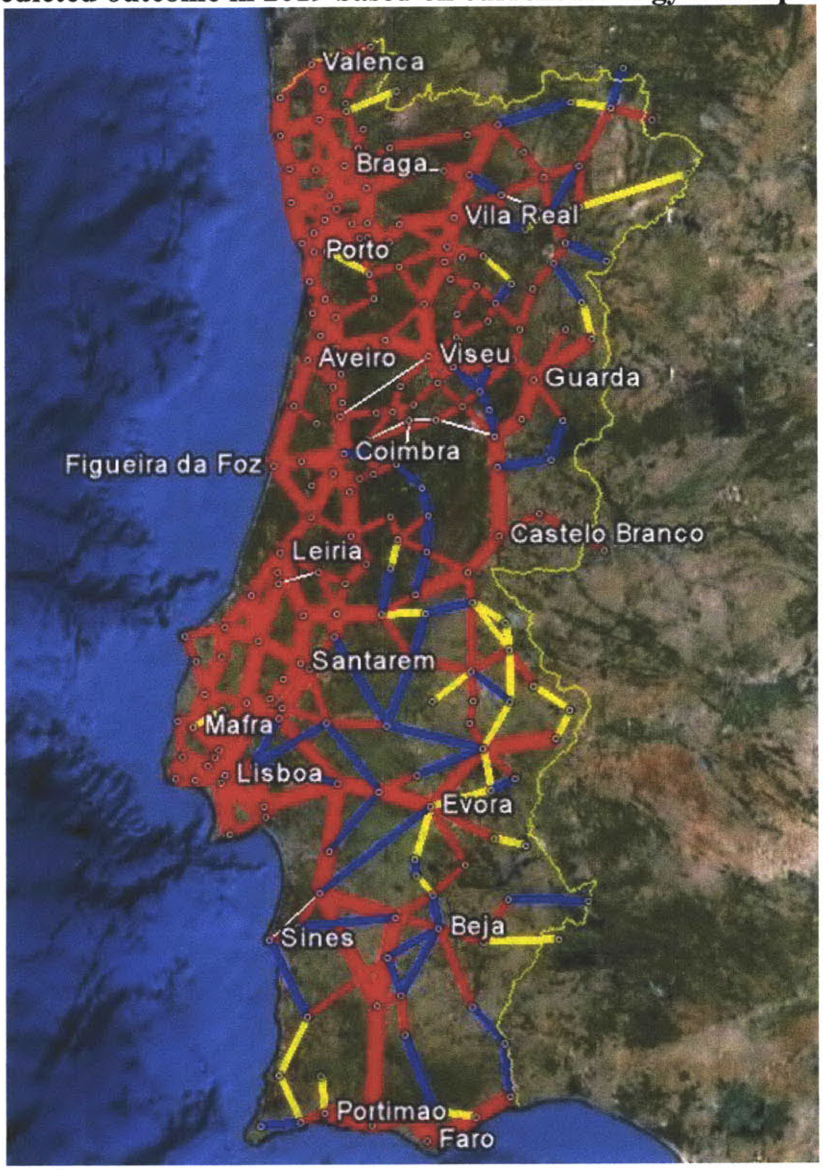
6.4.5 Future application

The simulation model was developed with a focus on examining the past evolution of infrastructure investments, revealing underlying emergent strategies, as a function of any of a variety of alternative frameworks. This chapter summarized results of these simulations of "parallel pasts." However, the same model can be used to examine the *future* evolution of infrastructure investments as a function of various strategy development frameworks. In this section we present an example of such an application to the future.

Below we present one simulation run, beginning in 2009, with the current-day intercity highway network of Portugal, looking out 10 years to the year 2019. The run is based on strategy development framework #1 (a nationally scaled state-owned enterprise with revenues derived in part from tolls and in part from taxes, allocated to projects each year on the basis of net present value). In addition, change in population, which is one of the key drivers of the simulation, is estimated for each municipality, with annual rates of increase or decrease in each of the next 10 years set equal to the average annual rate of increase or decrease for the past 10 years.

Figure 6-21 illustrates the network as it is predicted for the year 2019 based on the current strategy development framework, including most importantly the national geographic scale of decision making and the same level and types of funding as exist today. This network comes at a high cost of nearly €900 million per year, generates a 17% increase in VKT to over 38 billion, sees new construction of nearly 500 lane-km, and average peak-hour speeds of over 100 kph. Although difficult to validate a predictive model, some measures can be constructive. For example, the simulation predicts a total of 10,100 lane-km of high-speed "interstate" quality highways, which corresponds to approximately 1 lane-km per 1,050 residents, a ratio that is within 1% of the same ratio for the state of Florida based on 2005 data (FHWA, 2008).

Figure 6-21. Predicted outcome in 2019 based on current strategy development framework



According to the National Roadway Plan of 2000, Portugal's objectives for the road sector include "development of regional capabilities, reduction of the global cost of transport, improving travel security, accommodation of international traffic, and modernized network management." The deliberate strategy pursued to achieve these objectives is continual investment in the national road network, particularly to create stronger linkages between the interior and coastal regions. The investment patterns in Figure 6-21, however, show that despite broad investment in all parts of the country, almost every link in the Lisbon-Porto corridor is improved to high speed, with capacity enhancements throughout that corridor to relieve congestion on highly traveled links. The emergent strategy, as revealed by this investment pattern, will be one of accommodating the development of lower-density settlements as part of a continuous "megalopolis" stretching from Lisbon to Porto along the coast.

The emergent network predicted by the agent-based simulation reflects an underlying emergent strategy that could be characterized quite distinctly from the deliberate strategy as stated in the PRN 2000. For example, although the emergent strategy appears to develop regional capabilities and some international traffic, it strongly emphasizes improving the number, speed, and capacity of connections in the Lisbon-Porto corridor. Despite improvements in the interior of the country, the consequences of extensive investment in the coastal corridor will be to reinforce that region's dominance of the economic activities within Portugal, perhaps to the detriment of interior regions, despite better infrastructure connections among them. This is due to the phenomenon of preferential attachment, which leads to increasing growth within the already-dominant areas of a country or region.

Although not originally developed with the intent of being applied as a predictive model, the results of this section point in the direction of such an application. Moreover, the results can influence thinking about the efficacy of particular strategy development *frameworks* to achieve desired outcomes.

6.4.6 Model shortcomings

"All models are wrong. However, some are useful."[14]

The agent-based simulation model is, like all models, "wrong" in that it is an imperfect and incomplete representation of reality. It is "useful" in that it confirms some of our intuitions about how strategy emerges for transportation infrastructure networks under a variety of alternative frameworks, while helping us to understand the mechanisms that can explain both intuitive and unintuitive behaviors. Nonetheless, we can expand upon the conclusions afforded by analysis of the model results by considering qualitatively the omitted relationships among strategy development frameworks, system performance, and emergent strategies. This qualitative analysis is the subject of the next chapter.

6.5 References

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Federal Highway Administration (FHWA) (2008). *Highway Statistics 2005*. Available from www.fhwa.dot.gov. Accessed July 2009.

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[14] Attributed to George Box.

7 Qualitative Analysis of Alternative Frameworks

In this chapter we present three types of qualitative analysis of alternative strategy development frameworks to complement and extend the quantitative analysis of the simulation model from Chapter 6. First, in Section 7.1, we complement the simulation model results by analyzing the observed relationship between alternative strategy development frameworks and the performance of transportation infrastructure in a series of focused cases. The cases highlight empirical trade-offs along three key dimensions of alternative frameworks: ownership structure, geographic scale, and type of revenue. In Section 7.2, we extend the analysis by predicting qualitatively the consequences of two values that were not modeled: multi-modal institutional structures and multi-sectoral institutional structures. In Section 7.3, we analyze the stakeholders within the context of Portugal in order to understand more clearly the reasons for the existence of the strategy development framework currently observed there, the changes necessary to achieve an alternative framework, and the stakeholder behaviors we might observe under an alternative framework. Finally, we conclude in Section 7.4 with an integrated discussion of the quantitative and qualitative analysis of alternative frameworks.

7.1 Empirical cases

We begin with analysis of a series of focused empirical cases. The purpose of this analysis is to complement the simulation model results presented in Chapter 6 by relating the outcomes predicted there to observed evidence from the field. The cases were selected on several bases. First, we aim to highlight the contrasting consequences of distinct values along the same three key dimensions of an alternative framework that were highlighted in Chapter 6: ownership structure, geographic scale, and type of revenues. Secondly, we selected cases with sufficiently detailed information to allow us to draw conclusions about the relationship between a framework and its performance. Finally, we selected cases involving Portugal based in part on the availability of information and in part on a desire to connect the empirical results of the case analysis more strongly with the predicted results of the quantitative simulation.

We present a range of cases from throughout history that highlight the trade-offs of alternative ownership structures, geographic scales, and types of revenues. We begin by exploring infrastructure delivery under various ownership approaches, using as case illustrations the private turnpikes of the 19th-century U.S. and concessioned motorways of contemporary Portugal. Next, we discuss two contrasting cases of varying geographic scales in the delivery of infrastructure: European Union vs. Portugal. Finally, we discuss the role of revenues by examining the use of general taxes to fund France's extensive pre-revolutionary royal and military road network and the wide use of direct and indirect user fees in contemporary settings.

7.1.1 Ownership: public, private, or public-private?

In political economic theory, markets sometimes "fail," inviting public sector involvement, often through regulation and occasionally through direct ownership and/or administration of some economic activity. Typical sources of market failure include imperfect and/or asymmetric information, externalities, and natural monopolies. As discussed in Chapter 3, transportation infrastructure systems exhibit characteristics of natural monopoly due to the high costs and low mobility of infrastructure investments.

As a result, throughout history most transportation infrastructure has been provided by public authorities at varying geographic scales, most commonly with a military motive—that is, building roads to move soldiers and equipment over land to protect and/or solidify control over remote territories. Ancient Rome offers one of the most vivid illustrations of military motives driving extensive road construction. As Gibbon (1776) notes:

> [Roman highways] united the subjects of the most distant provinces by an easy and familiar intercourse; but their primary objective had been to facilitate the marches of the legions; nor was any country considered as completely subdued, till it had been rendered, in all its parts, pervious to the arms and authority of the conqueror.

Despite the propensity for public ownership and administration of transportation infrastructure, involvement of the private sector has been notable throughout history. Even in ancient Rome, the emperors and senators employed private contractors to construct and maintain many segments of the imperial highways (Laurence, 1999). Involvement of private contractors is very common to this day, and the spectrum of private involvement includes relatively less common approaches such as:

- Concession agreements, whereby the public owner leases a facility to the private builder for a defined period of time, in exchange for a revenue stream such as tolls or transfer payments based on traffic volumes, infrastructure availability, or other performance metrics.
- Fully private contracts, whereby a private infrastructure owner (supplier) provides a facility to private customers. Very few examples of this approach exist today, as discussed next.

A thorough examination of the history of infrastructure reveals many attempts to provide road and rail infrastructure either through purely private means or through franchise agreements with the public sector. Purely private efforts date at least as far back as the 18th and 19th century turnpikes of Great Britain and North America. Railroads in the U.S. were also built as private ventures in the 19th century and largely remain private, at least for freight, although it should be noted that government involvement was necessary in the granting of rights of way to railroad companies. Contemporary examples of large-scale private infrastructure include the 1995 Dulles Greenway in Virginia, the 2000 Camino Columbia Toll Road in Texas, and the 2004 Las Vegas Monorail. Such purely private examples, however, remain rare. Regulation is evident in almost every "private" infrastructure example; moreover, competition from the public sector usually leads to at least some degree of public ownership. The Camino Columbia, for example, went bankrupt, was auctioned to a bank and ultimately sold to the state of Texas. The Dulles Greenway remains a unique example of a successful private road in the U.S.

Public-private partnerships have been popular throughout history, with their relative popularity ebbing and flowing with changing politics. Many modern day governments and private corporations have developed infrastructure through public-private franchise agreements, including extensive networks in Western Europe (the UK, France, Spain, and Portugal) as well as experiments with concessions in Mexico, Chile, Brazil, Thailand, Vietnam, Australia, and elsewhere. The concept, however, is quite old. A rather early and local example is the Charles

River Bridge, built under contract between a private venture and the Commonwealth of Massachusetts in 1785 to connect Boston and Charlestown. Under the terms of the original contract, the private venture would build the bridge and own the right to collect tolls on it for 70 years, after which time ownership would to revert to the Commonwealth (*Charles River Bridge v Warren Bridge*, 1837). As often happens even in contemporary concession agreements, however, the Commonwealth built a competing bridge nearby and was forced, after considerable litigation, to renegotiate the original terms of the concession and compensate the private venture for lost revenues.

In this section we present two more detailed cases describing experiences with these less common approaches to infrastructure ownership. First, we discuss 19th-century American turnpikes as an example of a privately provided intercity infrastructure system. Next, we discuss today's concession-based intercity motorway network of Portugal.

7.1.1.1 19th century private turnpikes in the U.S.

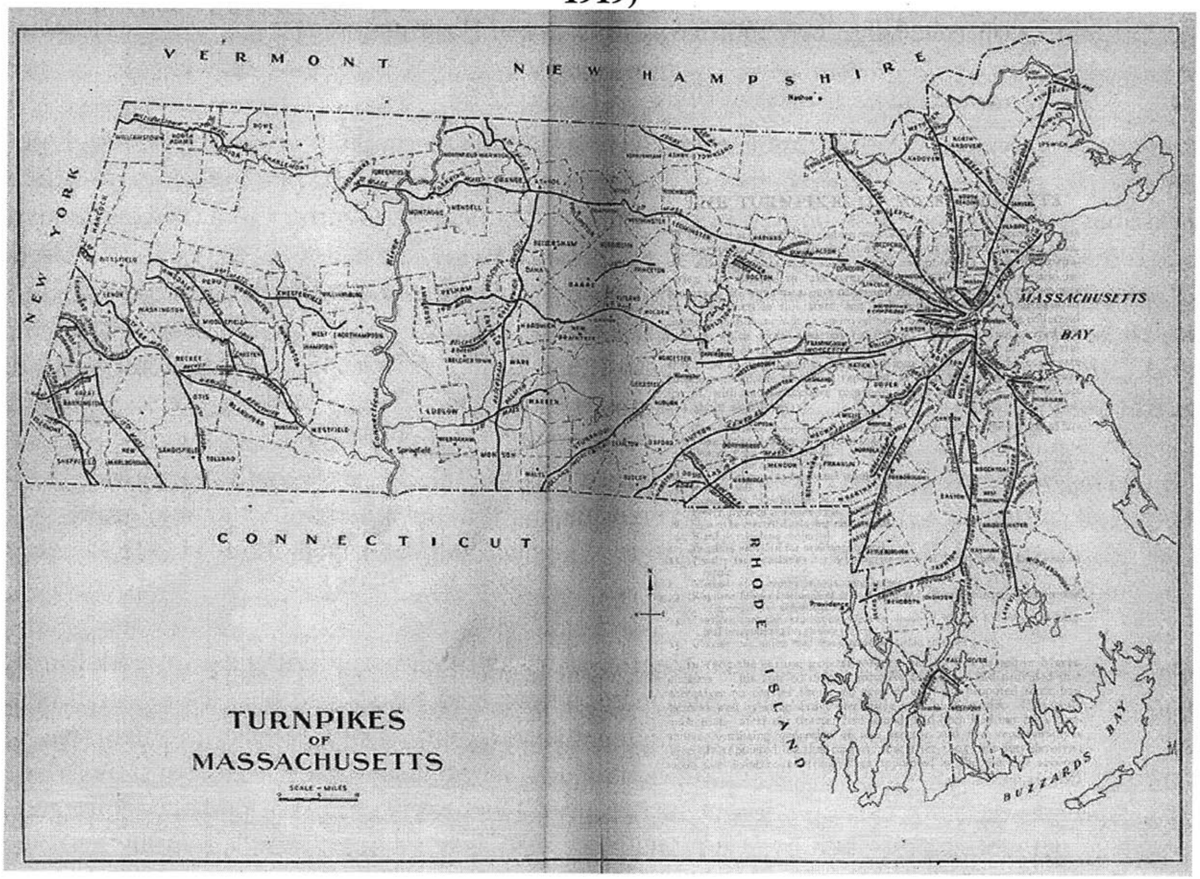
Klein and Majewski (2006) chronicle the private toll road ("turnpike") era in the eastern U.S. in the early 19th century. The basic business model was for a group of private investors to form a stock-financed corporation to build a bridge and/or road facility. Contrary to a conventional stock corporation, however, turnpikes rarely paid cash dividends, nor were they expected to do so. Toll receipts were sufficient to cover operating costs and in some cases return some dividends, but in most cases it was "generally known… that turnpike stock was worthless" (Wood, 1919). For example, Wood comments on the Blue Hill Turnpike which connected Milton and Randolph, Massachusetts (a distance of about 6 miles):

> The Blue Bill Turnpike was built at a cost of $78,300. To retire that road at the end of twenty years and keep it in repair during that term meant that annual gross earnings of $13,800 were to be secured. They actually averaged about $1,392, with $2,450 for a maximum.

Most turnpike investors were not enticed by the prospect of earning dividends. Instead, for the most part, stock purchasers were the landowners whose land values and businesses could benefit from the existence or improvement of an adjacent road facility. The free-rider problem was overcome by a public-mindedness among Americans, particularly in the Northern states, that led to widespread voluntary participation in such ventures as turnpikes corporations, encouraged through social tactics described by Klein and Majewski as anywhere from "charming and amusing" to "shrewd." The basic model of private turnpikes, then, could be summarized a sort of voluntary tax or impact fee in the form of stock purchases among indirect beneficiaries of infrastructure improvement (adjacent and nearby businesses and landowners), with facilities managed privately by the turnpike corporation which paid for a facility's operating costs through user tolls.

Lay (1992) claims that the private turnpike era produced an extensive network of road facilities, including 4,000 km in Pennsylvania and 7,000 km in New York. Klein and Majewski count 1,562 turnpike companies from Virginia to New Hampshire over the period 1792-1845. Many of the turnpikes built during this era served as the foundations for later development of highways. Examples include one of the first turnpikes of the era, the Little River Turnpike, many of whose remains today lie beneath Route 50 in northern Virginia and the Lancaster Turnpike connecting Lancaster with Philadelphia in Pennsylvania. They linked communities, sometimes over surprisingly long distances, enabling enhanced trade and travel and allowing for growth and settlement of new territories. These private ventures were often able to identify long-distance corridors with potential for high volumes of trade and traffic, piecing together segments of existing roads for improvement or identifying new routes altogether, such as the Pittsburgh Pike which connected Pittsburgh and Philadelphia. Often, these independent ventures formed networks that one might otherwise expect were the result of central management, as illustrated by the network of private turnpikes in Massachusetts in Figure 7-1.

Figure 7-1. Private turnpikes of Massachusetts, 19th century (reproduced from Wood, 1919)



The infrastructure developed during the turnpike era faced many challenges and drawbacks relative to conventional public provision of roadways. Many of the ventures failed before they were able to open a facility for operation; Klein and Majewski estimate at least 1/3 of ventures failed. Many others went bankrupt. Almost all of them faced high costs in collecting and enforcing toll payment; evasion was relatively common, especially for facilities with few toll collection points. Regulation and competition from the public sector represented another challenge. States maintained various standards for enforcement of the safety and suitability of the road infrastructures, while many invested in competing facilities. Such competition from the state was balanced, however, by the fact that some states participated in the purchase of stock in turnpike companies.

Today's experience in private road facilities is far less extensive. The public sector controls the process of selecting the location and alignment of various facilities, the funding scheme, the timing of construction, the decision of whether to collect tolls, and, if tolls are collected, whether to collect them directly or through a concession agreement with a private operator. Fully private roads such as the Dulles Greenway in Virginia and the Camino Columbia Toll Road in Texas face far greater barriers to entry than their turnpike forebears, principally in the form of competition from the states. The experience of private ownership from both eras informs our judgment of alternative strategy development frameworks. Lessons include the following:

- Privately provided infrastructure does not necessarily result in lower quantities of construction; to the contrary, due to the speculative nature of private enterprise, a framework which allows and encourages private development may actually result in a *greater* quantity of infrastructure than a framework of public ownership. Although some segments are destined for bankruptcy, experience of centuries past indicates that coherent networks are nonetheless likely to emerge from private, voluntary investment.
- Inevitably, some private ventures fail due to a variety of factors: uncertainty about future demand, competition from other investments, poor management, unclear or restrictive regulatory frameworks, expropriation, and others. The uncertainty associated with frequent infrastructure failures would potentially result in a misallocation of infrastructure-associated investments such as business and residence location.
- Failed infrastructure investments would either revert to some other land use or have ownership assumed by the state. When the latter approach is chosen, it represents a creeping state involvement that could lead to widespread public ownership and administration of infrastructure. This, combined with competition from other modes (canals at first and eventually railroads), effectively ended the private turnpike era in the U.S.
- "Rational" networks can and do form under private management, often connecting far-flung points that might otherwise be expected to emerge only under central, publicly managed direction.

7.1.1.2 Contemporary motorway concessions in Portugal

If the private turnpike era represents an experiment in largely private road provision, and the 20th century represents an experiment in largely public road provision (at least in the U.S.), then the relatively recent widespread adoption of concession agreements in Western Europe represents an attempt at finding a public-private middle ground that can, in theory, maximize the benefits of both approaches while attempting to avoid the disadvantages. Concessions have been in use for several decades in France, Spain, the United Kingdom, Portugal, and elsewhere in Europe and other parts of the world, but in this section we focus discussion and analysis specifically on the experience of Portugal's road-based concessions since 1990.

The basic structure of a concession approach to infrastructure development is for the government to grant exclusive rights to a private entity to build, operate, finance, and/or maintain a portion of an infrastructure network for a fixed period of time and to collect tolls or other user fees from the facility. In exchange, the public sector sometimes receives an upfront payment for the lease of those rights or simply enjoys the delivery of infrastructure free from constraints of state budgets.

Portuguese concessions vary by size and type of concession contract. By far the largest concessionaire is a rather unusual one: Estradas de Portugal (EP), which until recently was the highways agency of the national government, but now is a state-owned enterprise (SOE). However, this arrangement is unusual in that EP's concession is not a profitable venture; it relies on fuel taxes and heavy borrowing to meet the requirements specified in its agreement with the state. Requirements include maintenance of all existing intercity highway infrastructure in Portugal and construction of new links as directed by the government and in accordance with the 2000 National Road Plan. Concession agreements with non-SOEs are more typical of concession agreements found elsewhere in the world; therefore, we ignore the EP "concession" in this discussion and focus on the more conventional concessions with private companies.

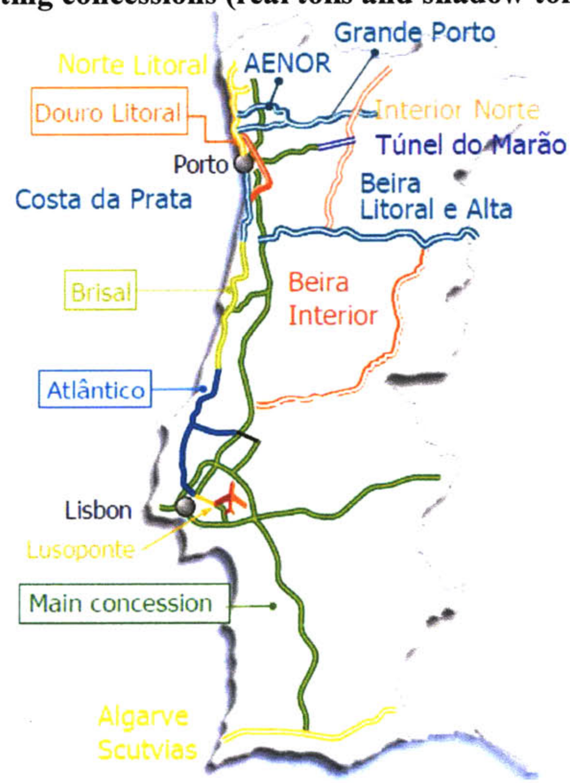
Currently, other than EP, there are 15 highways operating under concession agreements in Portugal: 8 "real toll" concessions and 7 "shadow toll" concessions. The government and its private partners are currently in the process of developing 9 new concession agreements. Information about the concessions is summarized in Table 7-1 and depicted on the map in Figure 7-2. Table 7-2 summarizes the proposed new concessions, which will be both real and shadow tolls, each to be decided by the government.

- *Real toll concessions*. Under a real toll concession agreement, the concessionaire sets toll rates (according to provisions in the contract and subject to regulatory approval) and collects tolls directly from motorists in order to fund its operations and repayment of debt incurred for the construction of the facility.
- *Shadow toll concessions*. Under a shadow toll agreement, known in Portugal by the acronym SCUT ("Sem Costa para os UTilizadores," or without cost to users), the central government makes transfer payments to concessionaires based on the amount and mix of traffic recorded on their segments of the roadway network.

Table 7-1. Summary of concessions in Portugal[15]

Type of Concession	Name of Concession	Length (km)	Average Annual Daily Traffic (AADT) (2008)	Revenues (2008) (€ millions)	Year granted
Real Toll	Brisa	1,093	22,971	530.4	1972
	Brisal	93	6,073	14.2	2004
	Douro Litoral	53	n/a	n/a	2004
	Atlântico	170	18,689	65.3	1998
	AENOR	174	9,396	48.3	1998
	Grande Lisboa	64	n/a	n/a	2004
	Lusoponte	24	86,579	64.5	1998
	Túnel de Marão[16]	30	n/a	n/a	2008
Shadow Toll (SCUT)	Grande Porto	64	n/a	Shadow-tolled motorways do not directly generate revenues	1998
	Costa da Prata	108	n/a		1998
	Beiras Litoral e Alta	174	n/a		1998
	Beira Interior	178	10,650		1998
	Norte Litoral	119	n/a		1999
	Interior Norte	158	n/a		1998
	Algarve	134	n/a		1998

Figure 7-2. Existing concessions (real tolls and shadow tolls) in Portugal



[15] Various sources: APCAP (2008), Mota Engil (2007), InIR (2010)

[16] Under construction as of 2010

Table 7-2. Summary of new concessions[17]

Name	New Construction (km)	Operations of existing (km)	Capital cost (€ millions)	Contract signed	Expected completion
Douro Interior	261	11	520	Nov 2008	Nov 2011
AE Transmontaña	130	56	500	Nov 2008	Jul 2011
Baixo Tejo	32	38	256	Jan 2009	Jan 2011
Baixo Alentejo	344	0	392	Dec 2008	Jan 2012
Litoral Oeste	85	24	273	Feb 2009	Feb 2010
Algarve Litoral	0	86	400	n/a	Dec 2010
AE Centro	184	185	740	n/a	n/a
Pinhal Interior	173	229	774	n/a	n/a
Alto Alentejo	n/a	n/a	n/a	n/a	n/a

Concession contracts specify a variety of conditions that the concessionaire must meet, including minimum maintenance performance levels, parameters for the toll increase schedule, and triggers for facility expansion (e.g., from 2 to 3 or from 3 to 4 lanes in each direction once average daily traffic counts exceed certain thresholds). In Portugal, the typical concession contract is for 30 years, although some have been tendered as variable-length concessions and most have been renegotiated before expiration of the term due to changing political conditions and governmental requirements, usually leading to compensation of the concessionaire (Viegas and Fernandes, 2005; InIR, 2009).

The fundamental advantage of a concession agreement is the ability to contractually transfer risk from the state to private entities better equipped to manage it. These risks include: construction and operating/maintenance risks, and, if properly structured, demand (or revenue) risk. Another commonly cited advantage is the ability to tap private capital for investments that the public sector cannot currently afford. Engel, et al. (2007) dismiss this advantage by pointing out that governments merely trade future toll revenues for a highway investment today such that there is no net advantage over the long-term. However, the relatively short-term nature of politics suggests that, when budgets are tight and state borrowing difficult, governments will turn to the private sector to relieve the pressure.

Disadvantages to the concession-based approach taken in Portugal have been chronicled by Viegas and Fernandes (2005). Perhaps the biggest disadvantage was the use by the government of minimum-revenue guarantees together with the shadow toll mechanism. Minimum-revenue guarantees are mechanisms that allow the public and private entities to share demand risk. If demand is too low, the state will provide a subsidy to the private company; if demand is higher than expected, however, the state will share in the excess profits. With a shadow toll, however, the state is contractually obligated to make payments to the concessionaire on behalf of the users, which is a burden on the general budget. When taken together with a minimum revenue guarantee, a shadow toll will always have a bidder. Thus the state loses its ability to discriminate between worthy and unworthy projects: with shadow tolls, the market (meaning the bidding concessionaires) fails to give a reliable signal as to whether an investment is worthwhile.

[17] Compiled from MOPTC (2009); information current as of December 2009.

Fully toll-based concessions that transfer the majority of demand risk to the private party result in lower quantities of investment in infrastructure. The state can propose a range of projects, but without the appropriate safeguards, private bidders will not participate. As demonstrated in the concession frameworks simulated in Chapters 5 and 6, the result is a much slimmer network where investments are devoted to high-traffic links and regions with high likelihood of acceptable financial returns. Interestingly, a concession-based approach will sometimes lead to less infrastructure than even a fully private approach, because the shareholders in a fully private framework can enjoy other benefits (e.g., if they own land near the facility). Concession investors, on the other hand, are not necessarily local and do not enjoy a similar level of indirect benefits; they therefore demand higher rates of return. This reduces the attractiveness to private participants of many potential investments.

Concessions also raise the problem of the "cash cow." If only the profitable links in a network are offered to private concessionaires, then the state must maintain the remainder of the network with general tax funds. The concessionaire's success, however, often depends on the proper maintenance and expansion of the complementary network as a feeder to the profitable trunk lines; maintenance by the state of these portions of the network represents an indirect but essential subsidy.

Relative to publicly administered road networks, concession-only networks would be modest in extent, and the public sector would enjoy zero or even negative financial advantage. A private network which is built by local landowners, by contrast, is likely to match or even exceed a public network in extent and connectivity. However, the problem of competitive/redundant facilities, bankruptcy, and non-uniform standards may be undesirable outcomes.

7.1.2 Geographic scale: global or local?

Transportation infrastructure providers exist for a range of geographic scales, regardless of ownership structure. For example, the private turnpike companies in the U.S. assembled projects of various scales, from the small and local to the rather extensive (e.g., the Pittsburgh Pike from Pittsburgh to Pennsylvania). Concessions likewise range in size, for example within Portugal from the 50-km Douro Litoral concession to the nearly 1,100-km Brisa concession. Public entities likewise exhibit a broad range of scales; consider, for example, the diversity of sizes and populations among the U.S. among the 50 states. Private infrastructure can take a range of scales, traversing political boundaries where appropriate and feasible, while the scale of public and concessioned transportation infrastructure under a single owner typically is limited by political boundaries of states and nations.[18] Throughout history, governments have experimented with a wide range of geographic scales, from the miniscule to the vast, sometimes opting for federalist approaches combining two or more scales for resource collection and allocation.

Identifying cases that reflect either "local" or "global" approaches to provision of infrastructure is an exercise in relativity. For example, Portugal's approach to infrastructure strategy development is global from the perspective of a municipality within Portugal, but local from the

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[18] Notable exceptions include multi-state and multi-national organizations which own infrastructure, along with a joint, cross-jurisdictional mandate to maintain and operate it—for example, the Port Authority of New York and New Jersey.

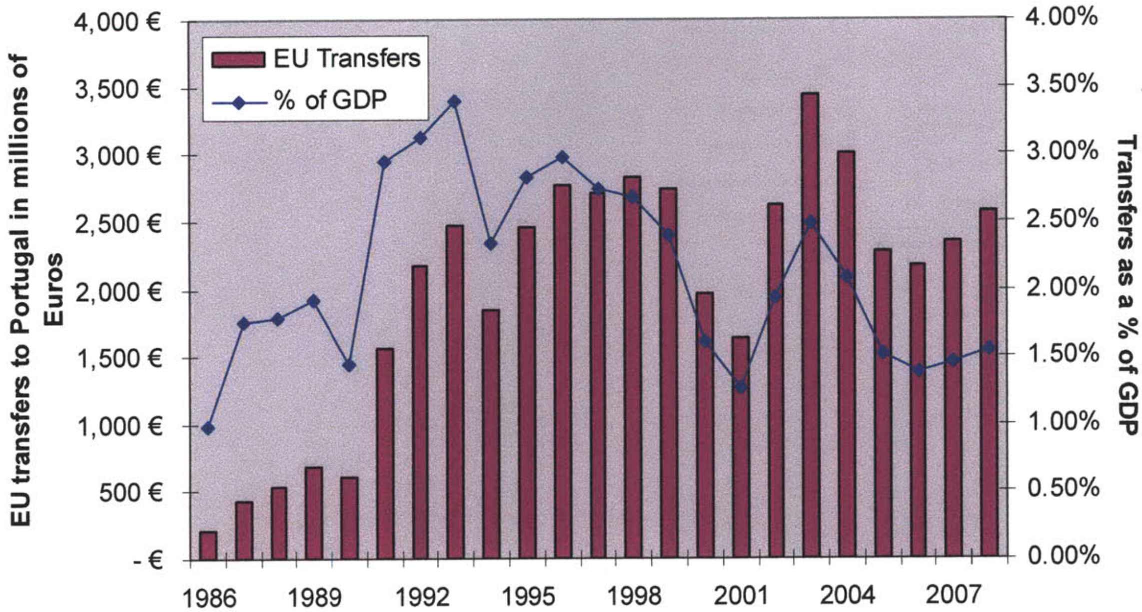
perspective of the European Union (EU). Moreover, Portugal's approach can simultaneously be viewed as highly federalist (because it participates in the shared decision-making of the federated EU) and highly unitary (because within Portugal the central government and the nationally scaled organizations it owns are effectively the only decision-making authorities). In this section, we discuss the contrasting infrastructure strategies of the EU and of Portugal. The selection of these two cases recognizes the point-of-reference dilemma by characterizing the EU and Portugal as, respectively, global and local *relative to one another*.

7.1.2.1 Global transportation strategy development: the EU

The purpose of this discussion is twofold: to describe the mechanisms used by the EU to develop and implement infrastructure strategies and to discuss the implications of an EU-dominated approach to strategy development for the shape and performance of Portugal's infrastructure systems. Elements of the EU's deliberate strategy include an infrastructure plan, financial incentives, redistribution of taxes for infrastructure development, and creation of transnational institutions to facilitate cooperative investments in long-distance infrastructure. If successfully implemented, the EU's deliberate strategy would have consequences specifically for Portugal including a relatively higher level of investments than that which is currently obtainable, questionable financial sustainability, and projects of dubious local benefit.

Portugal joined the EU in 1986. Today, the EU is a federation of 27 autonomous member countries with the objective of regional integration through standardized laws and regulations, lower barriers to trade, and investment in infrastructure corridors with broadly scaled benefits. One of the key mechanisms the EU uses to achieve these objectives is inter-governmental transfers. At the time of its accession, Portugal's economic performance was below the EU average, making it eligible for subsides for economic development, largely through investment in infrastructure. Portugal's infrastructure "building boom" in the 1990s and early 2000s was driven in part by financial support from the EU in the form of direct grants, largely for motorways, urban public transit, and rail improvements. Although support continues, the levels of subsidy have declined as a percentage of GDP since the 1990s. Figure 7-3 summarizes this trend, depicting net EU transfers to Portugal and transfers as a percentage of GDP from 1986 to 2008.

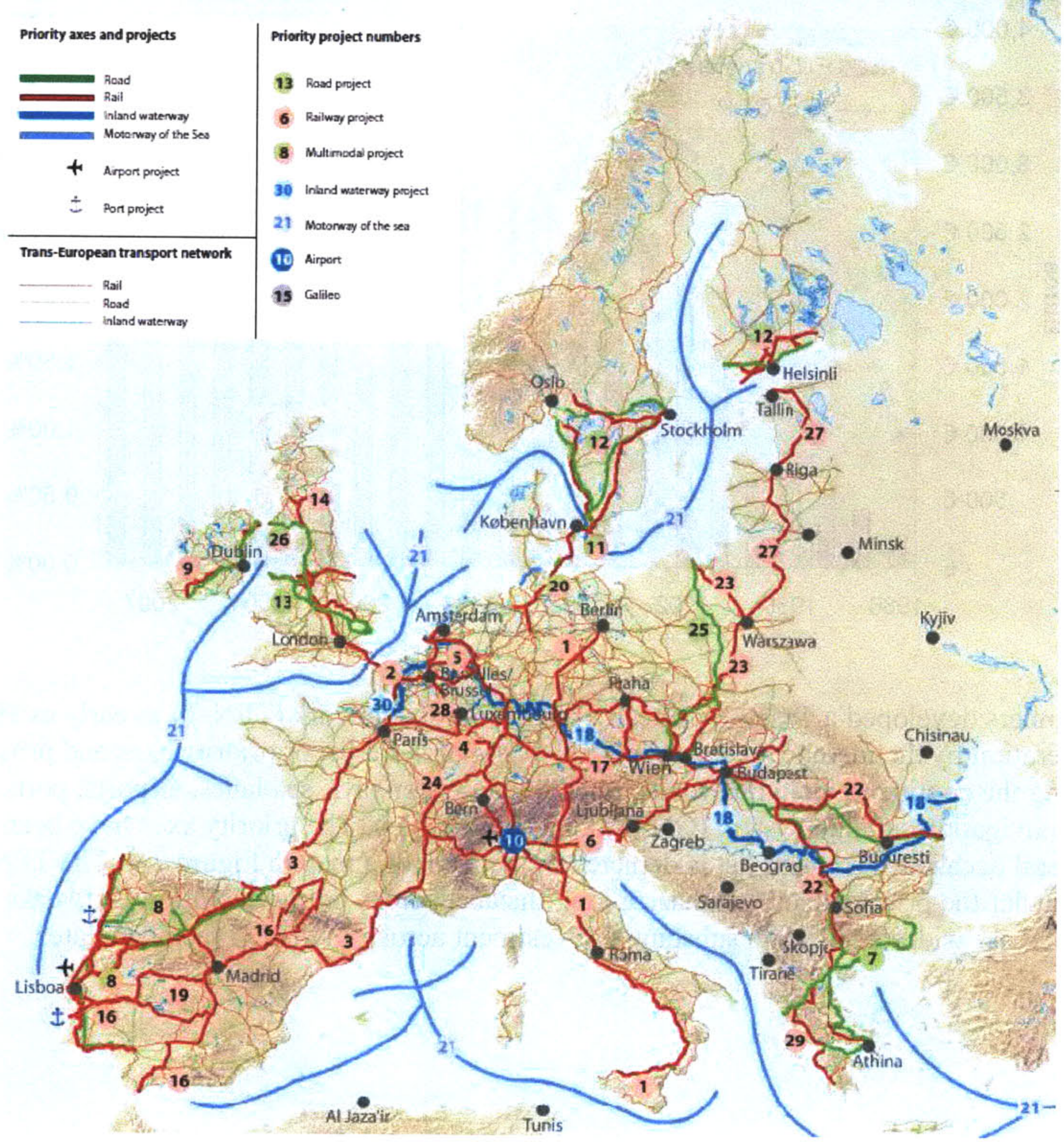
Figure 7-3. EU net transfers to Portugal (all sectors), 1986-2008[19]



EU planners developed a Trans-European Transportation Network (TEN-T) as early as 1994 for consideration by the member states. The TEN-T comprises a list of priority axes and projects spanning the continent, including roads, rails, inland waterways, sea lanes, airports, ports, and a global navigation satellite system (GNSS) known as Galileo. The priority axes have been refined on several occasions; a recent list is depicted in the form of a map in Figure 7-4. The TEN-T, and in particular the priority axes, emphasize long-distance, cross-border facilities. Networks identified are widespread, with substantial investment across all the EU member states.

[19] Figure computed based on transfers data from EU (2008) and GDP data from Eurostat (2010).

Figure 7-4. Trans-European Transportation Network (TEN-T) priority axes and projects[20]



TEN-T is, essentially, a *plan* reflecting an underlying deliberate strategy. However, we argue that the actual strategy that will emerge for Europe depends more on the framework within which the investments in the plan are pursued than on the plan itself. For most of its existence, the EU has lacked the institutional legitimacy to coerce investments, relying instead on financial incentives. That said, the incentives for TEN-T infrastructure are modest, with EU-provided funds accounting for less than 30% to the total TEN-T price tag of about €700 billion (EC, 2003a). The majority of funding (> €400 billion) is expected to be contributed directly by the member states.

In line with its objective of regional integration, the EU has provided incentives for Portugal to create stronger linkages with Spain, principally via development of a new HSR network. RAVE,

[20] Reproduced from EC, 2003b.

the Portuguese SOE responsible for developing the HSR network, projects completion of a Lisbon-Madrid link by 2013, followed by a link between Lisbon and Porto, connecting north to Vigo, Spain in 2015. The total investment required for the HSR network is substantial, estimated at nearly €9 billion in 2008, but the EU contribution is nearly 20% and the Portuguese government's contribution will be 36% (RAVE, 2008). The remainder of the investment will be funded privately through a series of build-operate-transfer agreements, but the EU will indirectly support much of the debt portion of the private financing with loans from the European Investment Bank (EIB).

In recognition of the challenges facing implementation, a series of EU policy reports laments the lack of coordinated investment in the priority axes and a continuous lag behind the target dates for implementation of improvements (e.g., EC, 2003b, EC, 2003c and EC, 2001). They suggest structural changes to the funding sources and institutional structures (i.e., changes to the strategy development framework) in order to align the EU's capabilities more closely with its objectives. Through these recommendations, we can observe the types of approaches that would be preferred by the EU and expected to allow it to more readily achieve its objectives under a more centralized strategy development framework.

Currently, the EU's revenue sources are limited to general taxes, including an EU-wide value-added tax (VAT), taxes on sugar, and mandatory contributions from member states' general budgets in proportion to national income levels. With the funding levels of the past two decades, TEN-T has not kept pace with its targets, leading a recent EC memo to conclude that innovation in funding is necessary. The memo refers to public-private partnerships and improving the efficiency of project delivery as options for increasing funds, but concedes that, in the end, "It is hard to see how the Union will be able to escape a debate on a substantial increase in the Community funds given over to building the TEN-T" (EC, 2003b). In short, given more power, it is clear that successful pursuit of its objectives would require the EU to increase its share of resources for investment in transportation infrastructure by raising taxes, increasing user fees, and/or competing more successfully for allocation of resources from other areas of the EU budget.

A series of policy papers identifies institutional changes that can increase the likelihood of the EU delivering on its TEN-T plan. Examples suggested include more "transnational" entities to coordinate investments. A current example of such an entity is High Speed Spain-Portugal (Alta Velocidade Espanha-Portugal, or AVEP), the collaborative body overseeing the development of a HSR link between the two countries.

According to an EU-commissioned report (SDG, 2009), the EU invested €4.22 billion in Portugal (most of it in TEN-T projects), nearly half of the total €9.13 billion in capital spending on transportation infrastructure, between 2000 and 2006. The European Investment Bank contributed an additional €6 billion in financing over the same period. What would be the role of Portugal as a decentralized unit within an even more centralized strategy development framework for the EU? Clearly, the role is diminished. A greater share of the Portugal's resources would be devoted to the EU for investment in infrastructure that meet EU-wide objectives; meanwhile, the country would be compelled to participate in more multi-national organizations (principally with Spain, the only nation with which it shares a land border) to coordinate the delivery of projects decided and pursued by the EU.

Although much of Portugal's financial contribution to the EU would be returned in the form of infrastructure investments (likely more than the country contributes, given its relatively weak connections with the rest of the EU), it remains unclear whether the EU's preferred investments and their phasing would align with purely domestic preferences. The influence of the EU on the development of Portugal's HSR network is an example of unclear transnational benefits likely driving investment decisions. The HSR example illustrates the potential problem of aligning EU preferences and Portuguese preferences. In some instances, preferences may be more closely aligned, such as the investment in a new airport for the Lisbon metropolitan area. Under more centralized EU control, however, alignment of benefits would be an ongoing challenge; moreover, given the likelihood of EU expansion and relatively smaller financial transfers to Portugal for infrastructure investment, an increasingly difficult one.

Another challenging impact of greater EU involvement in Portugal's infrastructure strategy development is financial sustainability. Many of the transportation infrastructure projects developed in the 1990s and 2000s were supported by EU funds and/or EIB loans, including major expansions of the urban transit systems in Lisbon and Porto, shadow-toll motorways, the Vasco da Gama Bridge in Lisbon, and the proposed HSR system and new Lisbon airport. Although the EU contributions were modest, they were sufficient to entice high levels of infrastructure investment by Portugal, much of it financed through debt. Today, these investments represent a major debt service challenge for Portugal. As Viegas and Fernandes (2005) state in reference to the shadow toll regime (although the lesson could be applicable across the transportation infrastructure sector as a whole): "the scale of the programme was over-ambitious and did not test both the need for this total coverage of territory in 10 years, and the possibility to pay the corresponding concession rents without excessively affecting the yearly budgets." The revenues needed to pay shadow-toll concessionaires alone will exceed €1 billion in 2010, substantially more than the amount dedicated to the road sector from fuel taxes.

The financial incentives of the "federalist" approach to infrastructure strategy development between the EU and Portugal led, in part, to overinvestment. Under a hypothetical framework of even greater centralization, with the EU directing a greater portion of Portugal's infrastructure investments, it is unlikely that over-investment could have been avoided. Particularly given the multi-modal nature of the TEN-T together with the dense concentration of investments it envisions for the Iberian peninsula, it is doubtful that, given even more control, the EU would have scaled back. However, by the same token, with more control, the EU would be more likely to service the long-term financial requirements of the initial investments rather than leaving Portugal to fund the obligations on its own.

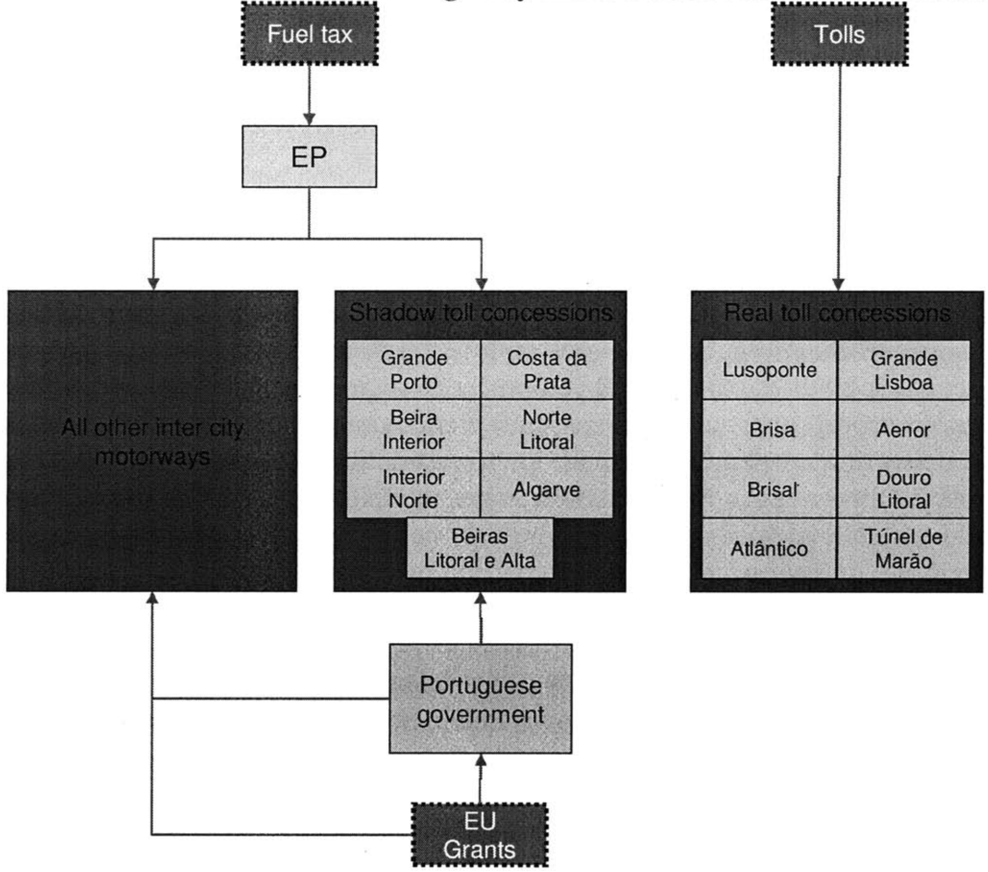
7.1.2.2 Local strategy development: Portugal

Portugal's domestic transportation infrastructure strategy is developed largely by the central government in a uni-modal fashion. Examples of documents reflecting the central government's deliberate strategy include the National Road Plan of 2000 (PRN 2000) and the Strategic Orientations for the rail sector. The objectives of each of these strategies is to improve the competitiveness of Portugal within the EU by creating better internal linkages and improving the quality of links that facilitate international trade. In this section we contrast the structure and approach of purely domestic infrastructure strategy development with that of the EU, and we describe the consequences of this more local approach. The local framework discussed here corresponds with the nationally scaled frameworks presented in Chapter 6 (i.e., frameworks 1-18 from the complete list of alternative frameworks in Appendix 2).

The first and most noticeable outcome of a more decentralized strategy development framework is that Portugal can afford less and therefore will choose to invest in fewer projects than it would under greater levels of EU control, influence, and explicit or implicit backing. At the same time, the focus of those projects would be on internal connections. Examination of the PRN 2000 reveals an emphasis on internal connections both in the plan's accompanying maps and in the text of the legislation which calls for "development of regional capabilities, reduction of the global cost of transport, improving travel security, accommodation of international traffic, and modernized network management." In addition to this deliberate statement of an internally focused strategy, the evidence from actual decisions about and investments in Portugal's intercity road and rail networks and urban transit systems over the past several decades indicate a clear emergent preference for internal infrastructure improvements over development of international connections.

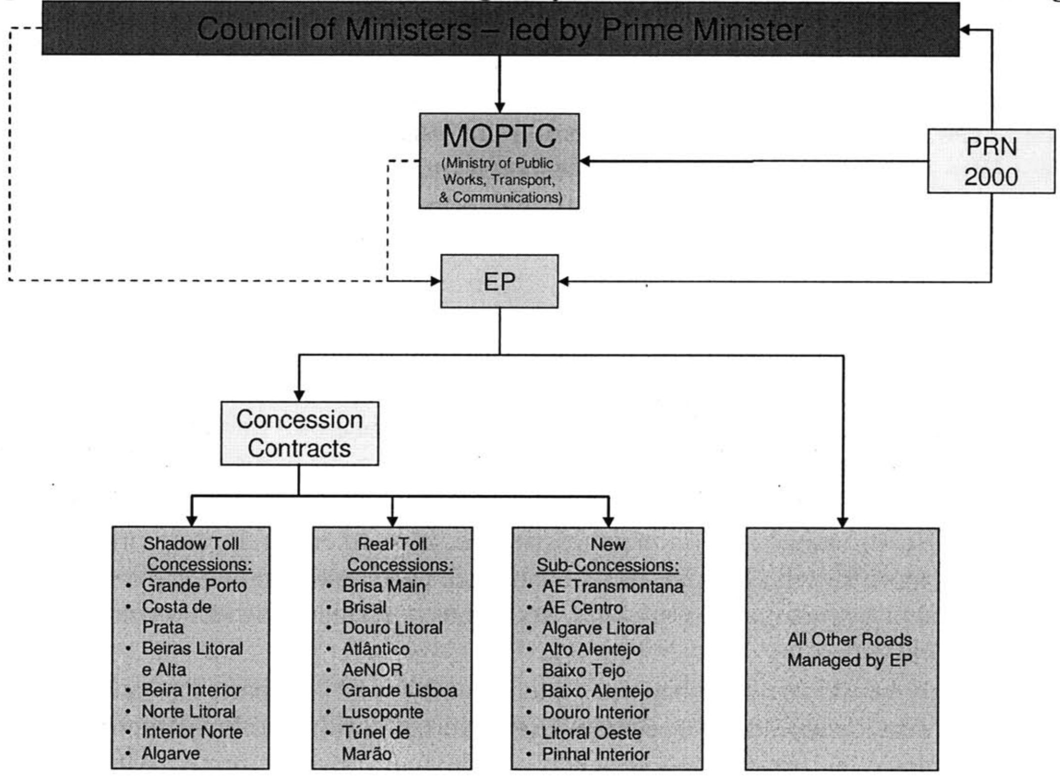
Figure 7-5 and Figure 7-6 illustrate the flow of revenues and decision, respectively, for the highway transportation infrastructure sector in Portugal. Although general tax revenues were allocated to the highway sector in Portugal in the past, no general funds have been allocated to highways since 2007. Instead, about 16% of fuel tax revenues are dedicated to EP which, together with loans, funds maintenance, operations, improvement, and expansion of all existing non-concessioned intercity motorways as well as payments to shadow toll concessionaires. Toll revenues, meanwhile, are dedicated to real toll concessionaires. EU grants are applied to non-concession highway projects and to some shadow toll concession highway projects. These grants can be made to the projects directly or via the Portuguese government, depending on the source of the funds (e.g., EU Cohesion Fund grants are delivered through a national government program, while EP and even private concessionaires can access other funds directly for particular projects).

Figure 7-5. Revenue flows for new highway infrastructure investment in Portugal



Decision flows for investment in new Portuguese highways follow the arrows indicated in Figure 7-6. The government has the authority to amend, update, or replace the National Road Plan (PRN) as it sees fit; until then, however, any new investment must stem from the PRN 2000. Estradas de Portugal (EP) has a concession agreement with the government, signed in 2007, which operationalizes its authority over the highway sector for 75 years. Ultimately, as an autonomous entity, EP is free to make infrastructure decisions as it sees fit, subject to the constraints of its concession contract with the government, as represented by the dark lines which connect EP to the infrastructure. For concessioned infrastructure (whether real toll concessions, shadow toll concessions, or new concessions), EP's decision-making is governed by the contract it shares with the concessionaire. Its decisions must follow the PRN 2000. However, the indirect and informal influence of the government is very much present in EP's decision-making, as represented by the dotted lines connecting the Council of Ministers and the MOPTC to EP.

Figure 7-6. Decision flows for new highway infrastructure investment in Portugal



The simulation model results in Chapter 6 illustrate how a single national decision-maker largely satisfies internal connections, particularly those in the heavily traveled urban and coastal regions of Portugal *before* increasing investment levels in the interior of the country and to the border with Spain. This emphasis on internal connections of clear local benefit is likewise evident in the pattern of infrastructure investments pursued by Portugal during the 1990s. A chronology of major investments in that decade follows:

- 1991. Completion of the Lisbon-Porto motorway.
- 1993. Extension of Green and Yellow Lines on Lisbon Metro.
- 1995. Outer Lisbon beltway (Circular Regional Exterior de Lisboa, or CREL) opens.
- 1997. Tendering of Atlântico (coastal region, north of Lisbon) and AENOR (greater Porto) motorway concessions; extension of Blue and Yellow Lines on Lisbon Metro.
- 1998. Vasco da Gama Bridge opens connecting Lisbon with southern bank of the Tagus; construction of Red Line on Lisbon Metro.
- 1998. Launching of 6 shadow toll concessions: 3 in interior regions, 2 in metropolitan Porto, and 1 in the Algarve.
- 1999. Opening of the Alfa Pendular high-speed rail service between Lisbon and Porto.

With regard to HSR, the benefit to Portugal of connecting with the rest of Europe is dubious. HSR is viewed as most competitive with auto and air when provided in markets with a travel distance between 150 and 800 km, although the most heavily traveled corridors in the world (Tokyo-Osaka, Tokyo-Hachinohe, Paris- Lyon, and Madrid-Barcelona) are all under 600 km (GAO, 2009). Assuming electricity is generated from fossil fuels, HSR enjoys an environmental advantage over other modes in some corridors, but this benefit diminishes with increasing distance. Kemp (2004) determined the threshold where aviation becomes advantageous from an environmental perspective to be roughly 600 km. The Lisbon-Madrid HSR link, a distance of 600 km, represents an opportunity to connect those two markets, but because it is on the high end of the range for market share and environmental competitiveness with other modes, success is far from guaranteed. Moreover, given the distance limitations of HSR, net benefits to passengers and society for HSR trips between Portugal and points *beyond* Madrid are virtually nonexistent. Given a decentralized strategy development framework without any incentives from Spain or the EU, it is likely that Portugal would focus instead on internal connections.

The machinations of domestic Portuguese politics dominate deliberate infrastructure strategy development, pitting forces within the central government against one another in a negotiation that results in familiar compromises about amounts and types of investments—transit vs. highway, urban vs. rural, congestion vs. safety. The emergence of a transportation infrastructure network in Portugal over the past several decades has resulted from this process, and it differs in several important ways from the expected emergence of a network under greater EU control.

- Without EU influence and financial assistance, investment in the network would have occurred more slowly. Despite this slower pace of investment and associated economic development opportunities lost, there would be a stronger prospect of financial sustainability.
- HSR likely would not have been considered without EU support. Instead, the Alfa Pendular service would have received continued attention and investment, with an aim toward improving travel times between Lisbon and Porto. Currently, Alfa Pendular has top travel speeds of 250 kph, with scheduled service between Lisbon and Porto in as little as 2 hours, 34 minutes.
- Although the HSR network would likely not have reached Spain and integrated with the EU, the international motorway connections afforded by the largely uni-lateral domestic investments do nonetheless fit within the TEN-T priority axes. However, as previously stated, the connections under a decentralized framework would have taken longer to emerge.

7.1.3 Revenues: tax or toll?

The final dimension of a strategy development framework that we examine through empirical cases is the type of revenues employed. The selection of revenues depends, to a large extent, on the other dimensions of the strategy development framework already discussed: ownership structure and geographic scale. Private and concession-based approaches depend almost entirely on user fee revenues, while public ownership and large geographic scales tend to favor general taxation over user fees to fund infrastructure. We describe two types of revenues categorized broadly as general taxes, which are paid by all members of society, and user fees, which are charged either directly or indirectly to transportation customers, roughly in proportion to their usage.

7.1.3.1 Pre-revolution France: general taxes

Lay (1992) provides a brief history of the French road system during the Middle Ages, claiming that between 1300 and 1900 the country "probably had the world's best road system… unrivaled with respect to national scale, quality, and condition." The key motivation for maintaining such a network was, like many similar networks throughout history, accommodation of a large army.

Other motivations identified for the period include enabling a national courier system, providing linkages among royal residences, and maintaining national unity. Another likely contributor to the momentum of the road system was the gradual development of a society of professionals specializing in road design and construction, culminating in the establishment of both a military and a civilian Corps of Engineers (in 1672 and 1716, respectively) and a school for training bridge and road engineers in 1747.

The framework within which French roads were developed relates importantly to the emergence of the network over this time period. Specifically, France had a strong, centralized monarchical system of government and an effective general tax revenue collection scheme to fund a national budget, much of which in turn was used to support infrastructure investment. In this section we briefly discuss two "general tax" methods: the *gabelle* (salt tax) and the *corvée* (mandatory labor).

Likely introduced in the 13th century by King Philip IV, the *gabelle* was a national tax on several commodities that eventually was restricted to salt. With few exceptions, French subjects had to pay the tax, whose rate varied among the regions of France; moreover, subjects had to purchase a minimum quantity of salt. Sands and Higby (1949) chronicle the turbulent history of the salt tax which was administered using a variety of clever and oppressive tactics designed to encourage both consumption of salt and compliance with tax payments, ranging from random household searches to discourage the purchase of black-market salt (easily distinguishable from "official" approved salt, which was diluted with plaster) to capital punishment for convicted smugglers to forbidding livestock from drinking from salt marshes or the sea:

> In some sections the officials even went so far as to employ "experts" to taste the skin of cattle in order to decide whether they had been fed salt. If the records showed that the owners had paid no tax for salt, they were prosecuted.

The linkage between the salt tax and infrastructure investment is indirect, as salt tax revenues supported a variety of other areas of government, notably funding of the military and fighting of wars, typically against Britain. The unfairness of the tax (nobles and clergy were largely exempt) and its brutal administrative tactics made it very unpopular, leading to several armed revolts as early as the mid-15th century. However, these revolts were suppressed and the revenues of the salt tax too attractive to warrant its outright abandonment. The French Revolution of the late 18th century led to a temporary abandonment, but Napoleon resurrected the tax, primarily to fund road construction, in 1806.

Another general tax related to infrastructure investment was the corvée, or mandatory labor. Originating in ancient societies, the corvée system survived well in to the middle ages as a feudal requirement that tenants of a manor compensate the lord of the manor for their land through military duty and manual labor, largely on the nearby roads and bridges. Although widely used throughout Europe and other parts of the world, the French corvée system eventually was extended beyond the manor and became a national law designed to employ labor for construction of a national road network. Enforcement of the corvée contributed to the revolutionary sentiments leading up to 1789.

Of course not all general taxes are so unjust as the corvée nor so unequal and cruel as the administration of the gabelle. The purpose of describing these methods is to illustrate the relationship between the power of and proclivity for general taxation; the relatively more centralized nature of administration; and the outcome which is a well-maintained, nationally scaled network of infrastructure. Had the administration and its tax powers taken a different form, the system of roads would not likely have evolved similarly. Consider, for example, a proposal just prior to the Revolution to replace the corvée with a property tax on all estates, which was vigorously opposed by the nobility and the Parliament (Cavanaugh, 1974).

In effect, the salt tax and mandatory labor were the means to build and maintain a road network serving the wealthy classes who paid neither general taxes nor user fees. If one imagines a tax or labor requirement based on *usage* of the road system rather than an exemption from both based on title or status, then the construction of an extensive network of royal roads becomes less likely. As Adam Smith noted, a road should not be built "merely because it happens to lead to the country villa of the intendant of the province, or to that of some great lord to whom the intendant finds it convenient to make his court." Instead, "they can be made only where that commerce requires them" (Smith, 1776). This philosophy leads us to another approach to road finance, which is based on charging fees to users and direct beneficiaries.

7.1.3.2 Direct user fees in contemporary usage

The use of tolls and other direct user fees to fund road infrastructure dates back many centuries. According to Lay (1992), the first historically recorded tolls were in India in 320 B.C.E. Much later, tolls were used as the funding mechanism for private turnpike companies in the U.S., as discussed in Section 7.1.1.1. User fees also supported a private road network in 18^{th}-century England, slightly predating the U.S. turnpike era and following a very similar history. However, tolls are not limited to private roads. In this section we discuss contemporary applications of direct road pricing in three contexts: North America, the United Kingdom, and continental Europe.

7.1.3.2.1 North America

Traditional toll roads are common in North America. Currently, toll roads exist in 32 states, Canada, and Mexico, concentrated largely in the Northeast and Midwest. Recently, congestion-based charging has been proposed; this form of pricing reflects not only the cost of the infrastructure but also the social cost (delay externality) imposed on other users. One form of congestion-based pricing, high occupancy/toll (HOT) lanes are in operation in 6 cities (Orange County, CA; San Diego, CA; Salt Lake City, UT; Houston, TX; Minneapolis, MN; and Denver, CO) and in varying stages of planning in San Francisco, Atlanta, Miami, and Washington, DC. A recent competition sponsored by the U.S. Department of Transportation attracted proposals for varying forms of congestion-based charging from over 20 cities. The majority proposed HOT schemes, while New York City proposed a relatively more ambitious area charging scheme. The five finalist cities selected to receive federal funds to study the schemes further included New York City (area charging), Miami (HOT lanes), San Francisco (congestion-based charging on an urban arterial), Seattle (traditional tolling), and Minneapolis (HOT lanes). New York City's scheme was rejected by the New York state legislature in 2008.

The Seattle region and the state of Oregon recently completed pilot programs for distance-based charging. In both cases, motorists received on-board GPS units to track and charge, by the mile, their use of roadway infrastructure. The Oregon scheme was "distance-place," while Seattle tested a time-distance-place (TDP) scheme. In Seattle, per-mile prices were a function of the type of facility (freeway vs. non-freeway), time of day (peak vs. offpeak), and day of week (weekday vs. weekend). Both tests were designed to measure user reaction to the pay-as-you-drive principle as well as to understand the technical challenges of managing a large-scale urban or regional road pricing scheme. A similar pilot test recently concluded in the Atlanta region, where the primary goal was to test the viability of distance-based pricing for auto insurance premiums.

7.1.3.2.2 United Kingdom

London has stolen headlines for its bold deployment of congestion-based charging in 2003. In fact, however, the smaller UK city of Durham was the first to deploy congestion charging: motorists entering the historic city center must pay approximately $4 (US) during the day in exchange for a ticket. An exit barrier lowers when the motorist wishes to exit once they provide the ticket. Security cameras are used as back-up. Traffic levels in the charging area have declined by approximately 90% since implementation of the scheme in 2002.

London's much broader scheme is an area charge which assesses motorists approximately $15 (US) to operate inside the charging zone (with discounts for residents, among other special groups) and has resulted in 18% reduction in traffic. In the wake of London's success, the Department for Transport (DfT) has invited other cities in the UK to apply for grant monies from central government as part of the Transport Innovation Fund (TIF). TIF grants will allow cities to make major public transit investments, but only if their proposals include a substantial road pricing component. Approximately 10 cities were expected to submit proposals. One of the most ambitious proposals was submitted by Greater Manchester, which called for two cordons (or, as referred to locally, a "double step" charge). Motorists traveling inbound during the morning peak would face a charge of $2 to cross the outer cordon and an additional $4 to cross the inner cordon. In the afternoon peak, outbound travelers face charges of $2 at each cordon. As in London, the congestion charge was integrated with other improvements, which recognized the multi-modal nature of urban transportation by emphasizing investments in public transportation services and roadway improvements together with road pricing. However, the Manchester proposal was defeated by popular vote in December 2008.

7.1.3.2.3 Europe

Italy's "seven cities" vignette program (Florence, Rome, Siena, Bologna, Pisa, Torino, and Padua) have all instituted "electronic gateways" to their historic city centers, with aims of reducing congestion and emissions. In order to access the city center, motorists are assessed a fee of €5 per day. Typical traffic reductions in the seven cities are approximately 15-25%. Because the objective of the Italian schemes is to reduce auto traffic and emissions, revenues were not seen as important. In fact, the scheme is operated "revenue neutral"—that is, the revenues generated by the congestion charges are allocated to operating the scheme.

By contrast, revenues are the motivating factor behind distance-based charging schemes in Central Europe. Germany, Austria, Switzerland, Czech Republic, and Slovakia have all instituted distance-based charges on motorways for heavy trucks. In Switzerland, passenger cars must purchase an annual pass for access to the motorway (effectively a toll). Similarly, in Austria, passenger cars are required to purchase weekly, monthly, or annual passes to use motorways. Each scheme is enforced using a unique technology. As a result, the EU is attempting to set standards for dedicated short-range communications (DSRC) that will make future deployments of road user charging interoperable across national boundaries. The heavy use of tolls in Central Europe is not surprising given the high proportion of pass-through (largely international) freight traffic.

The Netherlands recently completed a trial of TDP charging. The national government has specified an aggressive policy of replacing the currently convoluted system of financing transportation infrastructure with a single, user-financed road charge enabled by in-vehicle devices, while recognizing the potential mobility benefits of the scheme. The government has also set ambitious goals for the efficient operation of the scheme. The Dutch have tested their GPS-based devices, which use cellular networks and DSRC to communicate travel and transaction data from the in-vehicle device to the roadside, and intend to complete the deployment of the scheme by 2012.

7.1.3.2.4 Summary of direct and indirect user fee approaches

The recent renaissance in transportation user fees is made possible by the development of advanced, electronic toll collection (ETC) technologies. These technologies enable a wide range of pricing schemes, including: extensive pricing of long-distance networks, pricing of urban road-based transportation, and other sophisticated pricing schemes based on time of travel, level of congestion, type of vehicle (e.g., emissions and weight categories), and location. Yet, in the examples discussed, the facilities supported by direct user fees represent only a modest portion of the total network. The user fee-funded portions of these networks depend to a large extent on traffic that is made possible by the existence of other, "feeder" portions of the network, which are largely supported by indirect user fees (e.g., fuel taxes) and general tax revenues. Even if we expand consideration to include indirect user fees, however, the revenues from fee collection rarely equal the total costs associated with infrastructure provision. For example, in the U.S., much of the road network is funded by tolls, fuel tax receipts, and other indirect user fees. In an extensive analysis, Delucchi (2007) concluded that, depending on the method of counting, between 74-93% of motor-vehicle infrastructure and service (MVIS) costs are covered by user fees, and the rest by general tax mechanisms.

Exclusive reliance on user fees, whether direct or indirect, generally does not allow for the construction and maintenance of networks as extensive as those that are possible under general-tax revenue schemes. Moreover, the feedback mechanism of charging users directly for their consumption of travel has the effect of reducing total travel and, therefore, reducing revenues. This elasticity offers a self-regulating limitation on the amount of infrastructure than can be funded through direct user fee schemes relative to a framework with at least partial reliance on general tax revenues.

7.1.4 Section summary

In this section we have complemented the simulation model results by analyzing a series of empirical cases illustrating three dimensions of strategy development frameworks in practice: ownership structure, geographic scale, and type of revenues. What we find is that, in practice, frameworks are rarely straightforward or simple to characterize. For any given context, the geographic scales of decision-making and ownership, institutional architectures, and revenue mechanisms are dependent on one another and, often, involve a mixture of approaches.

Hybrid geographic scales. The national-municipal hybrid case considered in Chapters 5 and 6 is one example of a hybrid geographic scale, but many others exist in practice and can be imagined in theory. For example, the complex EU-Portugal relationship is an example of a "federalist" approach that is neither fully centralized nor fully decentralized. The EU offers matching grants to entice Portugal to invest in a network that corresponds with broader, EU-focused objectives.

Hybrid ownership. A framework that combines concession contracts for some portions of the network with publicly administered facilities for other portions represents a hybrid approach to ownership. This is, in fact, the approach taken in Portugal and was reflected in the simulation of concession-based frameworks. However, in the simulation model, SOE-owned portions of the highway network were not eligible for further investment. We see a range of approaches to hybrid ownership in reality, most often with public ownership, but sometimes with both concession-based and publicly administered facilities. Absent from almost all road infrastructure systems are fully private roads. Private freight rail systems still exist in the U.S., while passenger rail service is largely provided through public and/or concession-based approaches.

Hybrid revenues. As with geographic scale and ownership, the resources used to fund transportation infrastructure are most often a combination of general taxes and user fees.

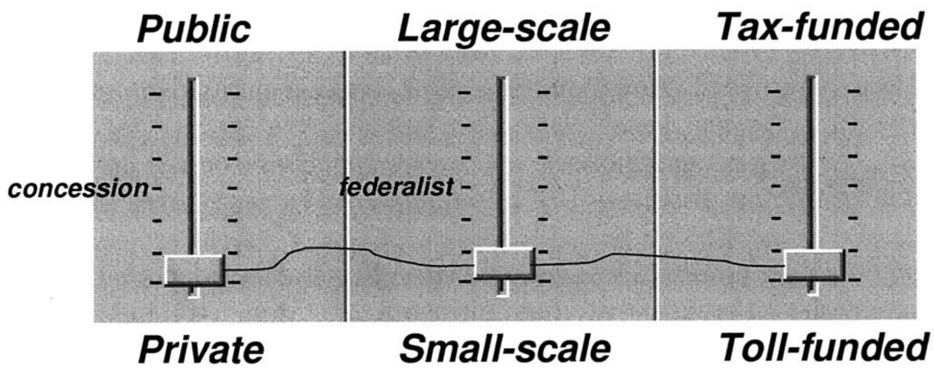
Relationship between geographic scale and revenues. Empirical evidence supports the theoretical contention that propensity to fund infrastructure through tolling and other direct user fees increases as the geographic scale of ownership decreases. Perhaps the clearest illustration of this relationships is the modern case of Central Europe, whose national governments have discovered an easy application for the most politically palatable form of revenue generation: tax foreigners living abroad. In the case of transportation infrastructure, this is achieved by tolling international pass-through traffic.

Relationship between ownership and revenues. The concession and private approaches to ownership generally require direct user fees (tolls, in the case of road infrastructure), but as the case of Portugal has demonstrated, general taxes can be used to compensate concessionaires under shadow toll schemes. More commonly, general taxes are associated with pure public facilities. Interestingly, the approach to private roads that has been most effective for development of large-scale networks, involved "voluntary" participation either as a bondholder in a turnpike trust or as a shareholder in a turnpike corporation. The success of this approach has hinged on consensus among communities and landowners that a road investment is worthwhile and a "public-minded" spirit to overcome the free-rider problem and entice widespread participation. Replicating this model in a purely private, voluntary manner may be extremely challenging. That said, participation as an investor in these scenarios is akin to a modern, mandatory property tax.

Relationship between geographic scale and ownership. Public ownership ranges widely in geographic scale, from the relatively small and decentralized to the relatively large and centralized. Concession-based approaches depend upon the public sector for existence. The scale of concessions in the cases explored here tends to be smaller than the public-sector scale. For example, Portugal has 15 independent, private motorway concessions.

For the types of infrastructure considered here (long-distance, intercity infrastructure), the relationship between the three dimensions analyzed through cases in this section is illustrated conceptually in Figure 7-7 as a series of three toggles on a vertical scale. All three toggles tend to move together, pulled by the "string" in the illustration that connects them. As the ownership structure, for instance, moves upward, from private toward public, there is also a tendency for geographic scale to move toward larger scales and for revenues to move toward general taxation. The relationship is imprecise (hence the slack in the string), and there are exceptions, but the empirical evidence of the cases discussed here supports the existence of these general relationships.

Figure 7-7. Conceptual illustration of the empirical relationship among ownership, geographic scale, and revenue type



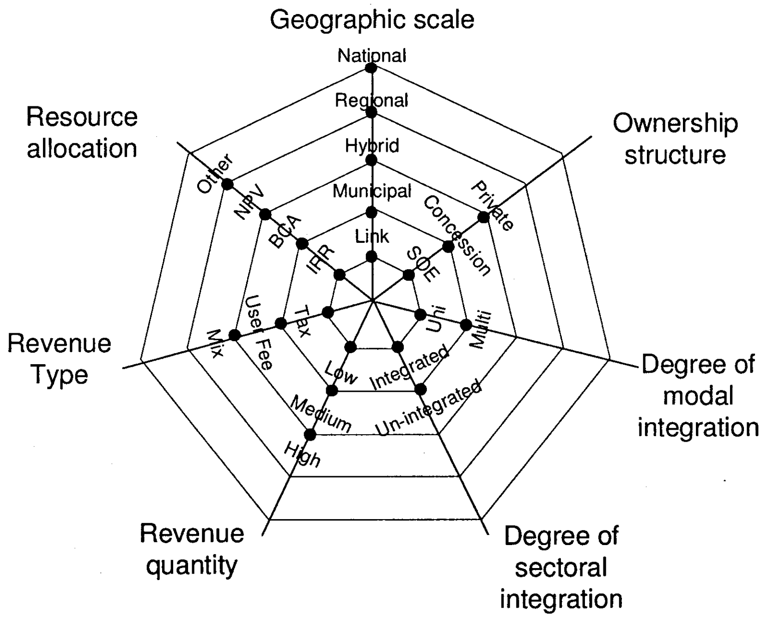
Having presented a qualitative, empirical analysis complementary to the quantitative, theoretical analysis, we next endeavor to *extend* the analysis by considering in greater detail some dimensions of and values for alternative frameworks that were neither modeled quantitatively in Chapter 6 nor considered empirically in this section.

7.2 Predicted influence of greater modal and sectoral integration

The simulation model results presented in Chapter 6 encompass 105 discrete alternative strategy development frameworks, each characterized by a discrete value along each of the following 7 dimensions: ownership structure, geographic scale, revenue type, revenue quantity, resource allocation process, degree of modal linkages, and degree of sectoral linkages. In Section 7.1, we complemented the results of the quantitative analysis by considering the empirical behavior along 3 of those 7 dimensions.

The purpose of this section is to extend the range of alternative frameworks by considering two important dimensions that were not explicitly captured by the simulation model or the empirical case analysis: multi-modal and multi-sectoral institutional architectures. These dimensions and values are again illustrated in Figure 7-8, together with the dimensions already considered in the quantitative and case analyses.

Figure 7-8. Illustration of additional strategy development framework dimensions



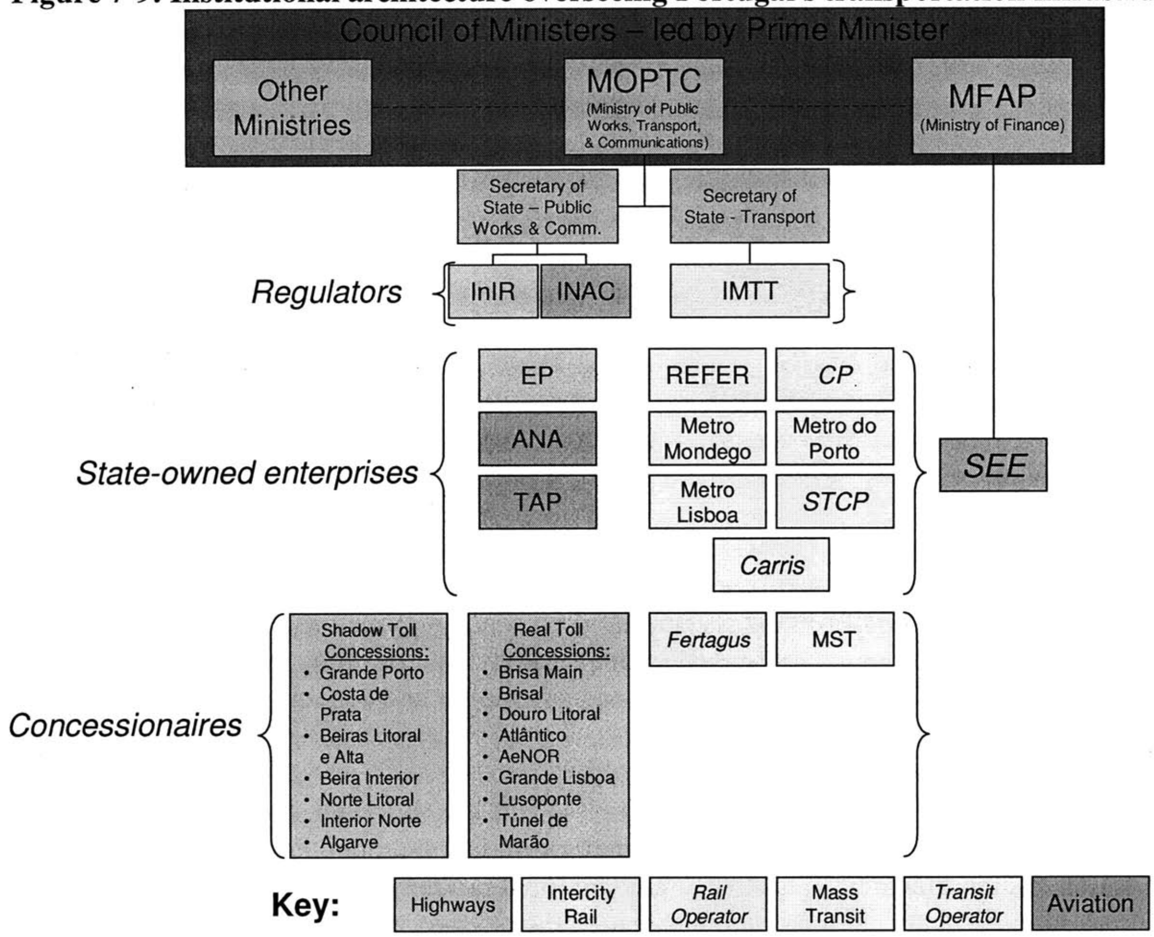
Multi-modal and multi-sectoral institutional architectures are of ongoing interest in Portugal and elsewhere due to contentions from the transportation research community that such approaches could provide more effective means of developing strategy. We examine what types of consequences to expect from greater integration across modes and/or sectors within the context of Portugal.

7.2.1 Degree of modal integration

In addition to the highway system represented in the simulation model, Portugal's surface transportation system includes an extensive conventional rail network providing regional (commuter), long-distance intercity, and international passenger service as well as freight service; urban public transit systems, including bus, light rail, subway, and ferry; and a proposed high-speed rail (HSR) network that will first connect Lisbon with Madrid, Spain via Elvas and, later, Lisbon with Porto. The institutional architecture overseeing this multi-modal physical system, however, is not formally integrated. Organizations, both public and private, largely have mandates that correspond only to a single mode of travel. In this section we discuss the potential impacts that changes to the institutional architecture, toward more integrated organizations within the transportation sector, would have on the physical system. We begin with an assessment of the consequences of the existing, uni-modal structure.

Figure 7-9 illustrates the institutional architecture that currently oversees Portugal's transportation infrastructure, portraying it as a hierarchy with four levels. The levels, from top to bottom, are: the central government (including the Council of Ministers, MOPTC, and MOPTC's constituent Secretariats of State), regulatory entities, state-owned enterprises (SOEs), and private concessionaires. We omit municipal governments from the discussion, which own and operate local transportation infrastructure (e.g., streets and sidewalks) and, in the case of some smaller municipalities, bus transit systems. We also omit regional authorities, which are administrative entities of the national government and metropolitan transportation authorities, which to date have very limited real powers and regulatory mandates yet to be clearly defined.

Figure 7-9. Institutional architecture overseeing Portugal's transportation infrastructure



Overseeing the transportation sector is the central government's Ministry of Public Works, Transportation, and Communication (Ministério das Obras Publicas, Transportes, e Comunicações, or MOPTC). Most transportation infrastructure investments are developed and decided at the highest levels of government (within the legislative National Assembly and the Council of Ministers, which is the cabinet of the executive branch) and within the MOPTC itself, while independent agencies such as the Highway Infrastructure Institute (Instituto de Infra-Estruturas Rodoviárias, or InIR) regulate each transportation mode. Resource allocation decisions result from negotiations within the government; these negotiations serve as a de facto multi-modal investment allocation mechanism, but are based on preservation of existing budgets and needs assessments which are formulated independently by stakeholders for each mode. The MOPTC itself is bifurcated, with one Secretariat of State for highways and aviation and another for railways and urban public transit. This bifurcation is common among government transportation departments and ministries—for example, the U.S. DOT has 11 distinct modal administrations. The SOEs acting on behalf of the government to deliver transportation infrastructure investments are uni-modal in character, with few formal connections to one another. For example, the 2000 National Road Plan (Plano Rodoviária Nacional, or PRN 2000) was developed by Estradas de Portugal (EP), while the HSR network was developed by RAVE, an SOE totally distinct from EP. There were no explicitly multi-modal considerations either in the decision to develop the plans nor in the ongoing execution of the plans.

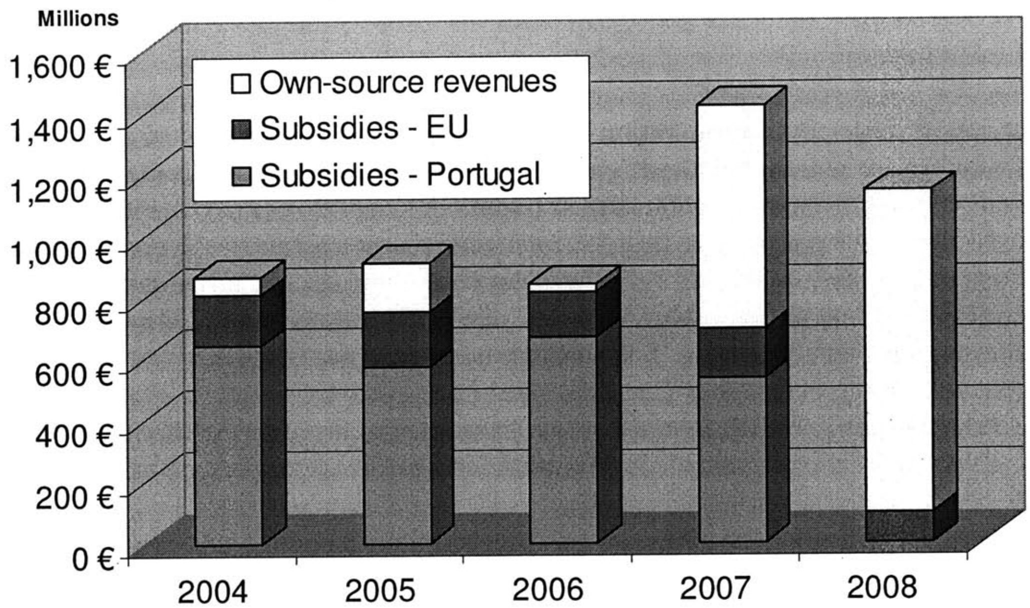
As a further illustration of the uni-modal nature of strategy development, consider the Strategic Orientations (Orientações Estratégicas) produced by the MOPTC in 2006. Each document corresponds to a single mode: rail, road, maritime, airports, and ports/logistics. The Strategic Orientation for rail characterizes highways largely as a competitor and refers to policies that promote highway use as a "threat." Instead, the rail sector endorses policies that favor rail over road-based travel, including pricing as a means of improving the attractiveness of rail to customers. For its part, the PRN 2000, which serves as the Strategic Orientation for highways, does not even mention rail.

The only opportunities for consideration of multi-modal tradeoffs in infrastructure investment decision-making are within the very highest levels of government and through informal connections of the uni-modal organizations. Even these opportunities, have in many cases disappeared due to the severing of ties, for financial reasons, between the government and the modally oriented SOEs. In late 2007, EP was converted into an autonomous company and empowered to fulfill its public objective of building road infrastructure through concession agreements with private companies and through borrowing (with the implicit backing of the state). Likewise, Rede Ferroviária Nacional (REFER), Portugal's state-owned railway infrastructure company, fulfills its obligations to maintain rail infrastructure largely through borrowing instead of direct grants from the state. The SOEs are organized by travel mode as follows:

- *Highways.* All intercity highways are owned by the state and operated under a concession agreement with EP, an autonomous SOE, and regulated by InIR, an independent regulator devoted exclusively to highway infrastructure.
- *Railways.* All railways are owned by the state and managed under a concession agreement with REFER, an SOE. The vast majority of rail service is provided by Comboios de Portugal (CP), an SOE, with some participation by private operators. Meanwhile, the HSR network is being planned and constructed by an autonomous SOE known as Rede Ferroviária de Alta Velocidade (RAVE), which is partly owned by REFER and partly owned by the state. The rail sector is regulated by the Institute for Surface Transportation and Mobility (Instituto da Mobilidade e dos Transportes Terrestres, or IMTT), an independent organization devoted to rail and transit.
- *Urban public transit.* In Lisbon, the subway infrastructure and service provider is Metro Lisboa, the bus and light rail service provider is Carris, and the ferry service provider is Transtejo. In Porto, the light rail infrastructure and service provider is Metro do Porto, while bus service is provided by STCP. In Coimbra, Metro Mondego is developing a light rail system. All six companies are SOEs and independent from one another.

The consequences of uni-modal strategy development are numerous. First, SOEs lack a formal venue for multi-modal planning or analysis of investment tradeoffs, leading to an increased likelihood of redundant infrastructure investments across modes. Policy objectives, sometimes including specific investments, are dictated to the SOEs by the government; however, because many of the SOEs now operate "off budget," they can pursue investments free from state-imposed budget constraints, which removes restraints on borrowing and spending. Consider, for example, the funding sources of EP, which was made autonomous in November 2007. Figure 7-10 summarizes the amounts of funding by source from 2004-2008. "Own-source" revenues include a portion of Portugal's motor fuel tax receipts (dedicated to EP beginning in 2007), but also a substantial increase in borrowing. This increase in spending is not necessarily good or bad; however, given the uni-modal nature of the budget process, it likely represents a less efficient set of investments than could be achieved with multi-modal budgeting.

Figure 7-10. Evolution of funding sources for Estradas de Portugal, 2004-2008[21]



Another consequence of the largely uni-modal approach to infrastructure strategy development is that SOEs will compete for the same traffic. For example, the motorways and the HSR network will connect many of the same points. With little population growth and a variety of options for intercity travel, it may be difficult for the infrastructure to meet demand expectations, at least in the short- and medium-term, which could become problematic for repayment of funds borrowed for construction. Moreover, with investments pursued uni-modally, there are limitations on the physical integration of infrastructure which could, in some contexts, provide not only for more efficient multi-modal trip opportunities for customers but more efficient, less costly network designs. Also, by sending uncoordinated signals about infrastructure investment to the market, land development patterns will likely respond in unintended and difficult-to-predict ways, compounding the challenge for design of policy in other areas such as environmental protection, land use, and economic development.

On the other hand, the consequences of greater multi-modalism in the development of transportation infrastructure strategy are also difficult to predict. Multi-modalism can be defined as an explicit effort to consider alternative infrastructure investments in an integrated fashion as part of the decision-making process. Rather than, for example, allocating budgets for each mode

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[21] Based on data from EP (2005-2008).

individually (e.g., highway, transit, railway), multi-modalism would involve evaluation of a variety of alternative programs of investments in order to determine a set of preferred investments, irrespective of mode.

Such a program of multi-modal strategy development in Portugal would result in investment outcomes that are different from those currently observed, likely with a lesser quantity of infrastructure. Instead of uni-modal Strategic Orientations referring to the various other modes as competitors, multi-modal strategy development would focus on opportunities for synergy and efficiency in the design of a multi-modal network for passengers and freight. Intercity infrastructures would no longer be built to compete for trips among modes, but instead to complement one another. The quantity of infrastructure developed and proposed in Portugal would likely be reduced under a multi-modal strategy development framework if for no other reason than the realization that redundant systems would be unable to draw sufficient traffic in order to be justified financially. What remains unclear, however, is what *type* of infrastructure would be preferred and whether an extensive network of either railways or highways would be deployed.

The prospects for more explicit and extensive multi-modalism in the development of transportation infrastructure strategies for Portugal are dim. Within the existing institutional architecture, the strongest prospects for multi-modalism are within the government (the "top layer" of Figure 7-9). MOPTC, for example, has a strategic planning unit which produced a national, multi-modal Strategic Transportation Plan (Plano Estratégico de Transporte, or PET) in May 2009. However, the plan is descriptive rather than prescriptive, indicating there is little opportunity within the planning unit to influence infrastructure investment decisions by the government in a multi-modal direction. The other layers offer even fewer opportunities for modal integration: SOEs (e.g., EP and REFER) and regulatory agencies (e.g., InIR for highways and IMTT for railways and urban public transit) each have substantial institutional inertia and entrenched industry interests focused on a particular mode. Nevertheless, with political negotiations and ever-changing budget constraints, the central government is, among the existing agents, in the strongest position to enforce any sort of consideration of multi-modal trade-offs in the development of transportation infrastructure strategy and investment decisions.

Difficulty integrating strategy development across modes is not unique to Portugal. In a study of California's intercity transportation system, Kanafani (2008) claims that "transportation planners have always accepted the integration of modes as a sound principle, but daunting challenges prevent its realization." The U.S. Government Accountability Office (GAO, 2004) likewise cited uni-modal institutional structures as a barrier to the potential for more multi-modal strategy development: "there are relatively few instances in which decisions involve trade-offs among the various transportation modes to meet passenger and freight mobility needs." GAO points to the conflict between the language of federal legislation which "emphasizes the goal" of intermodal planning and the "reality of federal funding structures" which are modally oriented.

The consequences of increasingly multi-modal strategy development are greater competition for resources, but potentially more efficient resource allocation decisions. Stakeholders and organizations resistance to multi-modal strategy development is strong, given the prospects of greater competition and fewer resources. Multi-sectoral strategy development introduces even more competition.

7.2.2 Implications of multi-sectoral strategy development

Given the difficulty of multi-modal coordination, multi-sectoral coordination of strategy development for transportation in Portugal is even less common and less likely to occur. Other sectors related to transportation that could be involved in a multi-sectoral strategy development framework include land-use regulation, environmental protection, and economic development. Currently, some multi-sectoral efforts are pursued through ad-hoc cooperation drawing on informal linkages among the Ministries of Transportation (MOPTC) and other ministries, notably Economic Development. The prospects for further formal integration, at least within the central government, remain small, but the potential consequences of integration are explored in this section on the basis of experiences elsewhere.

Transportation planners have long conjectured that there are benefits to integration across sectors in the development of transportation infrastructure strategies. For example, Hatzopoulou and Miller (2008) identify multi-sectoral policies whose "impacts extend beyond the transport sector itself to other sectors such as environment, health, and education" as a "common denominator" among sustainable transportation plans. By identifying a broader range of policy objectives outside of transportation that are related to transportation investments, decisions will more closely reflect the collective preferences of the population of infrastructure customers.

However, integration is not without its costs. Stough and Rietveld (1997) argue that the evolution toward broader sectoral participation in transportation strategy development is inevitable and reflects rapid changes in technology, culture, and values; however, the theoretical benefits are counteracted by the reality that broader participation also brings more conflict to the decision-making process, in turn slowing the process and increasing its costs. Many contemporary transportation institutions reflect the rigid, centralized character of organizations following the "Fordist" model of industrial growth. Put simply, institutions are averse to change and competition. In response, Stough and Rietveld advocate a research agenda that focuses on improving the decision tools to reduce the costs of integration.

Another consequence of integration is greater competition. Jones and Lucas (2000), for example, describe a "single capital pot" scheme operating on a pilot basis in Scotland, in which the central government grants resources to local authorities to spend as they see fit. The scheme "has led to a sharp drop in transport expenditures in some areas. Hence, transport schemes will need to demonstrate (and so be designed to achieve) wider social and economic benefits, if they are to compete successfully for limited resources." The benefits of such integration for the public could be substantial: greater competition among uses of public resources could lead to more efficient allocation decisions. However, it is doubtful that transportation industry stakeholders—or any industry stakeholder, for that matter—advocating for integrated strategy development would ex-ante expect nor would they ex-post favor a decline in transportation spending.

Despite some empirical evidence of the consequences of multi-sectoral integration in transportation strategy development and decision-making (i.e., greater competition for resources, higher costs to deliver infrastructure, and slower decision-making processes), the benefits (i.e., more efficient investments and policy decisions that better reflect the full set of public preferences) are typically asserted on theoretical grounds. As with multi-modal strategy development, research typically focuses instead on dealing with institutional barriers to integration.

7.2.3 Section summary

In this section we have discussed the hypothetical performance of alternative strategy development frameworks that differ along two dimensions (degree of multi-modal integration and degree of multi-sectoral integration), neither of which was considered in the simulation model in Chapter 6 or the case analysis of Section 7.1. Certainly additional dimensions and values could be imagined and analyzed; however, those discussed in this section are of particular interest due to an ongoing push from the research community for government organizations to integrate across modes and across sectors of the economy in the development of transportation strategies. The evidence presented in this section allows us understand more clearly the types of performance consequences we can anticipate if any attempts are made to move toward greater integration.

By considering the consequences of integration based political economic theory, several results are evident. First, the purported benefits of integration (competition and more efficient allocation of resources) are, paradoxically, also barriers to integration. Appropriately, the emphases of current research in multi-modal and multi-sectoral integration are on overcoming institutional barriers. However, at the same time, we find that integration is both more feasible and more likely to deliver benefits in Portugal at geographic scales *other than* the current (national) scale of strategy development. Consequences of and barriers to integration should be analyzed together with alternative geographic scales of strategy development.

Following the Stough and Rietveld observation that institutions resist integration due to rigid, centralized structures, it follows that decentralization of decision-making would allow for greater integration of modes and/or sectors. Decentralization has the added effect of reducing the number of participants, thereby reducing the potential points of conflict and improving the pace of decision-making. Moreover, returning to one of the central themes of this thesis, advanced technologies can facilitate the movement toward multi-modal and multi-sectoral strategy development frameworks by speeding the collaborative process and reducing its costs using such approaches as web-based input. On the other hand, larger geographic scales increase the potential points of conflict between decision-makers and stakeholders. Adding modes and cross-sectoral considerations to the process could exacerbate the problem.

Next, we turn to the final piece of the qualitative analysis: consideration of the stakeholders affected by the strategy development framework and their collective ability to move the system toward any particular framework.

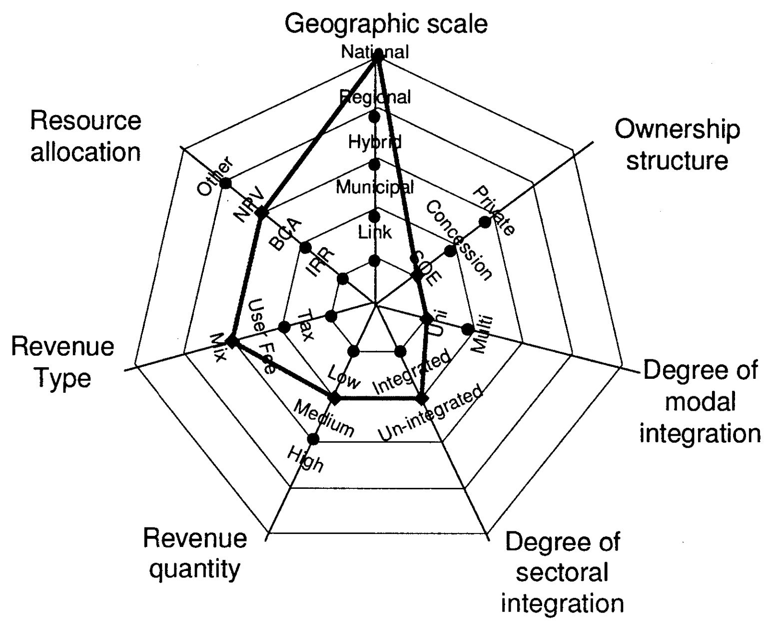
7.3 Stakeholder analysis

In Chapter 6 we evaluated a wide range of alternative strategy development frameworks according to a range of scenarios. Each scenario represented a hypothetical combination and weighting of performance metrics intended to reflect the diverse views of the diverse population of individuals and organizations affected by the transportation infrastructure system of Portugal.

In reality, however, the involved and affected individuals and organizations will not simply *judge* the performance of a system; some also hold the power to change it. In this section we analyze these individuals and organizations as stakeholders and active participants in the shaping of the transportation infrastructure strategy development framework.

In Chapter 3 we described the organizations involved in strategy development in Portugal, and in Chapter 4 we characterized Portugal's framework for transportation infrastructure strategy development along 7 explicit dimensions (illustrated in Figure 7-11). In this chapter, we treat that existing strategy development framework as the *baseline*. We examine stakeholder positions within that baseline framework. Furthermore, while recognizing that any change toward a new framework must be made with the baseline framework as the starting point, we evaluate the position of stakeholders in a hypothetical evolution toward those alternative frameworks.

Figure 7-11. Baseline strategy development framework for intercity transportation infrastructure in Portugal



Freeman (1984) defines a stakeholder as anyone "that can affect, or is affected by, the achievement of an organization's objectives." Mostashari (2005) points out that while there is general agreement on how to define stakeholders in a system, it is both more challenging and more important to determine why they count, how much they count, and how to involve them. He goes on to present a process for stakeholder involvement in complex system representation and policy design. Mitchell et al. (1997) offer a methodology not for involving stakeholders but for analyzing their strategic positions and their abilities to influence outcomes. Hanowsky and Sussman (2009) applied the Mitchell method to stakeholders affected by ground delay programs in the U.S. aviation system; here, we follow that model by applying the method to the set of stakeholders involved in the Portuguese transportation infrastructure system. The method takes the following steps:

- First, the stakeholders are enumerated and described (amounting to a justification for their inclusion in the system).

- Next, we discuss each stakeholder's relationship to the baseline strategy development framework in Portugal and consider its relative preference for alternative frameworks.
- Each stakeholder is characterized according to its "power, legitimacy, and urgency" as defined by Mitchell et al.
- Finally, based on its characteristics and preferences, each stakeholder is analyzed in order to determine its power in the current system and its ability to influence outcomes.

We use the results of this analysis to determine the stakeholder power structure in the baseline framework, identify conditions necessary for movement toward alternative frameworks, and then predict the stakeholder power structure under alternative frameworks. Although this analysis does not explicitly tell us which framework or frameworks are "optimal," we can determine which frameworks enable the greatest amount of participation and influence by two specific categories of stakeholders: users and residents. Frameworks that best align the interests of infrastructure *customers* (i.e., users and residents) with the more powerful collective interests of infrastructure *providers* (e.g., SOEs, concessionaires) can be seen as intrinsically "good."

7.3.1 Defining and characterizing stakeholders in Portugal

Defining and characterizing the stakeholders in our context (the surface transportation infrastructure system of Portugal) is based on information gathered in a series of interviews conducted with participants in January 2008, January 2009, and July 2009, as summarized in Table 7-3, as well as review of official documentation from a range of Portuguese organizations, as summarized in Table 7-4.

Table 7-3. Summary of stakeholder interviews

Category of organization	Organization	Title of interviewee(s)	Date
Central government	MOPTC, Office of the Minister	Chief of Staff	22 Jan 2009
	MOPTC, Office of the Secretary of State for Transportation	Deputy Secretary of State for Transportation	30 Jan 2009
	MOPTC, Department of Strategic Planning and International Relations	President; Director of Information Systems; Director of Planning and Strategy	29 Jan 2009
	Ministry of Finance	Financial Controller for MOPTC	Various
Regulator	InIR	Regulation and Concessions	5 Feb 2009
	IMTT	Member of the Board	20 Jan 2009
SOE – Roads	EP	Member of the Board; Director of Planning; Director of Concessions	7 Feb 2008; 20 Jan 2009
SOE – Rail infrastructure	REFER	Member of the Board; Director of Planning	26 Jan 2009
	RAVE	Director of Engineering	26 Jan 2009
SOE – Transit	Metro Lisboa	Director of Planning	30 Jan 2008
	Carris	Director of Finance	8 Feb 2008
	STCP	Director of Finance	4 Feb 2008
	Metro Mondego	President	1 Feb 2008
Concessionaire	Metro Sul do Tejo	President	7 Feb 2008
	Brisa	Director of Research	Various
Municipal government	Municipality of Lisbon	Director of Strategic Urban Planning	8 Feb 2008
	Municipality of Porto	Director of Finance	4 Feb 2008
	Municipality of Coimbra	Assistant Director, Municipal Buses	31 Jan 2008
Metro. Trans. Authority	AMT-Lisbon	Attorney	28 Jan 2009
Bank	European Investment Bank	Head of Lisbon Office	4 Feb 2009; 10 Jul 2009

Table 7-4. Summary of documents reviewed

Document	Organization(s)
Strategic Orientation for Rail, Logistics, Aviation Sectors, 2005	MOPTC
National Road Plan, 2000	Estradas de Portugal
Budget & Financial Accounts, 2004-2008	REFER, EP, Parpublica
Activities Plan and *Activities Program*, 2005-2009	MOPTC
National Strategic Plan (Transportation), 2009	MOPTC
Financial/Economic Indicators for Transportation, 1987-2006	MOPTC
Budget, Portuguese Government, 2008	Ministry of Finance
PIDDAC, 2004-2008	MOPTC
Concession Contract, EP	Portuguese Government
Concession Contract, Algarve SCUT	
Concession Contract, Douro Litoral	
Concession Contract, Grande Lisboa	
Novas Estradas (various reports on new road concessions), *2009*	MOPTC
Autoridade Metropolitana de Transporte Law, 2009	Portuguese Assembly
Project Appraisal Guidelines	EIB

Table 7-5 summarizes the stakeholders considered, including a description and brief, simple characterization of the deliberate strategy of each. The stakeholders have an implicit objective to survive and, if possible, to thrive. Recalling the definitions discussed in Section 3.1.1, the deliberate strategies of these stakeholders are the courses of action pursued in order to achieve specific, defined objectives. The collective decisions and behaviors, whether guided by an explicitly stated deliberate strategy or not, combine to form patterns and outcomes that reveal an underlying, often-unintended emergent strategy.

Table 7-5. List of stakeholders

Stakeholder	Description	Characterization of deliberate strategy
Central Government (CG)	Council of Ministers, MOPTC, National Assembly	**Control**: collect resources and make allocation decisions
Regulators	InIR, IMTT – independent regulators of infrastructure systems	**React**: oversee infrastructure sector as dictated by CG
SOEs (Road infrastructure)	EP – manager of the intercity highway system	**Execute**: design-build-operate-maintain road infrastructure
SOEs (Rail infrastructure)	REFER (manager of rail infrastructure), RAVE (HSR developer)	**Execute**: design-build-manage rail infrastructure
SOEs (Transit and rail operations)	Metro Lisboa, Metro Porto, Carris, STCP (transit operators); CP (rail)	**Execute**: operate transit & rail service
Municipal Government (MG)	Municipal councils corresponding to the territory of 278 mainland municipalities	**React**: defend autonomy, local revenue control, environment
Metro. Authorities (MA)	Metropolitan authorities are voluntary collaborations of municipalities	**Position**: define a role for participating in the sector
Metro. Transport Authorities (MTA)	MTAs, by contrast, were created by CG to regulate transport	**Position**: define a role for participating in the sector
Regional Authorities (RA)	5 regional development commissions (CCDRs) created by CG, funded by EU	**Position**: define a role for participating in the sector
Concessionaires (Conc.)	Private operators of infrastructure, including Brisa, Lusoponte, AENOR	**Profit**: build-operate profitable infrastructure systems
European Union (EU)	EU government, particularly the Directorate-General for Transportation	**Control**: collect resources and make allocation decisions
Financial Sector (Banks)	EIB & commercial banks making infrastructure loans	**Profit**: lend to projects with appropriate risks & returns
System Users	Motorists, passengers, freight shippers and carriers	**Consume**: enjoy improved mobility and accessibility
Residents	Residents and taxpayers (overlaps almost entirely with system users)	**Influence**: vote, express preferences through advocacy
Spain	The government of neighboring Spain, particularly the infrastructure agencies	**Negotiate**: make coordinated infrastructure investments

Given the relative positions and deliberate strategies of the stakeholders defined in Table 7-5, it is possible to describe the relative levels of preference toward the current (baseline) strategy development framework: nationally scaled SOE with a mixture of toll and tax revenues allocated using net present value analysis.

- Central government. The central government (CG) is by far the most powerful stakeholder in the baseline strategy development framework, controlling the majority of revenue collection and allocation decisions in the transportation infrastructure sector. CG prefers the current (baseline) framework, subject to protections against greater control by the EU, concessionaires, and banks; and maintenance of a limited role for regional, metropolitan, and municipal governments.
- Regulators. Regulators under the current framework have a relatively modest role in strategy development, as they are dependent on the central government, and react to its

decisions and directives. As creatures of the central government, regulatory bodies prefer the current framework; however, it is possible that an increasingly fragmented strategy development framework (i.e., more decentralized) would invite the need for greater harmonization and coordination, overseen by independent regulators. In addition, a reduction in the frequency of reorganizations of regulatory agencies (which is common under the current framework) would be desirable. This could be achieved under a framework in which the central government encountered fewer threats and therefore would need to adapt less frequently.

- State-owned enterprises (SOEs). SOEs, like regulators, largely react to the decisions and directives of the central government. In spite of any theoretical autonomy they may have, SOEs must execute the strategic decisions of central government in order to survive and increase the likelihood of thriving. They are satisfied with the current framework. An increased role for regional, metropolitan, and/or municipal governments would likely induce greater competition for the SOEs, while an increased role for the EU would invite greater scrutiny over the central government-SOE relationship.
- Municipal governments. Because municipal governments (MGs) are autonomous, they are not formally involved in the strategy development framework for infrastructure in Portugal. This constrained role (particularly for the intercity infrastructure sector) forces them to maintain a defensive posture toward decisions and actions of the central government. Some municipalities may benefit from the current framework, while others may suffer, depending upon the net transfer of resources in particular locations. Regardless, control over infrastructure resource allocation decisions is absent, leading to a preference for frameworks which enable greater involvement. This is particularly true for municipalities in metropolitan areas who are experiencing more rapid demographic, economic, and travel demand changes than municipalities in rural and low-growth areas experiencing slow change.
- Metropolitan authorities. Metropolitan authorities (MAs) are a bottom-up phenomenon composed of municipal governments. They reflect the clout of municipal governments acting in free association to exert greater control within the strategy development framework. The preferences of the MAs reflect the preferences of MGs located in metropolitan areas. As with MGs in general, MAs desire greater control over the infrastructure strategy development framework in order to direct resources more efficiently at problems that are unique to metropolitan areas.
- Metropolitan transport authorities. Metropolitan transport authorities (MTAs) have similar geographic scales as MAs, but they were recently created by the central government to regulate bus transit, conduct land-use and transportation planning, and coordinate local transportation investments for the metropolitan areas of Lisbon and Porto. Although this mandate was defined and codified into law by the central government, their specific roles remain unclear, particularly with respect to the participation of other stakeholders (the existing regulators, transit SOEs, municipalities, and metropolitan authorities). Moreover, an explicit budget for the MTAs is not provided by the central government; it remains unclear what sources of revenues MTAs will access to fund their activities.
- Regional authorities. The regional authorities (RAs) were mandated by the EU as a geographic mechanism for delivering EU resources to Portugal. However, the design of an administrative and a resource allocation process within the regions was left to the

central government. As a result, although created by the EU, RAs are (like regulators, SOEs, and MTAs) dependent on the CG for authority. That said, having been designated, they now seek a clear definition of a role in the strategy development framework and have some control over their own destiny in this regard by, for example, engaging other stakeholders who stand to benefit from greater regional control.

- Concessionaires. Concessionaires (CONC) are interested in opportunities to profit. This is most easily achieved through an infrastructure strategy development framework that favors expansion and a public sector that accommodates the profit motives of the concessionaires through lenient contractual mechanisms. The current framework has created numerous opportunities, and the regulators are effectively captured by the concessionaires. Greater EU involvement could further increase the number of opportunities, although competition for projects would likely increase, and the EU would likely be more sophisticated in negotiating concession contracts than Portugal. On the other hand, decentralization would fragment the number of opportunities and reduce profit potential.
- EU. The EU is competing with the central government for greater control over the resource collection and allocation aspects of the strategy development framework.
- Banks. Like concessionaires, banks thrive on opportunities to profit from expansionary infrastructure investment strategies, particularly when the state provides a buffer against down-side risks. The current framework is acceptable; however, greater EU involvement would reduce financial risks further (EU guarantees are more reliable than Portuguese government guarantees). On the other hand, decentralization of ownership and strategy development would increase financial risks and discourage participation by financial institutions.
- Users. Users of the infrastructure system are interested in high-quality, low-cost infrastructure performance. Participation in the strategy development framework is indirect, as the collective action problem is difficult for users to overcome—that is, organization of users to assert a role in the process is too costly. Users indirectly express their preferences through their consumption of infrastructure.
- Residents. The individuals composing the “user” and “resident” stakeholder groups are virtually identical. The distinction between the two groups is in the way that each relates to infrastructure. Whereas individuals interact directly with the infrastructure as users, they are, as residents, affected by infrastructure in other ways: as neighbors who must endure the visual and environmental impact of infrastructure and as businesses that rely on infrastructure to provide access for customers, employees, and suppliers. Residents do not participate directly in infrastructure strategy development, but their indirect participation is reflected in their participation in voting, paying taxes and voluntary advocacy.
- Spain. Greater EU participation would make coordination easier; however, that would also imply greater EU control over Spanish autonomy; decentralization would increase the cost of coordination.

In summary, some of the stakeholders groups are largely satisfied with the baseline strategy development framework, while some challenge it, and others are indifferent. Importantly, many of the stakeholder groups are dependent on others. For example, the SOEs and regulators are highly dependent on the central government. The central government is, in turn, dependent on residents (voters), although this dependence, at least for the infrastructure sector, is much weaker due to the presence of other issues outside of the infrastructure sector driving voter expression of preferences for central government leaders. As a result, the power of the central government over strategy development for the infrastructure sector in Portugal has been durable over many decades. By contrast, some other central governments are relatively weak with regard to strategy development in infrastructure; in the U.S., for example, strategy development is decentralized, driven largely by individual state interests.

7.3.2 Stakeholder typology

Next, we define a stakeholder typology based on the categories summarized in Mitchell, et al. (1997) and applied by Hanowsky and Sussman (2009) to an air transportation example. Stakeholders are defined according to three characteristics: power, legitimacy, and urgency. Each is defined below:

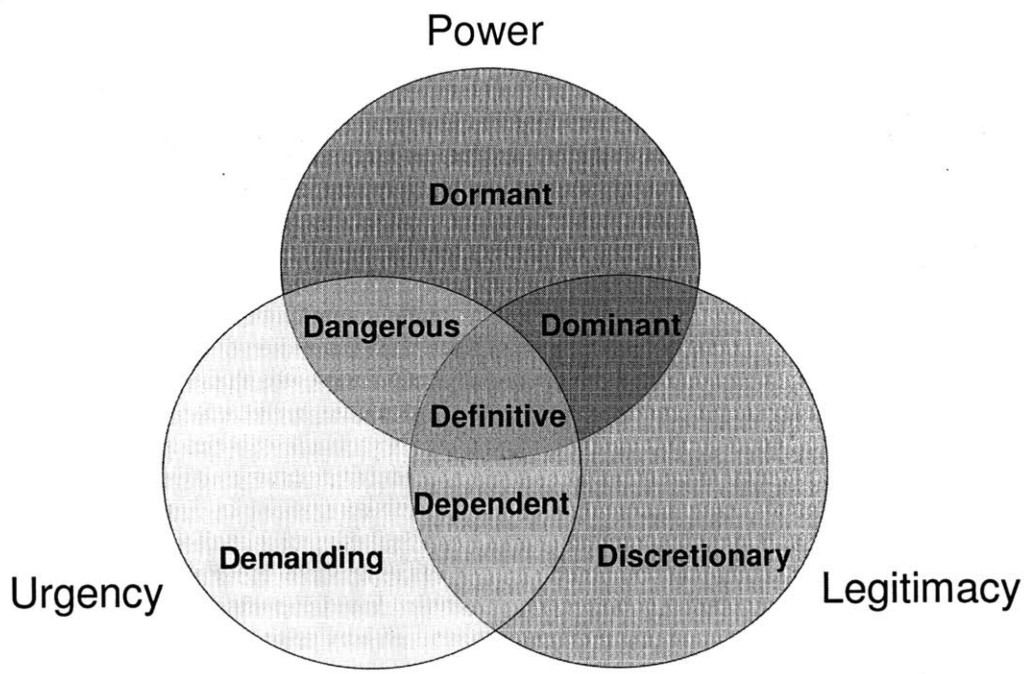
- *Power* is the extent to which a stakeholder has or can gain access to coercive, utilitarian, or normative power in order to influence the strategy development framework. An example of coercive power is the use of force (or the threat of the use of force). Utilitarian power refers to the ability to provide incentives to influence other stakeholders (typically financial incentives). Normative power is the ability to influence others based on the granting of non-tangible, symbolic rewards such as prestige.
- *Legitimacy* is the extent to which a stakeholder's actions are viewed as desirable, proper, and appropriate. Although this is a subjective judgment, for our purposes we characterize legitimacy as a function of the perspectives of all the other stakeholders in the system, principally the users and residents. For example, the central government stakeholder has a high level of legitimacy because almost all of the other stakeholders have validated its legitimacy through some means: residents by participating in elections and paying taxes, users by using the transportation system, municipal governments by accepting regulatory action, concessionaires by signing contracts, the EU by signing treaties, and so forth. Even if the actions or decisions of the central government are loathed by all of the aforementioned stakeholders, its legitimacy is clear.
- *Urgency* is the degree to which a stakeholder is advocating for some change to be made. Although urgency implies time-sensitivity, in our context it refers to the relative priority given to some desired change to the strategy development framework by a given stakeholder. For example, suppose hypothetically that the EU was advocating a broad shift in resource collection from general taxes to user fees as a top priority in the transportation sector. Regardless of its power to impose the change or its legitimacy in attempting to do so, the EU would nonetheless be characterized as having a high level of urgency with regard to the proposed change.

Each of these three characteristics is highly dynamic. As conditions and preferences change over time, so do the relative power, legitimacy, and urgency of any stakeholder. These changes may be brought about internally by a change within a given stakeholder (e.g., a decision to make urgent a particular issue over other issues) or by pressure from external stakeholders (e.g., a shift in power based on a reallocation of financial resources from one stakeholder to another).

Figure 7-12 summarizes these three characteristics in a Venn diagram. Stakeholders within the various overlap areas area classified in the following ways:

- Dormant. A stakeholder with power but neither legitimacy nor urgency.
- Demanding. A stakeholder with urgency but neither power nor legitimacy.
- Discretionary. A stakeholder with legitimacy but neither power nor urgency.
- Dominant. A stakeholder with power and legitimacy but no urgency.
- Dependent. A stakeholder with legitimacy and urgency but no power.
- Dangerous. A stakeholder with power and urgency but no legitimacy.
- Definitive. A stakeholder with power, urgency, and legitimacy.

Figure 7-12. Stakeholder typology as a Venn diagram (from Mitchell et al., 1997)



Imagine a stakeholder somewhere within the space represented by the Venn diagram—for example, in the "dependent" region, meaning the stakeholder has both legitimacy and urgency but no power. An impression given by this classification is that the stakeholder characteristics of power, urgency, and legitimacy are binary—you either have them or you don't. Of course, in reality, there is a range of continuous values for each characteristic. Rather than discrete lines separating the various regions of the diagram, it is instructive to think of stakeholders with increasing or decreasing values for power, legitimacy, and urgency. Likewise, where they are placed on the diagram corresponds to increasing or decreasing levels of dominance, danger, dependence, and so forth. As a stakeholder moves toward the center of the diagram, it has, in Mitchell's lexicon, increasing *salience*. Stakeholders with none of these characteristics have very little salience. For example, in our context, one could imagine a North American shipper who uses Portuguese infrastructure infrequently. Such a "stakeholder" may have very low levels of power, urgency, and legitimacy: still a stakeholder, to be sure, but at the far fringes of the Venn diagram and with very little salience.

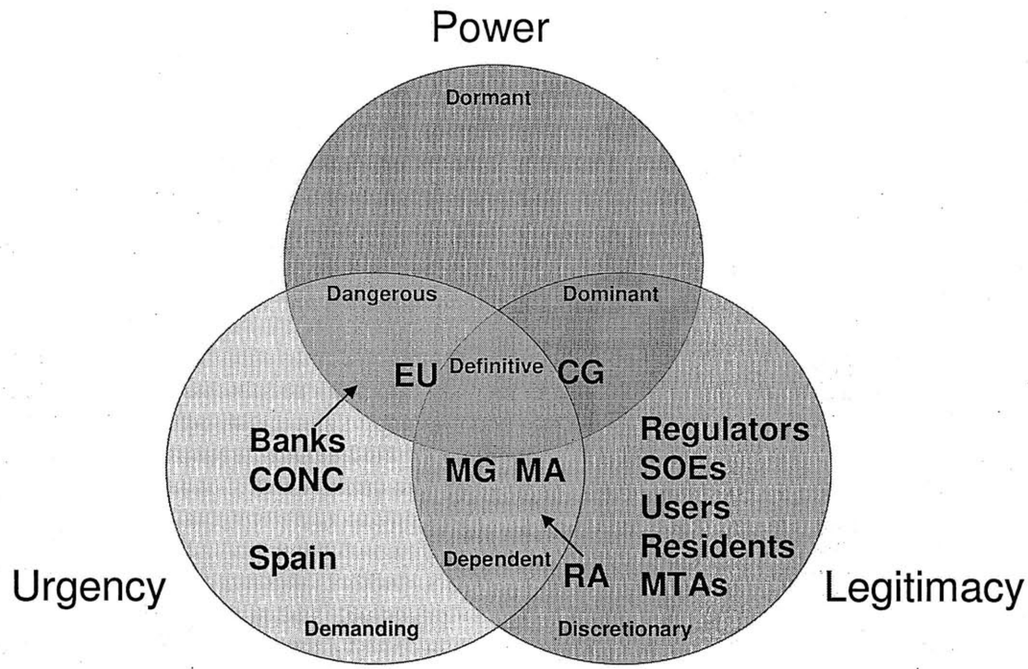
7.3.3 Positioning of stakeholders in the baseline framework

Results of this analysis are often used to understand the salience of stakeholders to determine the extent to which they should be involved in the design of a system or strategy. In our case, we are less interested in involving a collection of stakeholders in a design process; rather, we are interested in understanding the power structure of the various stakeholders under the baseline framework as well as under some of the alternative frameworks. Under which power structure are stakeholders most likely to enjoy good and stable outcomes? By understanding these dynamics we can assess more completely the potential performance of and explain potential barriers to alternative frameworks. Table 7-6 summarizes each of the stakeholders and their relative levels of power, legitimacy, and urgency with respect to the baseline strategy development framework, while Figure 7-13 illustrates each stakeholder's position on the Venn diagram.

Table 7-6. Characterization of stakeholder power, legitimacy, and urgency under the baseline framework

Stakeholder	Power	Legitimacy	Urgency
Central Government	High	High	Medium
Regulators	Dependent on CG	Medium	Low
SOEs (Road)	Dependent on CG	Medium	Low
SOEs (Rail)	Dependent on CG	Medium	Low
SOEs (Transit)	Dependent on CG	Medium	Low
Municipal Government	Medium	High	High
Metropolitan Authorities	Medium	High	High
Metro. Transport Authorities	Dependent on CG	Medium	Low
Regional Authorities	Low	Low	High
Concessionaires	Medium	Low	Medium
EU	High	Low	High
Financial Sector	High	Low	Potentially High
System Users	Low	High	Low
Residents	Medium	High	Low
Spain	Low	Low	Potentially High

Figure 7-13. Stakeholder power structure under baseline transportation strategy development framework



Within the baseline strategy development framework for transportation infrastructure, the two most salient stakeholders are the central government and the EU. In the view of the other stakeholders, the Portuguese central government's legitimacy is greater than that of the EU, making the central government a "dominant" stakeholder, and making the EU merely "dangerous." The central government has no urgency with respect to the strategy development framework. If threatened, however, it can attempt to change priorities and become the definitive stakeholder. Municipal governments and metropolitan authorities are likewise poised to become definitive stakeholders, but they currently lack the power to do so, and there are few imaginable scenarios in which they would attain such power. Metropolitan authorities, which bring together the collective power of two or more municipal governments, are more likely than municipal governments alone to attain the power necessary to challenge the central government's dominance of infrastructure strategy. This depends in part on their ability to self-organize and summon the financial resources necessary to seriously challenge the strength of the central government. Their success also depends on timing—that is, moving into the dominant position when the central government is unable to give urgent attention to the issue of infrastructure strategy development.

Financial institutions and concessionaires are poised to become "dangerous" stakeholders; they lack only power over strategy development. Their potential source of power lies principally in their ability to extort other stakeholders (e.g., in the case of concessionaires, monopoly power). However, monopoly power by concessionaires is contractually prohibited; meanwhile, both the central government and the EU have regulatory power over banks and concessionaires and ultimately can dominate them. Moreover, banks and concessionaires have little legitimacy in the eyes of other stakeholders.

Regulators, SOEs, and MTAs are unlikely to leave their status as "discretionary" stakeholders given their dependence on the central government for authority and resources. Likewise, Spain has little leverage for influencing strategy development and is likely to remain, at best, a "demanding" stakeholder. Lastly, "regional authorities" present an interesting and less predictable category. The power of regional authorities stems from both the EU and the central government. Like regulators, SOEs, and MTAs, regional authorities are in the "discretionary" category. However, given the uncertainty over the administrative hierarchy, it is possible that they could grow and advocate for greater involvement in the development of infrastructure strategy, putting them in a similar position as municipal governments and metropolitan authorities. Geographically speaking, regional authorities would have more leverage than metropolitan authorities in order to accumulate power, but this scenario is difficult to foresee given the administrative constraints imposed by the EU and the central government.

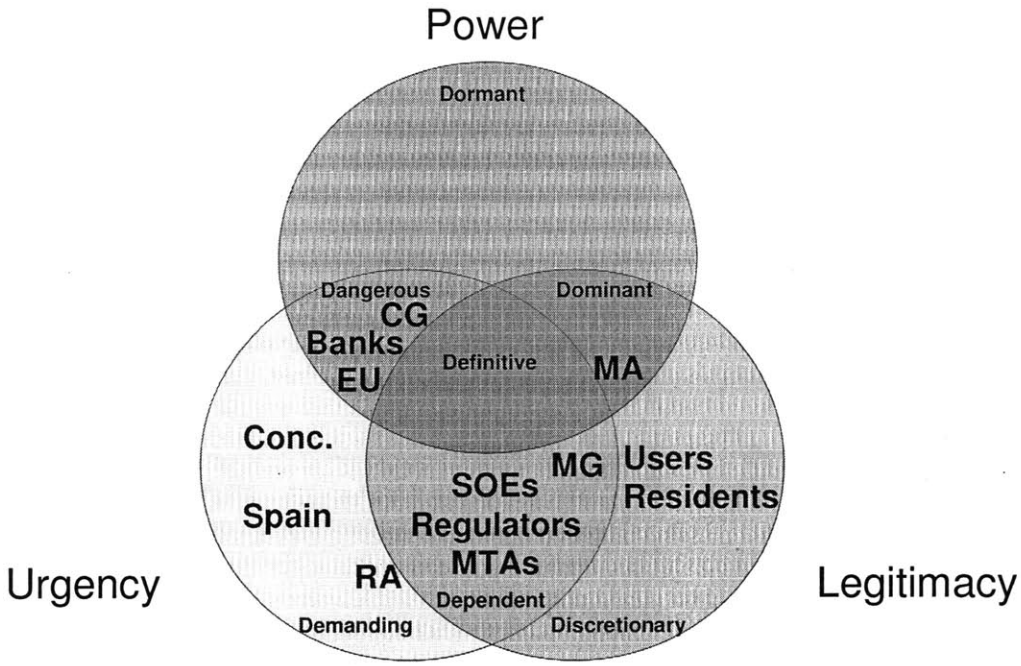
The key struggle for control of the strategy development framework, then, is among the EU, the central government, metropolitan authorities, and municipal governments. We now consider the power structure under alternative frameworks whereby organizations of various other geographic scales are able to achieve "definitive" status.

7.3.4 Positioning of stakeholders in alternative frameworks

Consider the scenario by which metropolitan authorities—bottom-up coalitions of municipal governments—are able to achieve greater control over Portugal's infrastructure strategy development. As previously discussed, a variety of factors would have to coalesce for this to occur. First, a metropolitan authority would have to self-organize, developing an institutional structure for delivering strategy accompanied by a legitimate and sustainable source of funding agreeable to the constituent residents and municipalities. Secondly, the authority would have to assert its influence over infrastructure strategy at a moment when the central government would be unable to respond by increasing the urgency of its own control over infrastructure—for example, during a political conflict or central government financial crisis. Of course, a single metropolitan authority would be unable to wrestle influence from the central government entirely. On the other hand, the metropolitan areas of Lisbon and Porto comprise over half the population and economic production of Portugal and would, together, represent a formidable challenge to central government authority over infrastructure strategy development.

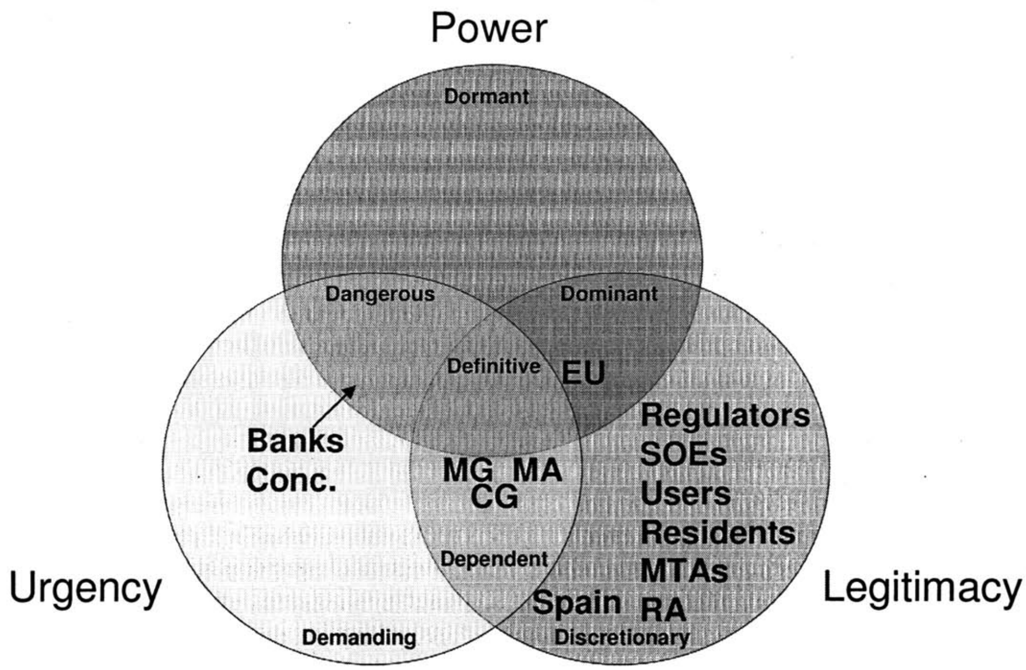
If the shift toward metropolitan authority dominance were to occur (Figure 7-14), then the EU would remain a "dangerous" stakeholder, and would be joined in that category by the central government. Notice the central government loses relative legitimacy in the process. However, the former apparatuses of central government influence (SOEs, regulators, MTAs) have enhanced urgency and, perhaps, diminished legitimacy. Importantly, the financial institutions have enhanced power over metropolitan authorities. Despite losing control over transportation infrastructure strategy, it is likely that the banking sector would remain under the regulatory control of the central government and/or the EU. Compared to the baseline framework, this represents a less stable situation. With the EU, central government, and banks all "dangerous" stakeholders, it takes only a modest misstep by the metropolitan authorities before the higher levels of government can legitimately reassert their influence over infrastructure strategy development.

Figure 7-14. Power structure with metropolitan dominance



On the other hand, if, starting from the baseline situation, the EU is able to gain greater legitimacy and move into the dominant position, the situation is more stable (Figure 7-15). All of the authorities representing lesser geographic scales (municipal governments, metropolitan authorities, and the central government) become dependent stakeholders with relatively less power over infrastructure decisions. Spain becomes a legitimate stakeholder, but because of EU dominance, its interest in Portugal's infrastructure strategy development is less likely to be urgent. Financial institutions and concessionaires still have the potential to become dangerous, but the threat is less than under central government dominance because, under this framework, the dominant stakeholder (the EU) is much more powerful.

Figure 7-15. Power structure with EU dominance



7.3.5 Discussion

Although we considered only 2 explicit cases in this stakeholder analysis (metropolitan-scaled and EU-scaled strategy development frameworks), the results represent directionally significant findings along the geographic scale dimension that can be applied across all 105 alternative frameworks considered in Chapter 6. The current (baseline) framework, in which the Portuguese central government exercises the greatest amount of control over strategy development, is unlikely to yield in the short term to any other geographic scales. The EU lacks the legitimacy within Portugal to assume greater control than it already has (even after two decades of generous transfers), while municipalities, metropolitan authorities, and regional authorities lack the power.

However, there are concerns that the lack of financial sustainability in the current nationally scaled framework for transportation strategy development could lead ultimately to a realignment of stakeholder salience. The stakeholder analysis reveals that moving toward smaller geographic scales would be unstable relative to the current framework, due to the combined looming influence of the EU, the central government, and financial institutions. On the other hand, moving toward a broader geographic scale (i.e., the EU), supposing the EU eventually gains legitimacy within Portugal, represents a relatively more stable situation.

A key outcome of this analysis is the relatively static "discretionary" status of two groups of stakeholders: users and residents. Every other stakeholder group identified in this chapter is a participant in the transportation sector: government authorities, road and rail builders, regulators, and so forth. Their relative salience waxes and wanes under varying frameworks. On the other hand, we find the users and residents persistently classified in our analysis as merely "discretionary"—classified as such because they face an insurmountable collective action problem. There are limited venues in which individuals can express their preferences to the more powerful, collective organizations that purport to represent them: voting, where an individual's preference for infrastructure policy is measured against preferences for a host of other important policy issues (e.g., health care, education, national defense); and consumption of transportation. As a result, the stakeholder analysis is somewhat of a self-fulfilling prophecy, as it confirms the power structure and salience of large stakeholders groups that collectively plan, build, and regulate transportation systems *as a means of existence* over individual users and residents who do not.

If one believes the results of the stakeholder analysis and simultaneously believes that the interests of collective stakeholder groups should be subservient to those of the individual users and residents, then alternative frameworks that favor the individual should be promoted. Strategy development frameworks should be designed in a way that elevates their power. After all, the transportation infrastructure system has a profound impact on everyone's lives, and ultimately the users and other impacted residents should be empowered as stakeholders. This is challenging, given the distributed, unorganized nature of users and residents vis-à-vis organized infrastructure providers.

Nevertheless, users' preferences are increasingly easy to measure using advanced revenue collection and other monitoring technologies. Residents' preferences remain difficult to measure; the democratic process of voting represents the most common—albeit indirect—method of measurement. For decades planners have relied on outreach to capture more input from users to supplement the coarse input obtained from elections, but only very recently have begun to harness the power of the internet as a tool for extracting greater information from residents (e.g., Lowry, et al., 2008). In addition to technology tools, smaller geographic scales for strategy development increase the likelihood that residents can self-organize and exert more power and influence over infrastructure strategy development than formally organized collectives such as SOEs and nationally and continentally scaled bureaucracies. For residents and users, then, this stakeholder analysis reveals that their salience in the development of infrastructure strategy will ultimately depend on greater emphasis on user fees and smaller geographic scales, alone and especially in combination. Given the entrenched interests and power structures of the collective organizations, however, getting there is a formidable challenge.

7.4 Integrated discussion of quantitative and qualitative analyses

The qualitative analyses presented in this chapter included empirical case studies, an expanded discussion of alternative framework dimensions, and analysis of stakeholders. The purpose was to complement and extend the quantitative analysis through an agent-based simulation whose results were presented in Chapter 6. We conclude in this section by comparing and contrasting the results of the two types of analyses. First we explore which phenomena were corroborated by both types of analysis, which were contradicted, and speculate why. Next, we discuss, based on the results of both types of analyses, which alternative strategy development frameworks are "good." Finally, we include a discussion of the significance of these results for the notions of deliberate and emergent strategy.

7.4.1 Comparison of quantitative and qualitative analysis results

The quantitative and qualitative analysis corroborated several phenomena. One of the more important outcomes predicted by both analyses is that larger geographic scales and increasing public ownership have a positive influence on the *quantity* of investment in infrastructure.

Moreover, both analyses confirm that the geographic scale of the agents responsible for making resource collection and allocation decisions within an infrastructure strategy development framework will tend to address local concerns *before* investing in connections to other jurisdictions. Municipalities, regions, and even the central government exhibited this behavior in the simulation model; in reality, Portugal also exhibited this behavior as it invested heavily in domestic infrastructure in the 1990s before embarking on international connections preferred by the EU. In some cases, despite a strong EU influence, many of those international connections, such as the HSR network, remain un-built.

Also, as expected, the quantitative and qualitative analyses both showed that concessions will invest more conservatively than infrastructure networks administered by a purely public authority. However, in reality, a variety of hybrid approaches and subsidy arrangements can alter the nature of this important relationship with concessionaires. For example, Portugal's extensive use of shadow tolls, EU subsidies, and minimum revenue guarantees enticed concessionaires to compete for the right to build more infrastructure than they would have built without those advantages. Experience suggests that purely private frameworks, under certain regulatory schemes, could invest more than a concession-based framework and may actually even out-invest some frameworks involving public ownership of infrastructure.

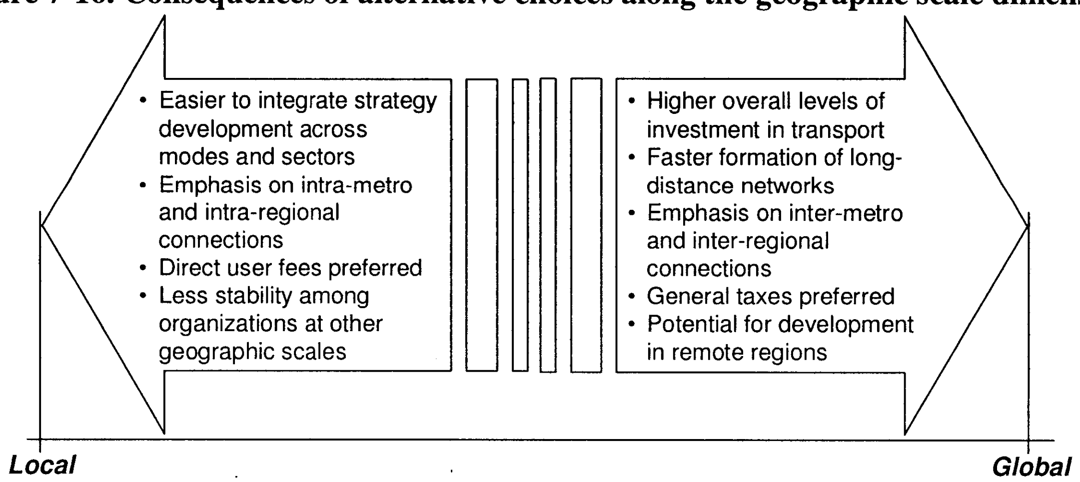
Several results of the quantitative analysis contradicted the results of the qualitative analysis. First, the simulation model under the highly decentralized frameworks of municipal and link-based geographic scales failed to invest in long-distance corridors in the same way that regionally and nationally scaled frameworks did. By contrast, empirical evidence from the case studies suggests it is possible for long-distance networks to emerge even under highly decentralized control. The case of the private turnpikes offers one such example, although it is not a transferable experience to modern Portugal. Another more transferable example is the emergence of trans-European networks even without direct EU control of investments. In order to achieve these long-distance corridors under decentralized frameworks in the EU, however, targeted assistance is provided, particularly for jurisdictions with poor revenue-generation capabilities. This "hybrid" approach, combines decentralized decision-making with centralized financial incentives. An explanation for the absence of long-distance corridors is the uneven distribution of wealth and population: sparsely population areas of the country simply do not have the financial means to overcome the lumpy costs of highway infrastructure investments. Although similar studies of decentralized infrastructure strategy development have discovered "emergent" corridors even under decentralized control, they tended to focus on areas with relatively more evenly distributed population and traffic such as metropolitan areas. For Portugal, the inability to connect important centers of commerce domestically or internationally under decentralized frameworks could hinder economic development and exacerbate the inequality of access and development between the country's coastal and interior regions.

Another point of contradiction was on the preferred geographic scale. In the final analysis of the simulation model results, it was suggested that the regionally based frameworks were robust, offering consistently strong performance across a range of evaluation scenarios. The qualitative analysis, however, particularly the stakeholder analysis, suggested that sub-national geographic scales would be unstable due to the looming strength of the "dangerous" central government, EU, and financial institutions. Any failure to deliver satisfactory results would offer openings for the central government to reclaim its dominant position in infrastructure strategy development. Especially given the relatively weaker revenue generation potential of sub-national jurisdictions in Portugal, it is not difficult to conceive of scenarios in which they lose favor with other stakeholder groups (namely voters), allowing the central government to reclaim its legitimacy and dominance.

7.4.2 Integrated findings for dimensions of strategy development frameworks

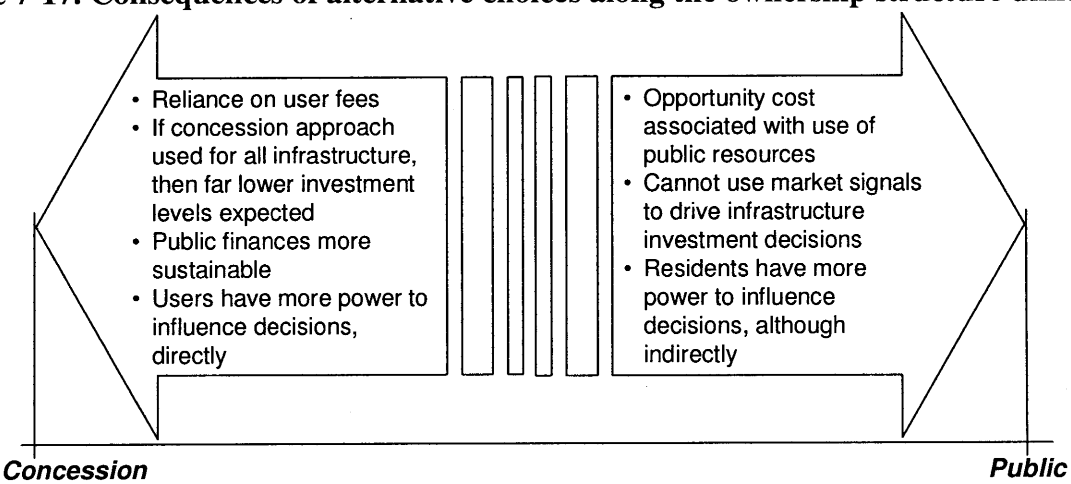
What is the "right" geographic scale? Figure 7-16 summarizes some of the key findings as one moves in either direction along the "geographic scale" dimension. As previously stated, the results of the simulation model suggest that regionally and nationally scaled governments offer a robust framework in the context of Portugal (i.e., the 5 regional authorities). There are several caveats, however. The stakeholder analysis suggests, for example, that any sub-national geographic scale in Portugal would be unstable and could easily lead back to nationally scaled control. By the same token, both the quantitative and qualitative analyses also suggest that larger geographic scales tend to over-invest in infrastructure, which will lead to inevitable financial problems. The fact that Portugal is facing a financial crisis in the transportation infrastructure sector is evidence of this tendency. The stakeholder analysis suggests that, at such a juncture, Portugal should be wary of creeping involvement of the EU. If the central government fails to deal with the financial challenges in a careful and responsible way, the EU could gain legitimacy and, as a consequence, a much greater role in the infrastructure strategy development framework (by the same mechanism that the central government would claim dominance over regional authorities). This means, for example, that rather than merely providing incentives for Portugal's decision-making, the EU will be *making* the resource allocation decisions.

Figure 7-16. Consequences of alternative choices along the geographic scale dimension



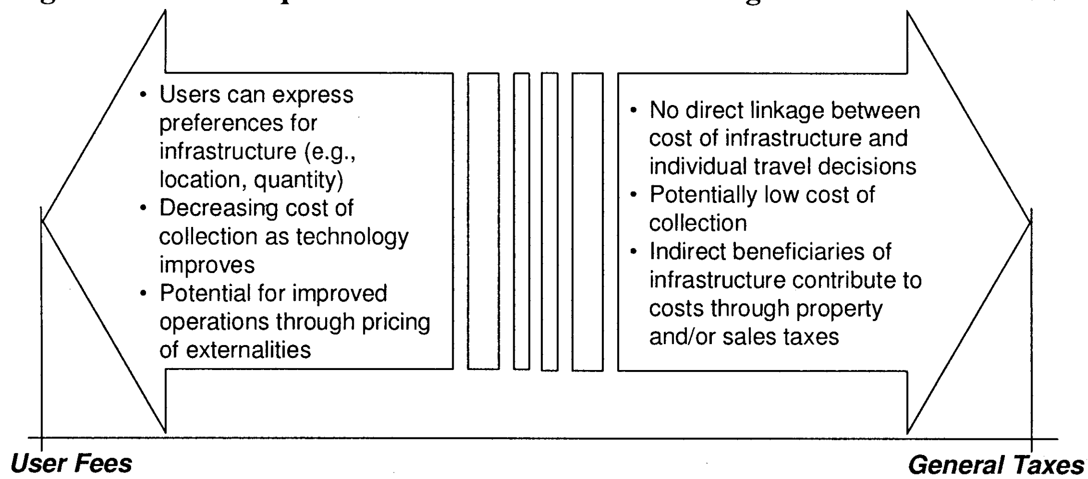
What is the "right" ownership structure? Figure 7-17 illustrates the key findings of the combined analysis along the dimension of ownership structure. Analyzing this dimension is challenging, given the ability of the public partner of a concession to entice participation from private sector bidders via subsidies, guarantees, and other favorable contractual conditions. Such mechanisms distort the market signals from the private infrastructure suppliers, negating one of the principal theoretical advantages of the concession approach. The result is that one can construct an equivalent network using a concession-based framework and a purely public ownership-based framework. If capital is not readily available or cheap to the public sector, then the concession approach can be an attractive short-term tactic; however, if capital is readily available and relatively cheap, then public ownership is more or less equivalent to, if not more cost-effective than, concessioned infrastructure. All that said, if the public sector uses the concession approach as a true gauge of what is affordable and desirable from a market standpoint, rather than as a means of financing, then there can be substantial benefits from the involvement of the private sector. The simulation model results suggest that concession arrangements can allow the public sector to identify and assemble packages of investments, combining some "winners" and some "losers" that, on the whole, are attractive to the private sector. As an aside, fully private ownership structures, though not feasible in today's Portugal (the institutional structure does not allow it; moreover, most transportation infrastructure corridors are largely built out), has similar advantages as a true concession.

Figure 7-17. Consequences of alternative choices along the ownership structure dimension



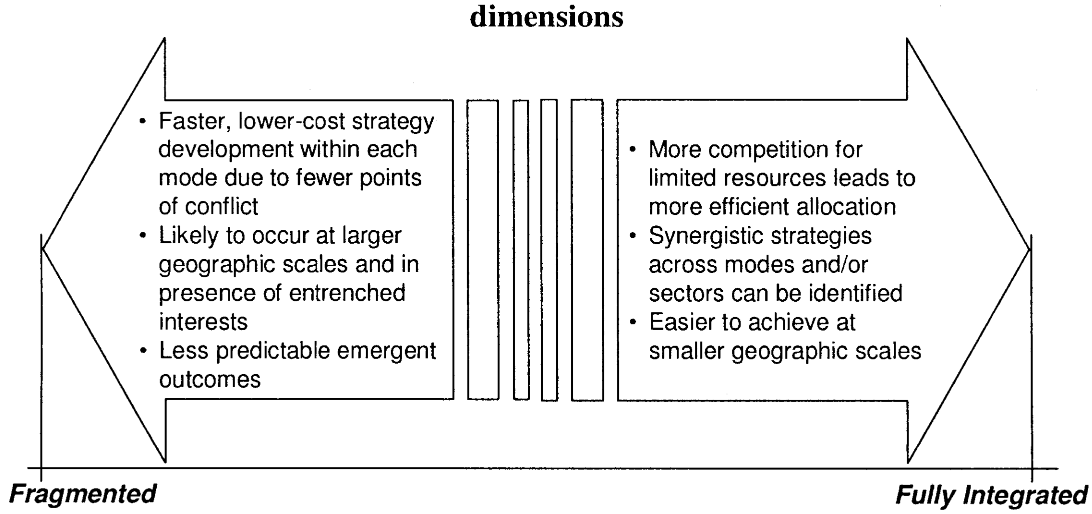
What is the "right" type of revenue? Figure 7-18 illustrates key findings along the revenue dimension. Direct user fees enable operational benefits by internalizing external costs of travel through such approaches as weight-, emissions-, and congestion-based pricing. Moreover, user fees allow transportation users to express their preference for location-specific infrastructure investment levels to system managers. By contrast, general taxes are blunt instruments, and it is difficult for residents to express through voting a detailed level of preference for tax rates (and, therefore, budgets) for infrastructure relative to other government services, particularly for specific locations. As the size of the government and/or the number of services it provides increases, the ability of consumers to express their infrastructure preferences becomes even more diluted. For relatively smaller jurisdictions with fewer services, user fees are still preferred, but taxes may offer a reasonable means of location-specific expression of preferences for tax rates and infrastructure budgets. User fees overall are preferable at least for funding a portion of infrastructure investments; at the same time, general taxes may be appropriate in some situations as a relatively low-cost mechanism for capturing contributions from indirect beneficiaries of infrastructure such as land owners and developers. Again, however, such taxes are best assessed at relatively smaller geographic scales in order to more closely match the contribution to the level of benefit—an approach akin to stock purchases in private turnpikes.

Figure 7-18. Consequences of alternative choices along the revenue dimension



What is the "right" institutional architecture? Figure 7-19 illustrates the consequences of alternative choices along this dimension. The qualitative analysis suggests several consequences of greater integration across modes and sectors as well as several barriers. The costs of greater integration are, essentially, longer and more costly decision-making processes due to the involvement of more stakeholders and opinions. The most predictable consequence of greater integration is greater competition: if the vision of integration is to pool resources across modes and sectors and to make resource allocation decisions with broadly measured benefits, then all participants should be prepared to compete in a larger field for those limited resources. The risk for some participants is that they will be allocated fewer resources under such a framework than under a uni-modal and/or uni-sectoral approach. Given the entrenched interests that exist in Portugal (and elsewhere) for transportation as a sector and for particular modes of travel within transportation, it is difficult to envision change toward more integration. Participants are reluctant to risk losing their "share." Moreover, design of a new, integrated resource allocation process is destined to be controversial, as each group attempts to design a framework that favors its own sector and/or mode.

Figure 7-19. Consequences of alternative choices along the modal/sectoral integration dimensions



Interestingly, the barriers to integration are less intense at smaller geographic scales. The entrenched interests at the municipal and metropolitan levels, for example, are quite different from those at the national scale. At smaller scales, there is less interest in perpetuating budgets of agencies or SOEs or other organizations that operate at a higher level. Smaller geographic scales, then, represent an opportunity to "divide and conquer" the entrenched interests and pursue a more integrated approach to infrastructure strategy development. Of course, this potential benefit must be traded off against the disadvantages of smaller-scaled decision-making units—namely, parochial interest, difficulty building consensus with neighbors, and more limited revenue generation capabilities.

7.4.3 Deliberate versus emergent strategy

In closing, it must not go unstated that the quantitative and qualitative analyses largely confirmed one of the principal assumptions of this entire exercise: that the transportation infrastructure networks we observe today are indeed *emergent*, reflecting emergent strategies which are influenced to varying degrees by the deliberate strategies of the various interacting organizations and individuals in the transportation sector and beyond. For almost any context examined, there is no single strategist with total control over the resource collection and allocation decisions in the transportation sector. Instead, resource collection and allocation are played out in a complex set of interactions among numerous stakeholders with distinct, often competing views and objectives, at a variety of geographic scales, with a variety of levels of resources available to them, and with unique ownership structures and decision-making approaches.

Infrastructure networks that emerge are more accurately predicted as functions of the underlying strategy development frameworks, rather than as a function of any deliberate strategies that may exist. For example, the statement that "large, centralized decision-makers tend to build more than small, decentralized decision-makers" is seemingly self-evident. But, importantly, this statement is observable in many contexts, more or less *regardless of the deliberate strategy of the constituent decision-makers.*

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8 Conclusions

This thesis has explored a range of issues in the areas of transportation infrastructure technology, strategy, and strategy development frameworks. In this chapter, we recapitulate the motivations, objectives, and key findings of the thesis. Next, we summarize future work and extensions of this research, including a more detailed illustration of one such extension: a predictive application of the agent-based simulation model. This leads into a set of recommendations for Portugal and, finally, a summary of the contributions of the thesis and a closing word.

8.1 Summary of motivations, questions, methodology, and findings

8.1.1 Motivation

We began this thesis with three underlying motivations.

1. Most research and practice relating to advanced transportation technology has, to date, focused on operational applications. The initial motivation of this work was to identify and explore the implications of advances in technology for transportation *strategy*.
2. Traditional theory and practice have emphasized *planning* as the exclusive and preferred method of strategy development, largely to the exclusion of other forms. We were motivated by an opportunity to expand the range of interpretations of the term *strategy* for transportation systems by building on the rich literature in strategy from other fields—specifically, to recognize and explore the notion of emergent strategy.
3. Finally, having identified strategic applications of technological advances and expanded the range of interpretations of strategy for transportation, it became possible to consider alternative strategy development frameworks. We were motivated by an interest in exploring the consequences of moving toward any of these alternative frameworks, most notably along the dimension of the geographic scale of infrastructure-supplying organizations.

8.1.2 Questions

Motivated by the above-described factors, we developed three sets of research questions (descriptive, exploratory, and normative), restated below. Following each set of questions is a summary response, based on the findings of our research. We elaborate on these responses in Sections 8.1.3 and 8.1.4.

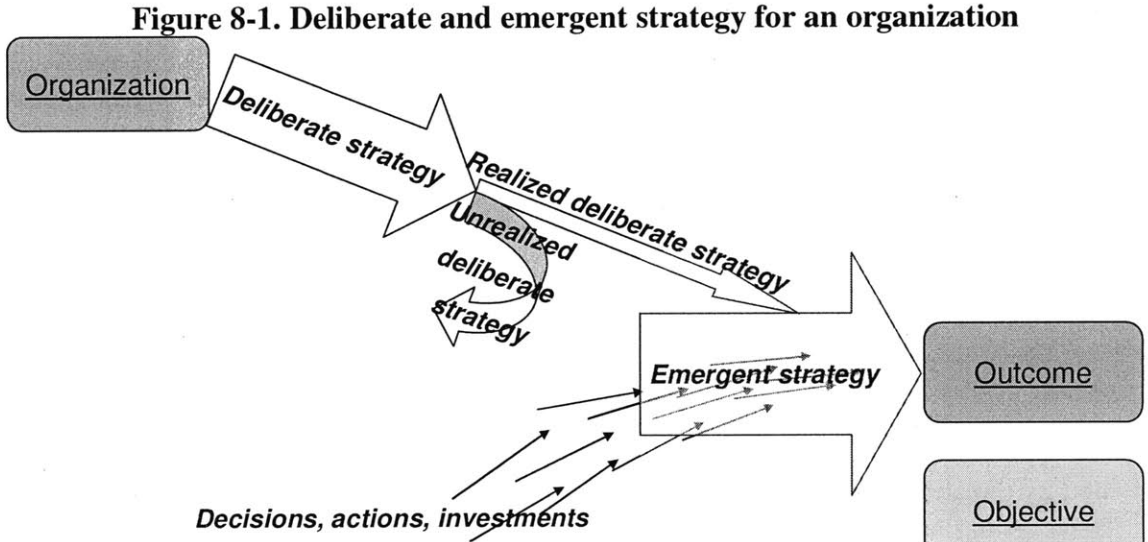
8.1.2.1 Descriptive

How *is* strategy currently developed for transportation infrastructure systems?

1. Strategy: Fundamentally, what *is* strategy (as a concept) in the context of surface transportation? How do organizations develop strategy for transportation infrastructure? How do "regions" develop strategy for transportation infrastructure?
2. Technology: What are the relationships between surface transportation technologies and strategies?
3. Scale: What are the historical and contemporary spatial scales at/for which infrastructure strategies are developed?

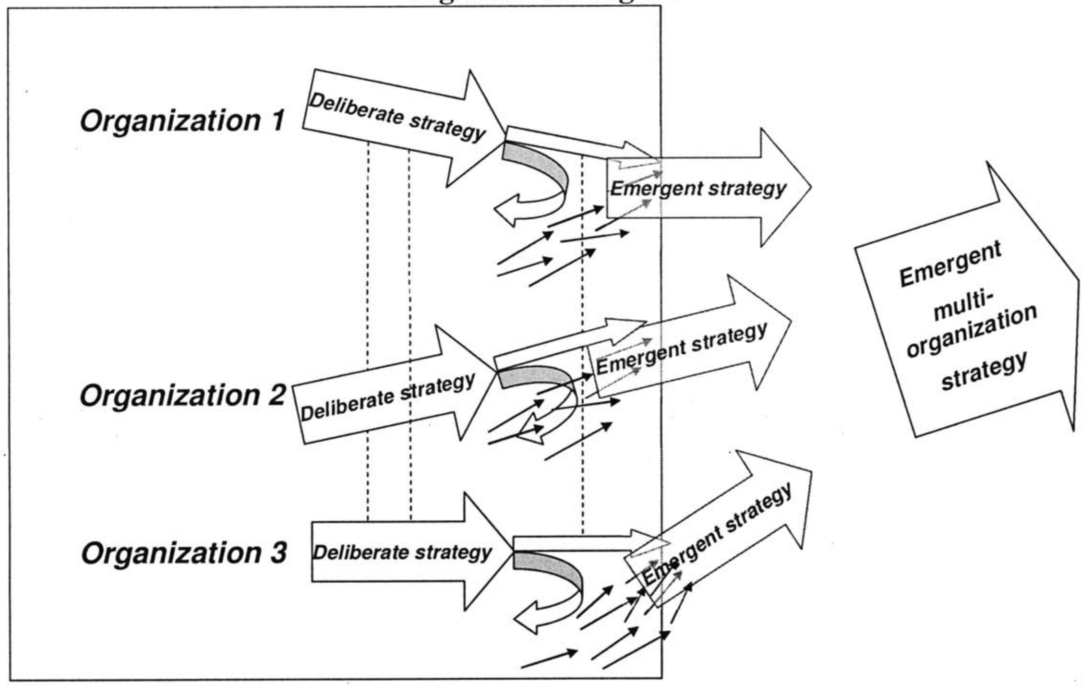
We define strategy as the set of processes, rules, principles, policies, guidelines, plans, actions, investments, decisions, behaviors and other heuristics employed by an individual, organization, or region – both pursued intentionally as deliberate strategy and observed in retrospect as emergent strategy – in order to survive and/or thrive in the presence of competition. Figure 8-1 summarizes the relationship between deliberate strategy and emergent strategy within an organization. Organizations can develop strategy through deliberate processes such as planning, although there are other deliberate approaches to strategy such as design and positioning as discussed in Chapter 3. Deliberate strategy development is distinguished by the fact that it is intentional, process-oriented, and objective-driven; the objective is illustrated at right. The product of deliberate strategy development is a deliberate strategy, which can be reflected at least in part in a *plan*; however, it may also be reflected in the principles, rules, guidelines, and other heuristics adopted by the organization. Over time, as the organization interacts with its environment, which includes other organizations (e.g., competitors, collaborators, owners), it will make decisions, take actions, and make investments. These decisions combine with decisions taken in concert with the deliberate strategy to reveal an organizational trajectory that results in an outcome. In retrospect, we can observe the emergent strategy inherent in this pattern. Although the deliberate strategy may influence the emergent strategy, the strategy that emerges often differs, sometimes substantially, from the one that was planned deliberately.

Figure 8-1. Deliberate and emergent strategy for an organization



For transportation, we are typically interested in the strategy and performance of a transportation infrastructure system over some geographically defined region, such as a neighborhood, metropolitan area, or country. Invariably, in such contexts, there are multiple organizations that influence transportation infrastructure strategy. Figure 8-2 illustrates the relationship between a strategy development framework, deliberate strategy, outcomes, and emergent strategy in a multi-organizational context. Each "row" represents deliberate and emergent strategy development processes for a single organization. The collection of organizations, their deliberate strategy development processes, their deliberate strategies, and their relationships with one another constitute a *strategy development framework*. The interactions among these organizations and their environment produce outcomes from which emergent strategies can be inferred, both for individual organizations and for the multi-organization region as a whole, as illustrated at the far right column of the figure.

Figure 8-2. Strategy development framework and emergent strategy for a multi-organization region



Throughout history, technology has influenced the development of surface transportation strategy. The 19th century gave us the steam engine and the railroad, which transformed surface transportation, only to see it transformed again by the advent of the combustion engine and the automobile in the 20th century. These technological advances represented major steps forward in the operational performance of transportation systems and, at the same time, forced substantial changes in the development of strategy for and the delivery of infrastructure systems. The application of information and communications technologies to transportation infrastructure systems in the 21st century is the latest in the continuing co-evolution of vehicle and infrastructure technologies. Studies of the impact of such technologies on transportation operations have been considerable; their impacts on transportation strategy, however, are nascent, and this thesis represents a contribution in that direction.

Infrastructure providers, ranging from individuals to administrations covering vast territories, have experimented over several millennia with numerous approaches for delivering infrastructure. Political and economic changes have led to many reorganizations of the institutions responsible for delivering infrastructure as well as a proliferation of approaches. Even today, there are many approaches across the world at a variety of scales, often overlapping within a single region—for example, a municipal street provider, a regional transit provider, and a national highway provider. The combination of new technologies and new conceptions of strategy invites us to consider anew the appropriateness of these alternative geographic scales in transportation infrastructure systems.

8.1.2.2 Exploratory

What is the universe ("solution space") of conceivable approaches for developing strategy—i.e., how *can* we imagine developing strategy for transportation infrastructure systems?

1. Strategy: What approaches to strategy development beyond the existing ones (principally planning) can be applied to the transportation sector?
2. Technology: What current and future anticipated technologies will impact the development of strategies for transportation infrastructure?
3. Scale: Especially in light of advanced technologies, what spatial scales of ownership and strategy development are available for transportation infrastructure systems?

The dimensions of interest along which strategy development frameworks vary include institutional architectures, decision-making processes, and geographic scales. In this research, we identified a wide range of combinations of values along these dimensions and discovered that many have, in fact, been pursued in practice to varying extents throughout history. Technology is one of the driving factors that determines the attractiveness of specific alternatives available for selection along each dimension.

In contemporary practice, a number of advanced technologies are allowing us to reconsider once again the strategy development frameworks of transportation infrastructure systems. Chief among them are improvements in revenue collection technologies such as electronic toll collection (ETC) systems and automated farecards. Together with system monitoring techniques, revenue collection technologies allow for a restoration of a more direct relationship between transportation customers and suppliers. In the last century, as speeds improved and travel volumes increased, it became impractical to track and/or charge users for their consumption of travel, effectively severing the relationship between customers and suppliers of infrastructure systems. This severed relationship with users invited governments to step in and represent the collective interests and preferences on their behalf and, in many cases, governments also became the suppliers of infrastructure.

Along with government involvement in transportation infrastructure come the institutions of government, including political boundaries. Political boundaries determined to a large extent the geographic scales at which transportation systems are supplied. As technologies allow for tracking and payment collection from large volumes of high-speed travelers, however, there is an important opportunity to restore the relationship between customers and providers of infrastructure. This restoration can drive significant changes in the strategy development framework, including new types of revenues (i.e., greater reliance on direct user fees), new ownership structures (i.e., a greater role for the private sector), and new geographic scales for infrastructure-supplying organizations (i.e., metropolitan, regional).

8.1.2.3 Normative

In order to improve the likelihood of a good strategy for a transportation infrastructure system, how *should* we develop strategy—using what frameworks?

1. Strategy: What is *good* strategy? How *should* transportation organizations develop infrastructure strategy? How should "regions" develop strategy for transportation infrastructure?
2. Technology: What surface transportation technologies are the most effective enablers of improvements to infrastructure strategy development?
3. Scale: What are the *appropriate* spatial scales for transportation infrastructure strategy development? What technologies can help us achieve those appropriate scales?

A good strategy in the context of transportation infrastructure systems is one that results in good performance, measured along the dimensions that matter to those who interact with the system. The many complexities inherent in infrastructure systems, however, confound the ability of any single organization or set of organizations to develop and pursue, unconstrained, a strategy for infrastructure. Constraints are imposed by other individuals and organizations (whether in competition or in cooperation), financial limits, changing political and economic conditions, environmental limits, and technological change. The deliberate strategies produced by organizations are often unrecognizable in the actual outcomes, and it is from these outcomes that we can discover and characterize emergent strategies. Given the existence of strategies both deliberate and emergent, we have concluded that a *good* strategy is one that:

- Recognizes the limits of deliberate, objective-driven strategy making to influence outcomes;
- Anticipates emergent outcomes by predicting what is likely in a given context; and
- Attempts to shape emergent strategy through deliberate efforts that explicitly recognize the existence and expectation of emergent outcomes.

The technologies that are the most effective enablers of improved strategy development are those that link strategists more strongly with infrastructure customers: revenue collection and other system monitoring technologies. Ultimately, customers are the most powerful drivers of infrastructure strategy development—whether directly through their contribution of user fees as consumers to capital budgets or indirectly through their influence as voters on elected officials who determine budgets. Consequently, whether governments or private companies, and whether operating at small or large geographic scales, organizations that supply infrastructure can best develop deliberate strategies and anticipate emergent strategies when they understand the preferences of the customers, and measurement of these preferences is increasingly enabled by a suite of transportation technologies.

Finally, there is no "one size fits all" geographic scale for development of strategy that leads to optimal performance of a transportation infrastructure system. The key trade-offs of relatively larger geographic scales are: a tendency to agglomerate revenues and spend more; improved connectivity and accessibility, broadly speaking; and greater imbalances in the level of investment relative to the level of revenues across regions, notably a net subsidy from urban to rural areas. For Portugal, the regional scale offered a consistently robust performance relative to a range of performance metrics considered in Chapter 6, but as we saw in Chapter 7, the development of capabilities among regional and/or metropolitan jurisdictions depends on authority that must be granted by the central government.

8.1.3 Methodology

To address the research questions described in Section 8.1.2, we developed and presented in Chapters 4 and 5 a combined quantitative and qualitative analysis. First, we characterized strategy for transportation systems and designed a range of alternative frameworks for strategy development, many of which were enabled by advances in technology. Next, we analyzed the alternative frameworks both quantitatively and qualitatively:

- Quantitative analysis comprised an agent-based simulation of organizational investment decision-making in a transportation infrastructure network under a variety of alternative

strategy development frameworks, using the intercity highway network of Portugal as a context for application of the simulation. The outputs of the simulation (a series of investments in the infrastructure network) reflected an emergent strategy and were evaluated according to a range of metrics in order to judge the relative performance of each framework.
- The qualitative analysis extended the simulation in two ways: by (1) presenting case studies of alternative frameworks from a variety of contexts and assessing the behavior and performance of these frameworks empirically; and (2) performing a stakeholder analysis which allowed us to judge the attractiveness, feasibility, and stability of alternative frameworks from various stakeholder perspectives.

8.1.4 Findings

The findings of the thesis stem not only from the quantitative and qualitative analyses but also from the execution of these tasks and the integrated evaluation, which enable us to provide more detailed responses to the research questions. We present the central findings in this section in bold text, along with extended discussion of trade-offs and caveats.

The combined quantitative-qualitative analysis produced a diverse set of results, some expected and some contradictory. As expected:

- One of the more important outcomes predicted by both analyses is that **larger geographic scales and increasing public ownership increase the quantity of investment** in infrastructure. The simulation results suggest a tipping point between the municipal and regional scales, below which the amount of investment in intercity transportation infrastructure drops off steeply, due to the inability of smaller-scaled jurisdictions to share revenues and the fact that relatively wealthier jurisdictions eventually saturate their external connections and continue accumulating budgets, unspent. The empirical cases likewise suggest that more centralized administrations lead to higher levels of investment. However, one caveat is that, at smaller geographic scales, organizations with excess budget could allocate it to internal transportation connections, external connections with local benefit, or to other sectors altogether. The simulation and empirical cases both suggest that public entities will invest in more extensive networks than they would through a pure concession approach, but there is little contemporary evidence of how a fully private framework would perform.
- Both analyses confirm that **organizations tend to address local concerns *before* investing in connections to other jurisdictions**, where "local" corresponds to the geographic scale of the organizations responsible for making resource collection and allocation decisions for the infrastructure system. Nationally scaled frameworks focused investment during early years of the simulation of internal congested connections, with corridors connecting to Spain emerging only in latter years. The empirical evidence from Portugal's experience likewise suggests that the country has been more likely to focus on internal connections (e.g., Lisbon-Porto corridor improvements and improved connections to the country's interior) before investing in large-scale international connections, whereas the EU is promoting and enticing international connections more quickly.
- As expected, the quantitative and qualitative analyses both suggested that **concession-based approaches invest more conservatively** than infrastructure networks

administered by a purely public authority. Many links in the network perform poorly financially, even with user fees, which makes a pure concession approach unlikely to result in a large, dense network. In the simulation model, it was possible to couple strong performers with poor performers in order to expand the size of the network, while in practice the public sector typically entices private participation in links with poor expected performance through revenue guarantees, grants, and low-interest loans.

Several results of the quantitative analysis contradicted the results of the qualitative analysis.

- **The simulation model results suggest that frameworks with highly decentralized geographic scales may fail to invest in long-distance corridors** in the same way that regionally and nationally scaled frameworks did, which is a potential drawback to competitiveness for Portugal. By contrast, empirical **evidence from the case studies suggests that some long-distance networks will emerge even under highly decentralized control**. This was particularly true in the case of the private turnpikes of the U.S. and the United Kingdom. However, in both cases, even where long-distance corridors emerge, the level of connectivity and accessibility is unequal, with dense nodes favored over sparsely populated regions.
- The final evaluation of the simulation model results suggested that **regionally scaled frameworks were robust**, offering consistently strong performance across a range of evaluation scenarios. The qualitative analysis, however, and in particular the stakeholder analysis, suggested that **sub-national geographic scales would be unstable** due to the larger number of "dangerous" stakeholders (using Mitchell's terminology): the central government, the EU, and financial institutions.

Methodologically, our findings are summarized as follows:

- **It is feasible to build a quantitative representation of strategy development frameworks and, through a simulation approach, to predict emergent outcomes**. The agent-based approach applied in this thesis captures the interaction of numerous actors within mainland Portugal, relating the physical elements of the transportation infrastructure system (the environment of the model) to the institutional sphere (the agents) via a set of modeling rules designed to reflect the physical-institutional linkages.
- **We can combine quantitative results from the simulation model with qualitative results of empirical case and stakeholder analyses** in order to derive a more subtle understanding of the relationships between strategy development frameworks for transportation infrastructure systems and the performance of those systems.
- The methodological findings that represents perhaps the most significant departure from prior research is the fact that we demonstrated how **real data from a rather extensive context (the nation of Portugal) can be used as inputs to both the quantitative and qualitative analyses**, allowing us to generate outputs that inform decisions of importance in an actual policy context.

Finally, with regard to dimensions of the strategy development frameworks, we offer the following findings:

- *What is the "right" geographic scale?* **The results of the simulation model suggest that regional and national governments offer a robust scale.**[22] The qualitative analysis suggests, however, that regional scales are unstable and could easily lead back to more centralized ownership. By the same token, both the quantitative and qualitative analyses also suggest that larger geographic scales tend to invest more in infrastructure, which often lead to financial problems if sufficient growth in taxes and/or tolls does not exist to support the investments. Moreover, the selection of any geographic scale comes with the caveat that the best scale depends on the set of performance metrics selected and the degree to which they are valued, which means that any scale could, in principle, be justified. One surprising outcome of the simulation model was the failure of municipally scaled frameworks to produce long-distance corridors. We hypothesized that even very small geographic scales would be capable of producing similar outcomes as large geographic scales due to the underlying dynamics of the travel demand, which would drive allocation of revenues and investments even in highly decentralized settings. However, the municipal frameworks performed quite differently from the regional and national frameworks, due largely to high capital costs and inability to share the excess revenues generated by relatively wealthier municipalities to overcome those high capital costs.
- *What is the "right" ownership structure?* **If the public sector uses the concession approach as a true gauge of what projects are desirable from a market-based standpoint, rather than as simply a means of financing, then there can be substantial benefits from the involvement of the private sector**. Using concessions can be beneficial, but as the simulation model demonstrated, there are limits to the extent of a network that can be supported through tolls. One way to extend the quantity of infrastructure, suggested through the simulation model results, is for the public sector to identify and assemble packages of investments in various links in the network, combining some "winners" and some "losers" that, on the whole, are attractive to the private sector. Moreover, some of the "losers" may in fact be necessary feeders of traffic into the more profitable segments of the concession. In order to construct portions of the network that are less desirable from the perspective of private participants, however, theory suggests that public sector is better served by delivering these itself, to the extent that it is financially capable. In practice, however, we see utilization of the concession approach as a means of *financing* infrastructure projects, together with incentives for private participants such as revenue guarantees. Moreover, shadow tolls allow for higher volumes of travel than would be achievable under real tolls, thereby serving as an indirect transfer from general tax to private concessionaires.
- *What is the "right" type of revenue?* **The quantitative simulation results suggest that general taxes offer better outcomes than user fees. The qualitative analysis, however, suggests that empowering the stakeholder groups of "users" and "residents" is better achieved through user fees**, which allow them to express preferences for location-specific infrastructure investments to system managers. Moreover, user fees shift the burden of infrastructure funding to customers, freeing general tax revenues for other purposes, a benefit that is not captured in the simulation model. Another outcome of the simulation model was that, assuming user fees are implemented, smaller geographic scales are preferred, while the use of general taxes has better outcomes for larger geographic scales. On the other hand, according to the qualitative analysis, it is difficult to express through voting a detailed level

[22] "Regions" refer to the 5 sub-national regional authorities designated within mainland Portugal.

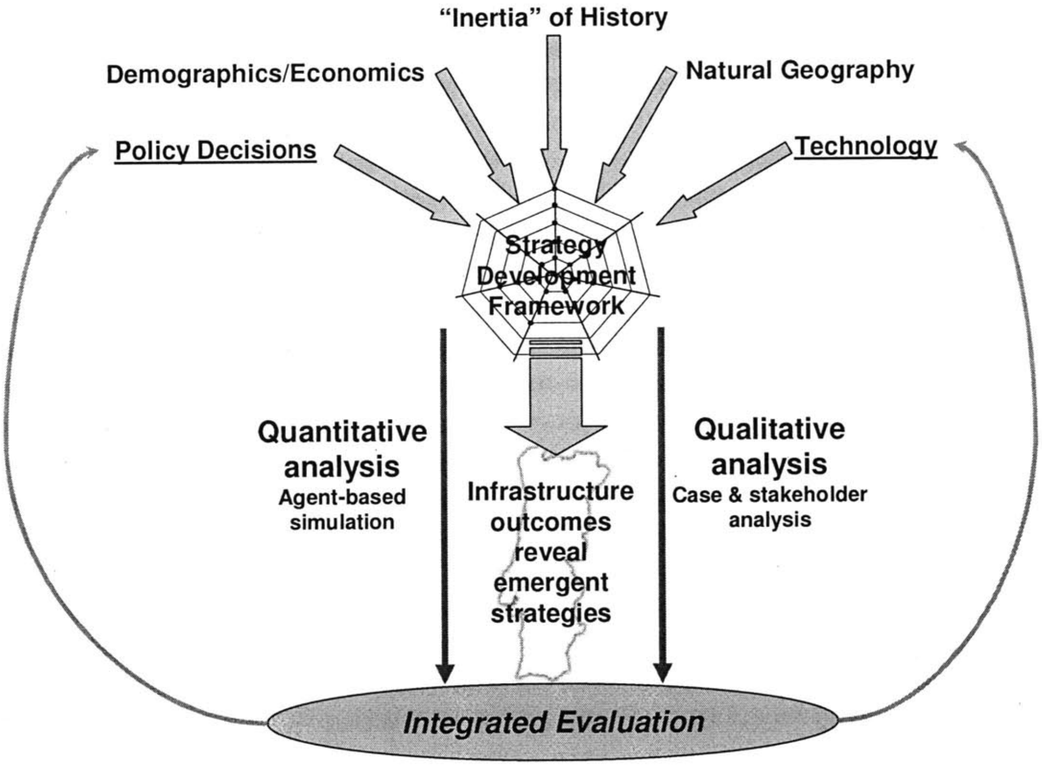
of preference for tax rates (and, therefore, budgets) for infrastructure relative to other government services, particularly for specific locations. As the size of the government and/or the number of services it provides increases, the ability of consumers to express their infrastructure preferences becomes even more diluted. For relatively smaller jurisdictions with fewer services, taxes offer a reasonable means of location-specific preference expression, due to the ability of residents to express their preferences for infrastructure budgets through more local representatives. We hypothesized that the evaluation would show a clear preference for user fees, but the results suggest a more complex situation, with important interactions between the type of revenue and the geographic scale.

- *What is the "right" institutional architecture?* **Greater integration offers efficiency benefits through increased competition and synergy, but there are substantial barriers to integration, and integrated decision-making processes are more costly.** The costs of greater integration are, essentially, longer and more costly decision-making processes due to the involvement of more stakeholders, more opinions, and more constraints. The most predictable consequence of greater integration is greater competition: if the vision of integration is to pool resources across modes and sectors and to make resource allocation decisions with broadly measured benefits, then all participants should be prepared to compete in a larger field for those limited resources. Interestingly, the **barriers to integration are weaker at smaller geographic scales**, due to the fact that decision-makers operating at smaller geographic scales can "divide and conquer" the entrenched interests in order to pursue a more integrated approach to infrastructure strategy development.

8.1.5 Section summary

Figure 8-3 is an illustration of the principal concepts and approaches of this thesis. One of the central concepts, the strategy development framework, is pictured at center; it represents the environment in which strategies are developed and from which they emerge. Strategy development frameworks are influenced by a wide range of factors, including demographics, economic conditions, the "inertia" of history, natural geography, active policy decisions of decision-makers, and available technology. In Chapter 3, we defined the term strategy development framework for transportation infrastructure systems, while in Chapter 4 we characterized a wide range of alternative frameworks.

Figure 8-3. Conceptual summary of thesis



Strategy development frameworks for transportation infrastructure, in turn, guide the actions of various constituent organizations, resulting in investment decisions over time for an infrastructure system. The resulting development and evolution of the infrastructure system reveal an emergent strategy for the region in question (in our case, mainland Portugal). In Chapters 5 and 6, we described and presented an approach for analyzing this phenomenon quantitatively through agent-based simulation; in Chapter 7, we presented a qualitative analysis of the phenomenon through empirical cases and stakeholder analysis. Together these analyses allowed us to predict and analyze the relationship between strategy development frameworks and measurable outcomes for an infrastructure system. At the end of Chapter 8, we presented an integrated (quantitative and qualitative) evaluation of the alternative strategy development frameworks. Finally, based on the evaluation, we can determine which frameworks perform best and recommend changes. The primary levers available for influencing strategy development frameworks are adoption of advanced technologies and adoption of new policies by decision-makers within the current strategy development framework.

8.2 Future work

In this section we summarize extensions to the research presented in this thesis. We begin by describing extensions to the simulation model and continue with conceptual extensions, including a more detailed description of a future-oriented application.

8.2.1 Improvements to and extensions of the simulation model

Improvements to and extensions of the simulation model fall into two general categories: (1) improving the accuracy with which it reflects reality and improving its predictive ability and (2) broadening its applicability.

To improve the accuracy and predictability of the simulation model, there are several improvements and extensions envisioned. Continual refinement and detailed estimation of parameters and input variables such as construction and maintenance costs, value of time, and volume-capacity relationships would improve the accuracy with which the model reflects reality and predicts decisions. A more complete description of the surface transportation network would also improve the accuracy of the model, including a fuller representation of the intercity *and* intra-city roadway networks. Along with a more complete network, more advanced demand estimation techniques, most importantly separate estimation and consideration of freight traffic, should be incorporated. Along these lines, finally, we envision the need to add a feedback loop between the transportation investment components of the simulation and other elements currently treated as exogenous such as land-use changes and population growth. By making land-development impacts and population changes endogenous, the modeler would be able to consider a broader range of alternative strategy development frameworks (e.g., incorporating revenues derived specifically from property taxes, based on land-use changes) over a longer period of time. In aggregate, these improvements would make the model more complex and costly, but would integrate some state-of-the-art approaches in demand and land use modeling together with the simulation of strategic decision-making by organizations introduced in this thesis. Once integrated, the model could provide powerful predictive abilities to planners in order to trace not only the expected consequences of specific policies and strategies, but also to predict the types of strategies that are most likely given a particular strategy development framework.

Broadening the applicability of the model is envisioned in several ways. First, we envision applying the model to a study of metropolitan transportation strategy development. Although one might expect similar types of results from a metropolitan-scaled application as those discovered for the intercity application of this thesis (e.g., impacts of broader geographic scales of decision making and various ownership schemes), there are important distinctions between an intercity network and a metropolitan network that warrant a more detailed inspection. For example, concentration of infrastructure investment and development in specific corridors may face more resistance in an urban context than in an inter-city context due to space limitations, property values, and environmental impacts. Network effects and peak-hour congestion also become much more pronounced in urban areas. Prerequisites for a metropolitan application of the simulation include the improvements described above as well as the explicit introduction of alternative modes (e.g., road, rail, pedestrian, bike). Alternative modes can also be added to the intercity model, notably conventional and high-speed rail.

On top of these new *applications* of the model, a broader range of alternative strategy development frameworks can be considered, including:

- More "hybrid" approaches, such as a combined concession/state-owned enterprise and hybrid geographic scales with project-based grants rather than across-the-board revenue sharing. In particular, it would be interesting to consider cases where municipalities are less "myopic"—rather than restricting their investments to adjacent links, allow them to invest broadly in the network. We might also envisions allowing municipal agents to interact in more ways than simply negotiating over specific projects—for example, by forming compacts for metropolitan regions or specific corridors. Adjusting the model environment to allow for such phenomena would extend the range of possible frameworks we can consider while enriching our ability to judge potentially more effective alternative approaches.

- Once alternative modes are added to the model, we can explicitly consider multi-modal versus uni-modal approaches and observe the competition for resources among the various modes. A particularly interesting modal addition to consider is high-speed rail (HSR), a network which is currently in the early stages of deployment in Portugal. Based on the results from the highway-based simulation model, we speculate that HSR would be more likely to enjoy broad deployment under a uni-modal institutional structure in which it would not have to compete for funding with highways. Moreover, because HSR is most effective at providing service between large concentrations separated by 100-600 km, it would be deployed most broadly under frameworks with relatively larger geographic scales in which such distances can be pursued by a single decision-maker. Highly decentralized frameworks would be ineffective at offering long-distance connections that bypass less important potential station locations, due to the disinterest of such intermediate locations in participating.
- A fully private framework would be interesting to consider, by allowing any agent to build and invest in any facility or combination of facilities. Rules would have to be instituted in the simulation environment to govern the competitive parameters, such as ownership of existing facilities and bankruptcy procedures.
- More nuanced pricing schemes are needed to reflect increasingly creative pricing schemes being deployed in reality. So far, we have considered a broad application direct user fees (tolls) with a single rate per km traveled. The impact of varying the rate by location and time of travel would more closely approximate interest around the world in congestion-based pricing. The consequences of studying such an approach would, in general, result in a larger share of revenues being collected from urban and metropolitan areas, where prices could be set higher for congested links. Depending on the other dimensions of the strategy development framework, these higher revenues may be used either to bolster the funding available for urban and metropolitan transportation systems or to further subsidize inter-metropolitan and/or rural portions of the transportation network.
- Finally, we envision an additional dimension of a strategy development framework characterizing the speed with which the other dimensions can be changed. This would be accomplished by inserting a decision making agent with the intelligence to measure performance of the evolving infrastructure network and make adjustments to the other dimensions of the strategy development framework in order to attempt to meet future performance targets. For example, this agent could change the quantity of revenues, the mix of revenues, the method of resource allocation, and even the geographic scale of decision making depending on the agent's understanding of how such changes may impact performance vis-à-vis system objectives. Allowing this type of adaptive feedback endogenously would increase manifold the number of effective alternative frameworks available for evaluation.

Another important envisioned extension is to expand the definition of *strategy*. Currently, the model is focused on strategies related to investments in infrastructure improvement and expansion. However, maintenance and operations are important activities worthy of strategic examination as well. Other areas could include modeling the development and emergence of land-use regulation strategies and multi-sectoral strategy development.

8.2.2 Conceptual extensions

Several conceptual extensions of this work are also envisioned. We categorize them broadly as: an exploration of the mechanisms for strategic application of advanced technologies, investigation of the prospects for emergence in the transportation planning field, and applications of the simulation model and qualitative analysis to the *future*.

First, this thesis has asserted a strong role for advanced technologies in shaping not just strategies but entire strategy development frameworks. However, the analysis focused on the potential *impacts* of advanced technologies, leaving considerable room for exploration of the specific mechanisms by which advanced technologies are implemented and by which they can assume a greater role in influencing strategy development. The alternative frameworks proposed and explored in this thesis are visions, but arriving at any one of those frameworks would require not only technological innovation, but also organizational change that avails itself of the technological innovations.

Another conceptual extension of this research is to examine the potential for emergence to be incorporated in transportation planning. The focus of innovations in planning is largely on improving the legitimacy of the planning process in order to influence outcomes. By contrast, the results of this work suggest that factors beyond the control of planners influence strategic outcomes in transportation more than the actual strategies and plans. Accepting that premise and accepting that strategies *emerge* is a paradigm shift which requires an admission that deliberate strategies pursued through planning often fail to be realized. The methods of transportation planning are extremely valuable, they constitute important deliberate strategies, and they often influence the emergence of strategies in significant ways. However, there is room to explore through further research how emergent results, such as those produced by the simulation approach in this thesis, can be constructively incorporated into the transportation planning (strategy development) process.

Finally, related to the last point about incorporating emergence into transportation strategy development processes, we envision applying the analytical framework of this thesis (both the simulation model and the qualitative considerations) to the *future*. So far, we have focused the analysis on predicting alternative histories that would have emerged under alternative strategy development frameworks, in order to inform our judgment of the relative merits of those alternative frameworks. However, the approach can also be applied to predict the emergence of *future* strategies under existing and alternative frameworks. Although historical applications of the analytical framework are useful for research, future applications are more useful for practitioners. We illustrate this possibility by applying the agent-based simulation over a 10-year future period in the next section.

8.2.3 Predictive application of agent-based simulation

At the end of Chapter 6, we presented an application of the agent-based simulation to the future. Recall, according to the National Roadway Plan of 2000, that Portugal's objectives for the road sector include "development of regional capabilities, reduction of the global cost of transport, improving travel security, accommodation of international traffic, and modernized network management." The deliberate strategy pursued to achieve these objectives is continual investment in the national road network, particularly to create stronger linkages between the interior and coastal regions. The investment patterns observed in the future simulation, however, show broad investment in *all* parts of the country, focused especially on the Lisbon-Porto corridor where almost every link is improved to high speed, with capacity enhancements throughout that corridor to relieve congestion on highly traveled links. The emergent strategy, as revealed by this investment pattern, is one of accommodating the development of lower-density settlements as part of a continuous "megalopolis" stretching from Lisbon to Porto along the coast. The emergent network predicted by the agent-based simulation reflects an underlying emergent strategy that could be characterized as quite different from the deliberate strategy as stated in the PRN 2000.

In addition to the general uncertainties of modeling, the future application adds another uncertainty related to future growth; it is impossible to verify the accuracy of the prediction, and likewise impossible to prescribe an alternative strategy development framework that is more likely to lead to the stated objectives of the current deliberate strategy. For example, we might suggest a regionally scaled strategy development framework in which the regions have greater flexibility to invest in sectors other than transportation. Such a framework might allow some interior regions to improve their attractiveness for economic activity by investing in sectors other than travel accessibility to the coastal region; meanwhile, others may eschew connections to the coastal region altogether in order to dampen the impact of preferential attachment and halt the march of the megalopolis from reaching their territories. However, what we can conclude from this brief exercise is that the current strategy development framework will lead to some emergent outcomes that are stated as part of the deliberate strategy, some outcomes that are not, and other outcomes that outright contradict it. Further work is envisioned that enhances the predictive capabilities of the simulation model such that it might be used to guide decision-making about strategy development frameworks, in light of their ability (or lack thereof) to achieve objectives specified as part of a deliberate strategy development process.

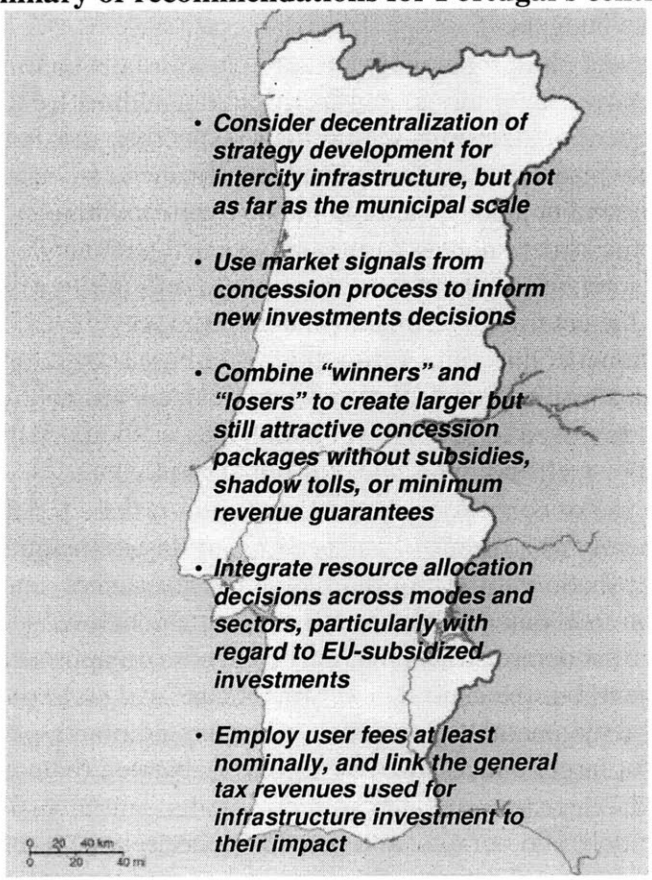
8.3 Recommendations for Portugal

Based on the research conducted and the results found, we have developed a set of recommendations. In this section we summarize the recommendations in three categories, one for each of the following audiences: Portugal's central government, sub-national governments, and the EU. Underlying these recommendations is the notion of *patience* with regard to the emergence of infrastructure networks. For the EU, patience means allowing member states to continue their individual regimes and eventually develop a coherent network in a financially sustainable way, without enticing misallocation of too many resources to EU-designated corridors. For Portugal, patience means building only what the country can afford—even if it means devolving control of infrastructure strategy development in order to achieve it.

8.3.1 Central government

The current chief concerns of Portugal's central government for the transportation infrastructure sector include sustainable funding of investments, relieving congestion in and around the metropolitan areas, improving safety and accessibility of the interior, and providing improved links to accommodate freight travel through the country. To that end, the government is pursuing an ambitious investment strategy, including commitments to build or improve over 2,000 km of new highways at a cost of over €5 billion; construct and operate a 600-km, cross-country, high-speed rail network with two connections to Spain for an estimated €8-10 billion; make substantial expansions to the existing urban rail transit systems in metropolitan Lisbon and Porto; and provide a new light-rail system in metropolitan Coimbra.

Figure 8-4. Summary of recommendations for Portugal's central government



Pursuit of Portugal's deliberate strategy is constrained by several factors, most notably financial limits. Our recommendations for improving the performance of transportation infrastructure through action by the central government, summarized in Figure 8-4, include the following:

- As the financial health of the infrastructure sector falters, the central government should be wary of the creeping influence of the EU. Over the long term, especially if the central government should fail to deliver on its promises (e.g., by defaulting on debt obligations or expropriating infrastructure assets), the stakeholder analysis suggests that the EU could gain greater legitimacy in the infrastructure sector and take greater control of infrastructure investment decisions within Portugal. To guard against this threat, the government should focus its efforts on maintaining a financially sound infrastructure sector. However, the results of the analyses suggest that changes in the stated objectives and *deliberate* strategies of the central government will do little to change the patterns of spending in infrastructure. Instead, changes to the strategy development *framework* may be required. Examples include: devolving some authority to regionally scaled authorities for strategy development; greater reliance on true concessions in order to guide investments in the transportation sector; and more integrated resource allocation decisions across modes and sectors. Another more controversial approach would be to delay or discard projects advocated by the EU with questionable long-term financial sustainability. This may mean a loss of EU subsidies for some projects such as highway investments in the interior and perhaps even some segments of the proposed HSR network. However, the EU cost share is relatively low (e.g., 19% for HSR), and the long-term burden of maintaining the infrastructure and providing service falls entirely on future Portuguese budgets.

- In order to achieve a more financially sustainable transport sector, the central government can consider empowering regional and metropolitan authorities to exercise greater control over resource allocation decisions within their respective jurisdictions. Our results suggest that many projects of inter-regional significance can be pursued through collaborative agreement among the regional and metropolitan authorities. However, smaller geographic scales such as municipally scaled strategy development make development of inter-regional projects much more difficult to achieve without financial incentives from the central government (much in the way the EU entices member states to build international connections through grants of assistance for projects of EU-wide significance). As a result, if control over strategic decision-making for intercity infrastructure is devolved to lower-level authorities, it should fall to organizations of either a regional or metropolitan scale, but not to municipalities.
- Discontinue the use of concessions and other public-private partnerships for delivery of infrastructure merely as a means of finance. According to the qualitative analysis, concessions with shadow tolls, minimum revenue guarantees, and other subsidies entice private interest in investments that are otherwise unappealing to the market. The quantitative analysis demonstrates that a true concession approach would result in a lower level of investment, but the central government can fund non-concessioned portions of the network through general tax revenues, combine them with more financially profitable projects as part of larger concession packages, or abandon them altogether.
- Truly multi-modal decision-making can reduce redundant investments, reduce the accumulation of debt and deficits, and provide better service to users. The uni-modal nature of infrastructure investment decision-making evident currently in Portugal, particularly combined with the off-budget approach of modally oriented SOEs, is exacerbating the already-poor financial condition of the sector. The qualitative analysis suggests that multi-modal decision-making invites greater competition for limited funds among modal interests, which would inevitably lead to a decline in budgets for at least some of those interests. However, we do not have quantitative results to estimate exactly what the impact would be.
- User fees are already common in Portugal, at least for the highway sector (e.g., fuel taxes and tolls). However, it would be advisable to expand user fees, at least nominally, and to dedicate all transportation-generated user fees to the transportation sector (at least a portion of fuel taxes, tolls, transit fares, and other direct and indirect user fees should be

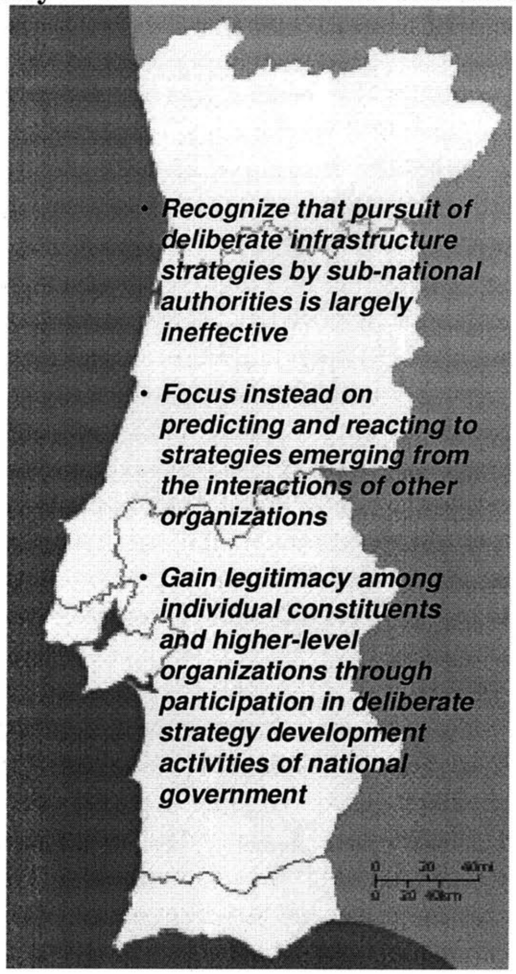
dedicated to maintaining, operating, and making strategic investments in the transportation sector). Given the ambiguity in the results over whether user fees are preferable to general taxes, it is inadvisable to recommend adopting one approach or the other; it is likely that a combination of user fees and taxes is appropriate. However, one clear result is that the information inherent in electronically collected direct user fees can be used to guide the quantity and location of investment decisions. Doing so will improve the spatial and temporal connection between users and collective infrastructure suppliers responsible for development of strategy.

- Although smaller geographic scales can improve the financial sustainability of the infrastructure sector and create a more balanced spatial match of revenues and investments (e.g., equal levels of spending in rural areas relative to the revenues they contribute), one of the potential drawbacks of smaller scales resulting from our analysis is a slower pace of investment in long-distance, inter-metropolitan connections. Maintenance and expansion of these connections is important for the growth of urban and metropolitan areas. Should the central government pursue more decentralized decision-making, it should ensure that metropolitan and regional authorities have mechanisms for collaborating in continuing the development of inter-metropolitan linkages, and should adopt a posture of patience with regard to the emergence of such networks.

8.3.2 Sub-national governments

Under the current framework of largely central government direction of resource allocation in the infrastructure sector, some municipalities benefit relative to others. In particular, at least in the highway sector, rural municipalities receive more in investments relative to urban and suburban areas. Moreover, the central government's decisions for highways, urban public transit, and railways occasionally conflict with objectives of municipal governments and metropolitan authorities. In the absence of central government willingness to devolve authority explicitly to regional authorities or metropolitan transportation authorities, municipalities can assert greater control via such mechanisms as the bottom-up, self-organized metropolitan authorities. However, metropolitan authorities and municipal governments currently lack any funds for investment in infrastructure systems. Their best prospects for influencing the emergence of strategy is through advocacy and through careful allocation of whatever resources they are able to accumulate over time for investment.

Figure 8-5. Summary of recommendations for sub-national organizations



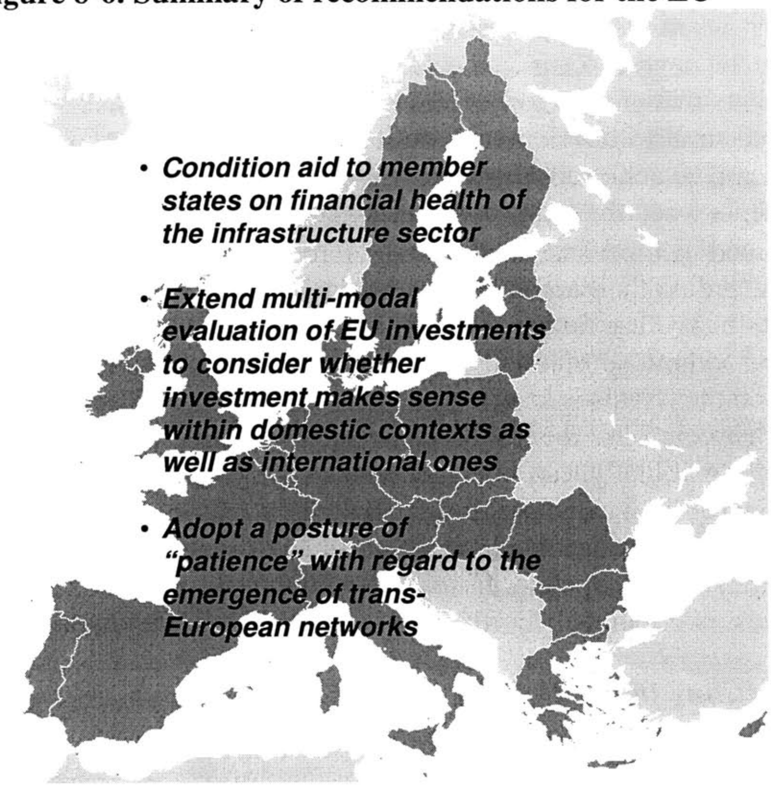
Specific recommendations, summarized in Figure 8-5, include the following:

- Traditional "planning" efforts of metropolitan authorities are unlikely to have much effect on transportation investment outcomes given the dominance of the process by the central government. Instead, metropolitan authorities should focus on predicting investment patterns that are likely to occur within the current framework, following closely the actions of central government, and taking a stronger advocacy role in supporting and opposing specific investment decisions. In other words, the authorities can best position themselves to predict emergent outcomes and strategies, understand their dynamics, and react by attempting to influence aspects of the current strategy development framework that lead to particular outcomes.
- According to the stakeholder analysis, in order to improve their power over resource collection and allocation decisions, metropolitan and regional authorities must gain greater legitimacy from constituents as well as from the central government. One potential avenue for increasing their legitimacy is to participate in central government decision-making about inter-regional connections. HSR, for example, was developed largely without input from explicitly metropolitan or regional stakeholders; future similar strategy development activities could benefit from such participation, while allowing the participants to grow their salience.

8.3.3 European Union

EU leaders are pursuing a strategy of infrastructure development and regional integration across the continent. However, enticing Portugal to participate in such ventures as rural motorway and HSR construction has contributed to the ongoing debt crisis in the infrastructure sector. According to the stakeholder analysis, one potential consequence of such a crisis is for the EU to take a greater role in directing the infrastructure policy of Portugal.

Figure 8-6. Summary of recommendations for the EU



An acute illustration of the consequences of broader involvement of the EU in domestic policies is Greece, where excessive debt has led to financial support from other member states conditional on fiscal austerity measures. In light of this experience, the results of the analysis in Chapters 6 and 1, and the current conditions in Portugal, we offer the following recommendations for the EU, as summarized in Figure 8-6:

- In order to improve financial sustainability of the infrastructure sector, the EU should condition aid for infrastructure projects on the financial sustainability of the particular project *as well as* of the infrastructure sector as a whole. For example, the EU has provided financial support to Portugal in the form of grants and low-interest loans for motorway construction, urban public transit systems, and now HSR. Enticed by "free money," Portugal has simply pursued too many projects; a strategy development framework that provides funding from a larger geographic scales tends to over-invest in an attempt to achieve broad benefits from large-scale, long-distance projects. This has been shown both within and beyond Portugal. We have already recommended changes to the strategy development framework within Portugal—including the controversial and likely unrealizable suggestion to devolve some authority for resource allocation decisions to smaller geographic scales and to reject EU subsides for projects that the country cannot afford. For its part, the EU should design aid programs that do not encourage overspending.

- EU leaders have emphasized multi-modal networks in order to achieve more efficient investments, noting that "combinations of rail and road networks have shown themselves to be of significant value (more efficient use of space, reduced costs and environmental impact)." Indeed, the Trans-European transportation network (TEN-T) is a multi-modal network which considers trade-offs between, for example, road and rail projects. However, when it comes to supporting specific projects, the EU does not necessarily consider the degree to which the TEN-T investment complements domestic infrastructure investments that are not part of TEN-T. The result is a potential success in more integrated strategy development, but only from the perspective of the EU. Greater benefits can be achieved if more consideration is given to domestic multi-modal investments when the EU is considering support for TEN-T projects.
- The EU and members states alike are interested in preserving the autonomy of member states, including their autonomy over decision-making in transportation infrastructure. To that end, the EU has favored financial incentives as a means of enticing particular decisions without substantially disrupting the existing strategy development framework of each country. This is an effective approach, but the EU should resist tendencies to take any further control of the resource allocation process, which as the analysis has suggested, will likely lead to higher levels of investment in the infrastructure sector, unsustainable financial conditions, and an emphasis on inter-metropolitan, inter-regional, and international connections, to the detriment of intra-metropolitan, and intra-regional transportation development. Instead, the EU should continue its modest financial incentives, international coordination, and broadly scaled multi-modal planning.

8.4 Contributions to the field

The contributions of this research are threefold: (1) we determine the influence of advanced transportation technologies (typically studied for their operational benefits) on *strategy* development; (2) we offer the notion of strategy development, which allows for recognition and inclusion of emergent outcomes, as an alternative to the narrower concept of transportation planning, and present an innovative analytical approach for exploring the relationship between strategy development frameworks and strategies, applied in a real context; and (3) we explore the consequences of fundamental changes to the strategy development framework, notably along the dimension of geographic scale.

The first contribution of this thesis is the explicit identification of strategic applications of advanced technologies. The alternative strategy development frameworks defined in Chapter 4 and explored through quantitative and qualitative analysis in Chapters 6 and 1 are observed in a variety of contexts throughout history as well as in contemporary practice. Typically the factors attributed to changes in these frameworks over time and from place to place include demographics, geography, economic conditions, politics, and technology. We explicitly recognize the influence of technology in making various frameworks relatively more or less preferable and explain the mechanisms by which contemporary advances in technology can push frameworks in a context such as Portugal in particular directions.

The second contribution of this thesis is the development and demonstrated application of an approach for exploring relationships among strategy development frameworks, strategies, and the performance of those strategies for transportation infrastructures systems. The quantitative agent-based simulation of strategy development predicts outcomes based on the values along several dimensions of strategy development frameworks: ownership structure, type and quantity of revenues, resource allocation approach, and geographic scale. We have complemented the simulation with a qualitative analysis that considers even more dimensions, compares empirical evidence of strategy development frameworks from cases, and analyzes stakeholder responses. This combined approach represents an extension of efforts to understand, explain, and predict the relationship between the individual behavior of travelers and the collective strategic behavior of infrastructure providers.

Finally, through this analysis and its results, we have contributed a conceptual advance with important implications for the practice of transportation planning. Through our exploration of competing concepts of strategy from management literature and our analysis of alternative strategy development frameworks (made possible to a large extent by advanced technologies), we have suggested a re-framing of *planning* as a subset of activities contributing to the development of strategy for transportation infrastructure systems. Moreover, we have introduced the notion of *emergent strategy* and illustrated the importance of understanding emergent outcomes, and in particular their relationships with deliberate strategies such as transportation plans. Transportation planners and decision-makers can improve their ability to match outcomes with the multi-objective demands of individual customers and residents through awareness of emergence and prediction of emergent outcomes, and by positioning themselves and their organizations to influence emergent outcomes as they unfold. For example, in Portugal, if one believes the emergent strategy revealed by Figure 6-21 (predicted highway network in 2019 based on the existing strategy development framework) to be accurate, then fundamental changes to the strategy development framework such as a decrease in revenues allocated to the transportation sector, new ownership structures (such as true concessions), and smaller geographic scales could all be pursued as more effective—albeit more difficult to implement—means of influencing the expected future state than merely updating the plan.

8.5 A closing word

Transportation decision-makers work in a wide range of contexts. They sit in the offices of highway and public works departments, transit agencies, city governments, planning authorities, non-profit advocacy groups, private consultancies, concession companies, freight operators, legislative bodies, cabinet agencies, transnational entities, investment banks, and universities. They envision the future shape of highway networks, transit networks, land-use patterns, development patterns, and environmental impacts for neighborhoods, cities, metropolitan areas, countries, and even continents. They produce strategic plans, financial plans, operating plans, and political plans. In other words, they are engaged in *deliberate* strategy development.

Given the proliferation of organizations, not to mention the users of the transportation system themselves, no single strategist out of this group fully controls the development of strategy. Instead, the deliberate strategies combine in a complex set of interactions among agents that produces an emergent outcome. The patterns of investment, decisions, and other behaviors visible in this emergent outcome reflect an underlying *emergent* strategy.

This research started as a deliberate effort to understand the consequences of alternative strategy development frameworks. By forecasting the strategies that emerge under a variety of frameworks, we could determine which frameworks are preferable. At the same time, however, through the pursuit of this objective, new applications have emerged, chief among them the notion that planners (strategists) can apply techniques such as those presented here in order to predict and better understand the types of strategies that are likely to emerge in their particular contexts, such that they might devote resources more effectively at shaping and responding to those outcomes instead of allocating resources to develop deliberate strategies with little effect.

In short, decision-makers must recognize the existence and inevitability of *emergence* in the presence of complexity such as that of a transportation system, be prepared to respond to it, and understand the key influential parameters so that they might shape it more effectively. This thesis provides tools and findings from a real context that represent steps in that direction that we hope will prove useful for researchers and practitioners.

APPENDIX

1 Technology

In Chapter 3 we discussed strategy in the context of surface transportation and identified several key dimensions of strategy development, including: institutional architectures, decision-making processes, and geographic scales. As was alluded to throughout, a variety of factors influence these dimensions of strategy development, including politics, culture, and technology; in this chapter, we focus specifically on the influence of advanced technologies.

Having surveyed the historical role that technology has played in influencing surface transportation strategy development frameworks in the previous chapter, we begin here by describing a range of contemporary and near-term advanced transportation technologies. Next, we discuss how these advances in technology can expand the range of feasible institutional structures, decision-making processes, and geographic scales that characterize transportation strategy development frameworks. From this expanded range of possible frameworks, we select several for further development and conclude with sketches of their features.

1.1 Recent and near-term advances in transportation technology

This section summarizes various current and future technologies for surface transportation with the potential to influence strategy development. Table 1-1 summarizes a variety of technologies according to the function of the technology and the entity upon which it acts.

Table 1-1. Summary of technologies by function and entity acting upon[23]

Function / Entity Acting upon	Sensing	Communication	Revenue collection
	Detection, location, tracking, identification, and assessment	*Communication of data among users and system managers*	*Collection of taxes, tolls, fares, or other user fees*
People	Surveys, human observation, mobile devices (e.g., cellular phones), smartcards, WiFi	Smartcards (short-range RFID), Cellular, WiFi	Sales/property/income tax, Manual collection (cash, tokens, paper tickets), Smartcards
Vehicles	Human observation, loop detectors, RFID (incl. DSRC), GNSS, onboard monitoring systems, video systems (ANPR), WiFi	RFID, Cellular, WiFi	Fuel/sales/tire/property tax, ETC enabled by RFID, VMT-based charging enabled by RFID and/or GNSS
Infrastructure	Human observation, satellite/aerial surveys, deflectometers	RFID, Cellular, WiFi	n/a

[23] See text for explanation of acronyms

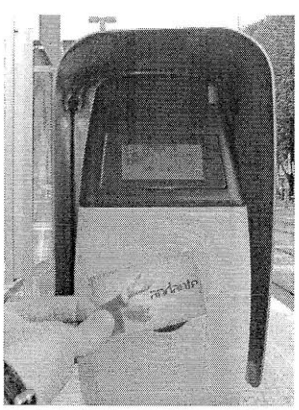
Beyond manual approaches (e.g., surveys, human observation, manual toll and fare collection, sales taxes, income taxes), which were discussed in Chapter 3, we are interested in the following "building block" innovations, which appear in several cells throughout Table 1-1:

- Radio frequency identification (**RFID**), which includes anything from low-frequency smartcards to higher-frequency electronic toll collection (ETC) systems operating at 915 MHz, to the high-frequency Dedicated Short-Range Communications (DSRC) operating at 5.8 GHz in Europe and 5.9 GHz in the U.S.
- Global navigation satellite systems (**GNSS**), which refers to a system of space-based satellites and land-based devices which can use signals received from the satellites to compute location information.
- Demonstrations have shown the possibility of using **WiFi** technology for communication among individuals, vehicles, infrastructure, and system managers as well as for positioning.
- Like WiFi, **Cellular** networks can be used for communication among individuals, vehicles, infrastructure, and system managers as well as for sensing and positioning of individuals and vehicles.
- **Video-based** technologies, commonly referred to as automated number-plate reading (ANPR) can be used to support sensing of vehicles at fixed points in a network. ANPR is most commonly used for enforcement of electronic tolling systems, often as a back-up for RFID systems, beyond traditional applications in the area of operations monitoring.

The following sections discuss each of these technologies, pointing out their applications in sensing, communications, and revenue collections. Much of this discussion is based on Cottingham et al. (2007) and Pickford and Blythe (2006).

1.1.1 Radio frequency identification (RFID)

RFID refers to the use of microwave signals for transmission of data. Although RFID technology can be used to transmit many types of data, the most common applications in surface transportation to date are for revenue collection. RFID devices are commonly categorized as "tags" (e.g., transit smartcards or in-vehicle devices) and "beacons" (e.g., transit smartcard readers at turnstiles or overhead gantry-mounted tag readers at toll plazas). Dedicated short-range communications (DSRC) refers to a particular class of RFID which operates at 5.8 GHz frequency in Europe and 5.9 GHz in the U.S. The U.S. Federal Communications Commission (FCC) allocated bandwidth around 5.9 GHz for exclusive use by the U.S. DOT.



In urban public transit, electronic transactions rely on RFID technology in contactless smartcards. Given the close proximity of customers to RFID antennas at entry and exit payment points (e.g., at a rail transit station gate or bus farebox), smartcards for transit operate at much lower frequencies than vehicle-based RFID devices. Also, transit smartcards contain small chips for processing information, which allows them to write and store memory to the card. An example of a smartcard for transit is the Andante card in Porto, pictured at left near an RFID reader.

Transactions for road pricing using microwave communications are similarly executed using a tag and beacon system, whereby a tag fixed to a vehicle's windshield communicates with an overhead or roadside reader at toll-collecting locations. Tag and beacon systems for roads must be capable of transmitting information over longer distances and at higher speeds than transit smartcards, requiring utilization of higher frequencies and more power. Microwave communications are fairly flexible in that they can support most conceivable road pricing schemes. For instance, tag and beacon systems are very commonly used in traditional tolling systems (e.g., E-ZPass and FastLane in the Northeast U.S., Via Verde in Portugal). Under these schemes, the tag (an in-vehicle RFID device) and beacon (an RFID reader mounted to a toll plaza) communicate with one another via radio waves. Systems are built and operated by private contractors using proprietary communications techniques (Samuel, 2004). In the case of a passive tag, the beacon "scans" the tag much like a barcode, identifies the tag, and deducts the price for the particular toll location from the user's account. Active tags emit a signal that can be received by the beacon, but require power either from a built-in battery or an external power source, and are more expensive than passive tags.

As the sophistication of the scheme design increases from traditional point-based tolling to distance-based tolling to congestion-based or time-distance-place (TDP) tolling, the density of roadside units required to support a pricing scheme likewise increases. For example, in distance-place tolling, roadside units must be spaced with sufficient frequency to allow for full coverage of the priced road network, such that the path length of any vehicle on the network can be calculated (or estimated accurately) based on the data collected by the roadside beacons.

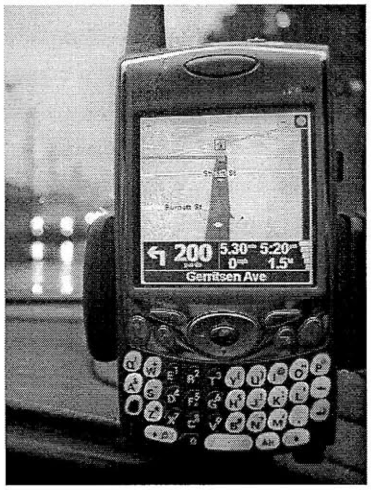
Almost all of the existing RFID electronic toll collection systems in the U.S. utilize frequencies between 902 and 928 MHz, while European toll systems operate at 5.8 GHz. Because the systems are proprietary, road operators will often select a single vendor to provide the in-vehicle tags for all motorists on its network. An example illustrated at left is the Texas Department of Transportation's (TxDOT's) *TxTag*, which is a thin "sticker tag" equipped with a small RFID chip which drivers can affix to their windshields. However, the U.S. Department of Transportation (U.S. DOT) is promoting a new standard for electronic toll collection at 5.9 GHz, called DSRC, which it hopes will provide an open-source, nationally interoperable platform on which multiple vendors can build competing in-vehicle devices. The larger bandwidth afforded by DSRC at 5.9 GHz will also be capable of handling greater volumes of data, allowing multiple applications to be built (e.g., for safety and traveler information). In particular, U.S. DOT's Intellidrive initiative[24] aims to set common standards and an open architecture for deployment of DSRC roadside units along the U.S. road transportation network (SIRIT, 2005).

1.1.2 GNSS

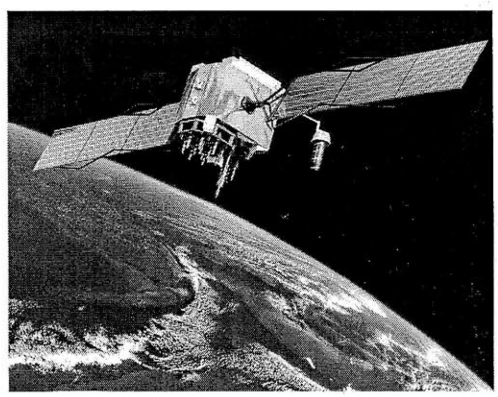
Global navigation satellite systems (GNSS) (such as the U.S.-developed Global Positioning System, or GPS) offer the potential to track continuously the movements of GNSS-equipped

[24] In late 2009, U.S. DOT renamed the VII initiative to Intellidrive after reducing the scope of the program to focus on "tactical" deployment rather than comprehensive nation-wide deployment and expanding the potential platforms for communications applications beyond DSCR, such as GPS-based.

receiver devices (e.g., in-vehicle GPS units) across a network (e.g., a highway network). Currently, GPS is the only functioning GNSS, although the European Union expects that its Galileo system will be operational by 2013, while the Russian government is currently refurbishing its GLONASS system. Several other countries, notably India and China, are in the process of deploying "regional" satellite navigation systems with coverage only for their territories. GPS, the only GNSS currently operating, functions as follows: a constellation of between 24-32 satellites sends microwave signals over the 1.57 GHz frequency to land-based devices. The land-based devices are equipped with signal processing algorithms that, in order to compute location longitude, latitude, and elevation accurately, must receive signals from at least 4 satellites. GPS was originally developed for military applications and has a wide range of civilian applications, including for transportation systems. An artist's rendering of a GPS satellite is pictured above.



For road pricing schemes which require extensive network coverage, GNSS can enable perhaps the most complete, if not most accurate, record of distances and paths traveled. However, GNSS devices have not yet achieved sufficiently consistent accuracy for the purposes of calculating travel distances of large numbers of users, particularly in urban areas where satellite coverage can be disrupted by tall buildings or confused by dense road networks. Recent efforts by several companies have resulted in some claims of success in overcoming this "multipath" problem.



Still, the computational burden of GNSS for road pricing can be costly. In-vehicle units must receive location data from satellites, map the data onto pre-loaded geographic information system (GIS) software, and then communicate some information (e.g., the actual information about the path traveled and/or a price to be charged) back to the road operator via some other land-based communications channel such as a cellular network. This is, for instance, the basic architecture of the heavy-vehicle tolling program currently in place on over 12,000 km of German motorways (TollCollect, 2008). The cost of an in-vehicle unit with all these capabilities is high, exceeding $100 US, perhaps a prohibitive price for most consumers, although there are possibilities to mitigate the cost by offloading some of the hardware and computational functions to the roadside. For example, with a deployed network of roadside DSRC units, the correlation of location data to maps could conceivably take place on the roadside, leaving the in-vehicle devices simply to record and transmit raw location data. However, such arrangements trade off privacy of data with computational speed and cost. Specifically, there is no way to guarantee privacy of travel path data for consumers if they are transmitted to the roadside and/or road operators' back offices for further processing.

1.1.3 Wi-Fi

There are two general applications of Wi-Fi for transportation systems. The first is for communications. The second, more recent application is for positioning.

Wi-Fi networks are most commonly used for wireless communication of data using IEEE 802.11 standards over 2.4 GHz or 5 GHz, with a range of approximately 120 feet. Infrastructure operators can use Wi-Fi networks as the means of communicating a wide range of data among vehicles and system management centers. Many transit authorities, for instance, collect condition and performance data from buses over Wi-Fi networks at selected points, such as bus depots.

A more recent application is to use Wi-Fi for positioning, similar to GNSS. The company Skyhook has developed proprietary methods for positioning Wi-Fi-enabled devices based on reception of Wi-Fi signals. Skyhook maintains and regularly updates a database of the positions of tens of millions of Wi-Fi access points worldwide. Devices receiving Wi-Fi signals from those access points can use Skyhook's service to triangulate position data based on the signal strengths. The company has also developed a hybrid positioning system that takes advantage of cellular signals, Wi-Fi signals, and GPS signals for more refined location determination (Skyhook, 2008).

1.1.4 Cellular

Another mechanism for communicating information among vehicles and infrastructure is cellular networks. For example, MIT's *Senseable City* laboratory has evaluated travel patterns of individuals in urban areas such as Rome by plotting signals received from cell phone users in the city. In addition, the 3G cellular network is capable of transmitting travel information between and among travelers on a variety of modes.

1.1.5 Video-based

Video-based systems are common for surveillance of infrastructure networks and enforcement of revenue collection. Advanced video schemes with image recognition software are generally known as automated number plate recognition (ANPR) systems. The key distinction between ANPR and other advanced, automated transaction technologies is that the cameras do not actually facilitate any transaction between customers and operators; rather, cameras serve as a "backup" method to enforce transactions made by other means. In London, for instance, the urban area congestion charging scheme is enforced entirely by ANPR. Cameras placed throughout the charging zone record the license numbers of all vehicles inside the charging zone over the course of a day. Meanwhile, motorists linked with a vehicle traveling inside the charging zone must make a payment via the internet, mobile phone, or one of many kiosks located throughout the city. The back-office processing database matches records of vehicles detected inside the charging zone against payments received, and issues violation notices to the owners of number plates that have been recorded inside the charging zone but for which no payments have been received.

Video-based systems are inexpensive to motorists (who need not purchase any in-vehicle device to communicate with the road charging infrastructure), but relatively more costly for scheme operators. The costliness of video-based systems stems from the sheer computational power required to record, process, and translate using pixel recognition software the license plates of a large number of vehicles; the labor and materials required to process and distribute violation notices; and the cost to operate and maintain a network of cameras. During the first several years of London's congestion charge, the agency overseeing the scheme has reported costs equal to approximately half of all revenues collected (TfL, 2006).

1.2 Implications of advanced technology for strategy development

Technologies such as those summarized in Section 1.1 can play an important role in enabling fundamental changes to the strategy development frameworks surface transportation. New technologies expand the range of options available for institutional architectures; decision-making processes related to revenues, information, and timing; and geographic scales for the development, evaluation, and application of transportation strategies. In the following sections, we discuss each of the three dimensions of strategy development frameworks and the potential for technology to enable a broader range of approaches within each dimension.

1.2.1 Institutional architectures

As discussed in Section 3.2, transportation infrastructure systems feature nested complexity: the physical transportation system is nested within an institutional architecture. The relationship between the physical system and the institutional architecture is based on economic, political, cultural, and technological factors. Technological factors include the broad range of system monitoring and revenue collection technologies that enable various ownership schemes and varying degrees of multi-modalism.

Ownership of transportation infrastructure typically rests with the public sector; however, via public-private partnerships, the public sector can transfer guardianship temporarily to the private sector. In order to do so, however, both parties require system monitoring methods in order to verify the performance in accordance with contractual obligations. As the ability to monitor highway traffic levels, for example, improves via electronic vehicle counting devices, weigh-in-motion devices, and other detection technologies, public owners and private managers of infrastructure can determine a broader range of agreements, increasing the amount and types of infrastructure that can be managed via concession agreements.

Another aspect of the institutional architecture of transportation infrastructure systems is the degree of multi-modalism. For example, "uni-modal" organizations concern themselves with one type of infrastructure (e.g., railways), while multi-modal organizations develop strategy for more than one type of infrastructure simultaneously (e.g., highways, railways, and urban public transit). As technology improves, the real-time, operational management of these systems is increasingly multi-modal, yet the development of strategy for infrastructure remains largely a uni-modal venture (Kanafani, 2008). As systems are operated multi-modally and as technology delivers increasing quantities and types of multi-modal data to system managers, integrated strategy development for infrastructure across modes becomes a more feasible opportunity to pursue.

1.2.2 Decision-making processes

1.2.2.1 Resource collection

Electronic toll collection (ETC) refers to the use of advanced technology for automated collection of revenues directly from road users, whether through RFID, GNSS, or ANPR schemes. ETC supports a wide range of revenue collection schemes, with technologies available to serve any of the configurations summarized below.

- *Traditional tolling*. ETC is most commonly deployed in a traditional tolling configuration, with electronic tollbooths merely replacing manually operated tollbooths at various fixed points along a highway facility or throughout a highway network. Often, ETC lanes operate alongside manual tollbooths at toll plazas. Open road tolling (ORT) constitutes a more advanced configuration, whereby toll plazas are eliminated altogether and vehicles can register toll payments without reducing speed via electronic overhead or roadside ETC equipment, such as RFID- or camera-based systems. ORT is less common than mixed manual-and-ETC toll plazas, but examples include the 407 Express Toll Route (ETR) in Toronto and the Illinois Tollway in the Chicago area. ORT has been proposed for many other facilities throughout the world. In Portugal, the ETC system, known as Via Verde, is used in traditional tolling configurations and has been proposed for use in some ORT configurations along the Brisa concession.
- *Facility charging*. Facility charging differs slightly from traditional tolling in that motorists are charged fees to access a particular facility such as a bridge, tunnel, or express lane (such as a high-occupancy/toll, or HOT lane). Examples include the SR-91 Express Lanes in Orange County, CA, the MnPass HOT lanes in Minneapolis, and the Ponte 25 de Abril Bridge in Lisbon.
- *Area charging*. Under area charging, motorists are charged a fee for using the road network within a defined region. Motorists entering central Singapore under the area licensing scheme (ALS) in the 1970s, for example, were required to display pre-purchased placards on their windshields; however, this constrained travel options for motorists and limited the operator to charging discrete sums on a periodic basis. By contrast, today's ETC-enabled area charging schemes in Singapore and London (using RFID-based and video-based technology, respectively) enable motorists to make travel decisions much more freely and allow (potentially) for more dynamic pricing and lower costs of revenue collection.
- *Cordon charging*. Cordon charging is similar to area charging, except that motorists are charged only when they *cross* the imaginary "cordon" that is drawn to encircle a defined region such as a central business district. Cordon charging schemes can be enforced manually (e.g., with tollbooths at entry and exit points), but are more feasible to implement and operate with ETC. An example of an ETC-enabled cordon charging scheme in operation today is in Stockholm.
- *Distance charging*. Under this form of road pricing, road users pay a fee directly proportional to their distance traveled. Some traditional tolling environments approximate distance-based charging by setting toll rates as a function of users' entry and exit points (e.g., the New Jersey Turnpike, Massachusetts Turnpike, and Kansas Turnpike). While distance charging can be enforced manually through a pre-determined schedule of toll rates or odometer checks, ETC-enabled schemes offer some advantages in both the flexibility of setting toll rates and ease of revenue collection. Examples of distance-based,

ETC-enabled schemes include heavy truck fees in Germany, Austria, and Switzerland (enabled by GNSS, RFID, and cellular).

- *Congestion-based charging*. Each of above schemes can also include congestion-based components. The purpose of congestion-based charging is to manage traffic volumes by regulating access either to a road facility (such as a tunnel, bridge, or expressway) or to an area (such as a central business district, urban agglomeration, or historical district). In practice, congestion-based charging is most common in large urban areas, but need not be limited to urban applications. The exact amount of fee charged can be fixed, vary with time according to a fixed schedule, or vary dynamically dependent upon travel volumes. In addition, operators of congestion-based charging may choose to grant discounts and exemptions to certain classes of roadway users or vary charges based on vehicle size, weight, and emissions. Refined versions of congestion-based charging include the following:
    - *Distance-place charging*. Under a distance-place scheme, motorists face a schedule of prices for various roadway facilities that varies based on the location of the facility. For example, under distance-place charging, the price per mile of an urban expressway, a rural arterial, and a local city street are different from one another. Prices may even vary along a single facility. One example is the recently completed distance-based charging pilot test in the state of Oregon.
    - *Time-distance-place (TDP) charging*. Time-distance-place charging, or TDP charging, combines distance-place and congestion-based charging. Under a TDP scheme, motorists are assessed fees based on the distance traveled over particular pieces of the roadway network at specific times. For example, a motorist traveling 1 mile over a congested urban expressway during a peak period would be assessed a fee that is greater than the amount charged to motorists traveling 1 mile over an uncongested rural route during a non-peak period. TDP schemes are perhaps the most "pure" form of road pricing from an economic perspective in that they seek to influence behavior both spatially and temporally by charging users a price approximating the marginal social cost of travel. Examples of TDP pricing include recently completed pilot tests in Seattle, WA and the Netherlands (e.g., Eurlings, 2007).

Each of these pricing approaches can be applied over geographic areas of varying extent. In practice, congestion-based charging is most commonly studied for and deployed in congested urban areas. Tolling, distance-based, and distance-place charging are more common for long-distance, inter-regional facilities. TDP charging is most suitable for application across a large urban region where differential pricing structures based on roadway type, time of day, and extent of travel can result in more efficient allocation of traffic across the network. In smaller, less congested networks, the benefits of such refined schemes may not be substantial enough to warrant the more costly investment in the ETC systems necessary to operate them.

The schemes summarized above are enabled by advanced revenue collection technology. Although manual revenue collection techniques can support some of the schemes outlined above, they rarely can do so efficiently. For instance, manual toll collection would cause congestion and be prohibitively costly to operate for enforcement of a TDP scheme in a heavily traveled urban region. By contrast, ETC allows for the exchange of three types of information among vehicles on the road network and the entity collecting revenues: identity of the vehicle (and/or occupants); location/position of the vehicle; and a price based on the time, distance traveled, type of vehicle, and/or location of the vehicle. The level of detail associated with each piece of information varies depending on the type of scheme. For example, in a traditional tolling environment, the road operator need only know the identity of the vehicle at specific, pre-determined points in space. However, in a TDP charging scheme, the road operator must be able to answer who, where (i.e., a path traveled), and when for each trip over the charged network. Increasingly, operators are turning to advanced technologies to help conduct transactions requiring such heavy loads of information exchange more efficiently (Doll & Schaffer, 2006; Nash, 2007; Ieromanchou et al., 2006 discuss recent pricing schemes in Germany, the UK, and Norway, respectively).

Allocation of resources is one of the most important strategic activities of any organization. Resource allocation decisions reflect to varying extents the organization's deliberate strategy and, at the same time, ultimately become a major part of the organization's emergent strategy. ETC systems make numerous revenue sources more feasible. As such, by changing both the quantity and composition of resources available to decision makers for investment in transportation system, ETC systems have a major influence on the strategy development framework.

1.2.2.2 Resource allocation

As discussed in Chapter 3, increasing utilization of system data can be used to de-politicize resource allocation decisions for transportation. As technology delivers new and more reliable sources of information, the trend toward technically driven decisions can be strengthened. Table 1-2 summarizes several types of transportation data useful for resource allocation decisions and indicates specifically what data can be obtained with increasing technological sophistication (i.e., moving from manual to electronic data collection).

Table 1-2. Types of transportation data

Data category	Types of data enabled by increasing technological sophistication
Highway travel demand	Samples from surveys → Samples from manual traffic counts → Samples from automated traffic counts → Detailed O/D data from vehicle tracking
Transit ridership	Aggregate, revenue-based estimates → User surveys and manual ridechecks → Detailed O/D data from farecards
Revenues	Aggregate resource allocation from general funds → Aggregate user fees → User fees disaggregated by time, location collected, and customer type
Safety	Manual crash reports → Electronic/automated crash reports

Table 1-3, adapted from FHWA (2005), summarizes various characteristics of transportation data when collected by traditional means versus when collected using advanced technologies such as ITS. This summary highlights some of the advantages and disadvantages of using ITS to collect data.

Table 1-3. Characteristics of Survey vs. ITS Data (adapted from FHWA, 2005)

Characteristic	Traditional Survey Data Sources	Advanced, ITS Data Sources
Timeframe	Infrequent	Continuous
Resource requirements	Labor intensive; individual efforts	Automated
Sample	Specific time period; broad coverage	All time periods; specific coverage
Reliability	High reliability; errors apparent during inspection	Reliability checks required; errors easily missed
Storage requirements	Small	Large

As technologies for collecting information about the transportation system change, the types of data available inevitably change; however, incorporating new data into strategy development processes requires more than technology. Transitioning from politically driven to technical, data-driven resource allocation decision approaches requires organizational and cultural changes. For example, if surveys, traffic counts, census data, and other data are utilized routinely to support established analytical processes, then advanced technologies can offer an improvement to the quality of data already being used or new sources of data that fit easily within the framework of the existing analytical process. However, new types of data not currently used in the strategy development process will not necessarily be useful without first changing the approach. In short, incorporating new types and sources of data into existing resource allocation approaches faces practical hurdles. However, in principle, the potential exists to harness these new sources and types of data to change and improve existing approaches.

1.2.3 Geographic scales

Strategies are observed to emerge at any geographic scale. In practice, deliberate strategies for transportation have been developed at a wide range of geographic scales, from individual landowners to neighborhood associations to municipalities to nations to international consortia. Although politics and institutional structures play an important role in the determination of the geographic scales for deliberate strategy development, technology also plays an important role. As discussed in Chapter 3, transportation vehicle and infrastructure technology, data collection technology, and revenue collection technology all influence the geographic scale of transportation strategy development. Advances in each of these technologies will enable adoption of new (or, perhaps, re-enable the adoption of old) geographic scales.

Depending upon one's point of view, metropolitan strategy development can be viewed as either centralized or decentralized. For example, the metropolitan scale is centralized when seen from the perspective of the constituent municipal governments, neighborhood associations, businesses, and residents. On the other hand, the metropolitan scale is decentralized when seen from the perspective of higher-level government entities (e.g., in the U.S., state governments and the national government and, in Portugal, the national government and the EU). Tradeoffs exist between centralized and decentralized governance. Depending upon which approach individuals in a particular region pursue, technology can be used to enable and improve either. In this section we propose three geographic scales for strategy development—scales at which strategy currently is not developed—and describe the enabling role of technology for each.

1.2.3.1 Strategy development at the regional scale

Researchers and practitioners in transportation and other fields have stressed the importance of "regionally scaled" governance. For early transportation planners, the metropolitan scale was appropriate for the application of large-scale alternative future visions of a regional highway network and of the mathematical models that had been developed to estimate travel demand on urban highways (e.g., CATS, 1962). More recently, some transportation planners suggest pursuing a "supra-regional" scale, noting that "as several metropolitan areas achieve megacity status and in some cases morph into megalopolises, the planning period and area may effectively have to expand accordingly" (Amekudzi et al., 2007). In economics, Porter (1990 and 2001) emphasizes the importance of regions as economic units and recommends the development of regionally scaled strategies in order for regions to compete with one another more effectively. In ITS, Sussman, et al. (2005) argue that deployment of advanced technology requires a regionally scaled perspective. In each of these cases, there is no precise definition of the geographic or demographic extent of a region, but implicitly metropolitan at minimum.

Despite these and other arguments in favor of metropolitan-scaled development of strategies (for transportation and other services), the experience with metropolitan governance has been "disappointing," according to Lefèvre (1998), who discusses 20th-century attempts at metropolitan governance in North American and Western Europe. Lefèvre cites economies of scale and the ability of planners to develop "more harmonious" facility location policies as benefits of metropolitan governance, but diagnoses two causes for the widespread failure to establish effective metropolitan governance. First, metropolitan-scaled governments have often failed to establish legitimacy, a persistent obstacle resulting from the difficulty in creating a coherent sense of community across large, diverse metropolitan regions with multiple, established municipal governments and other special-purpose government entities. Second, the "authoritarian manner" (top-down) of implementation of metropolitan governments often generates resistance by constituent governments and individuals. Although Lefèvre's analysis considers metropolitan governments in general, many of the lessons are applicable to the transportation sector specifically.

Advanced technologies can play a role in facilitating more successful metropolitan-scaled governance for transportation by generating new resources, providing new sources of data, and enabling stronger community ties. For example, revenue collection technologies enable direct road pricing on facilities within the metropolitan region, generating funds which in principle can be retained for re-investment within the region. System monitoring can allow metropolitan planners to collect more accurate, complete data about travel patterns within the region, improving their ability to develop responsive investment strategies for the entire region, rather than developing plans based on limited input data such as surveys, manual system observation, and input from self-selecting constituents. Higher-quality regional data also allows planners to tailor solutions to their own regions and to reject solutions suggested by higher levels of government. Finally, advanced communications can allow individuals to participate in metropolitan transportation decision-making, either directly or indirectly. For example, web-based participation by residents (e.g., Lowry et al., 2008) can improve the ability of planners to measure public opinion accurately on a variety of strategic issues, from specific investment alternatives to general transportation policies. In each case, technology can facilitate strengthening of the "community," whether through protecting metropolitan resources for transport, improving the quality of metropolitan-level transportation data, or increasing the participation of individuals in metropolitan-scale transportation decision-making.

1.2.3.2 Decentralized strategy development

For a more decentralized approach, one can envision development of deliberate strategies by multiple jurisdictions of smaller geographies within a metropolitan area. As with metropolitan strategy development, advanced technologies—particularly revenue collection and system monitoring technologies—can enable this approach to perform more effectively.

There are some clear difficulties associated with a highly decentralized approach to transportation strategy development. Neighboring jurisdictions could pursue divergent investment strategies, resulting in a disjointed infrastructure network. For example, some portions of the network could be maintained to very high standards with adjacent links maintained to low standards or perhaps unconnected entirely. In principle, fluctuations in capacity from jurisdiction to jurisdiction could cause bottlenecks and prevent the efficient movement of people and goods over long distances. Moreover, traffic-poor regions could suffer from an inability to generate sufficient revenues to maintain their network, resulting in distributional equity problems across the larger region.

Despite such challenges, advanced revenue collection technology combined with system monitoring overcome at least one obstacle to decentralized strategy making that prohibited its implementation in the past by enabling the collection and allocation of revenues over very small regions. In the past, frequent collection of revenues in a densely traveled network (e.g., using manual toll collection) would likely result in unacceptably high levels of congestion and numerous safety hazards for motorists and toll collectors. Moreover, the inability to monitor users of the network could complicate the adjudication of revenues across neighboring jurisdictions. Today, armed with advanced revenue collection, system monitoring, and communications technology, small sub-regions within a metropolitan area could, in principle, control the setting of prices, collection of revenues, and re-allocation of revenues over their portions of the physical transportation network.

1.2.3.3 User-driven transportation strategy

In perhaps the most extreme case of decentralization, one can envision the reduction of the geographic scale for transportation strategy development to the level of the individual, somewhat akin to a purely voluntary, market-based approach. This approach is an admittedly unorthodox one for transportation strategy development. However, that we can conceive and even design elements of such an unusual approach highlights the usefulness of technology as an enabling factor for alternative approaches to strategy development.

The notion of user-driver transportation strategy development can be described as follows. Collective authorities with jurisdiction over any geography—no matter how centralized or decentralized—refrain from exercising the power to create strategies for transportation: they do not plan, finance, or develop transportation infrastructure or provide transportation services. Instead, individuals create transportation infrastructure and provide transportation services either alone or through voluntary collaboration with other individuals (e.g., profit-motivated private companies or voluntary, non-profit collectives). Rather than crafting a strategy for some arbitrarily designated geography, strategies are crafted by each individual. The decisions and behaviors of individuals then organize into observable emergent strategies at a variety of geographic scales, including metropolitan.

This approach to the provision of transportation is difficult to conceive in practice, particularly for most existing physical transportation systems, which already have complex, entrenched organizational structures built around complex, entrenched physical networks. Nevertheless, using advanced transportation technologies, we can envision elements of such an approach and illustrate how technology enables a movement *toward* user-driven transportation systems. In particular, electronic revenue collection significantly reduces the transaction costs associated with road user charging, which enables owners of ever-smaller segments of infrastructure to set prices, collect payments, and make investment decisions without relying on a centralized bureaucracy to do so. In principle, segment sizes could shrink such that even a relatively modestly sized link or corridor could be divided among a large number of owners, each with its own policies and strategies. Of course, it is possible that the emergent behavior of such a system could be undesirable at a macro scale from the perspective of a centralized authority. Nevertheless, "user-driven" infrastructure systems, driven by the micro strategies of individuals, are increasingly feasible—at least conceptually—as the technologies of transportation systems improve.

1.2.3.4 Potential impacts of technology on geographic scale

The issues associated with the selection of a geographic scale for the development, evaluation, and implementation of transportation strategies are economic, political, technical, social, and beyond. For any given region (e.g., nation, state, metropolitan area), these issues can be debated and negotiated in order to determine where along the spectrum of centralized to decentralized governance the community selects for transportation. However, in the past, some segments at either extreme of the spectrum were unavailable as a matter of pure practicality. Highly centralized systems suffered from sluggishness and unresponsiveness, hampered by a lack of data and communications over wide territories. Highly decentralized systems suffered from an inability to collect revenues or monitor usage effectively, and the perception of uncoordinated and/or redundant investments. With advances in revenue collection, system monitoring, and communications technologies, a wider range of geographic scales for development of transportation strategy has become feasible, but little is known about the potential short- and long-term behavior of systems operating under such governance scenarios.

1.3 Summary

In this discussion we have explored the possible future implications of advanced technology deployment on *strategy* development in the surface transportation sector. While the *operational* benefits of electronic toll collection, automated vehicle tracking, smartcards, system monitoring devices, and other innovations have been demonstrated and realized in many places, their strategic implications remain unclear. By first decomposing strategy development frameworks into several key dimensions, we can begin to target the areas in which advanced technologies will play influential roles. And, as illustrated in this discussion, there are a number of ways in which advanced technologies can influence the selection of institutional architectures, decision-making processes, and geographic scales. For example, ETC enables more sophisticated application of direct user fees and consideration of geographic scales for decision-making that differ from the status quo.

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2 Complete list of alternative frameworks

Alternative Framework #	Geographic Scale	Resource allocation approach	Revenue type	Revenue quantity
1	National	BCA (SOE)	Tax	High
2				Medium
3				Low
4			Toll	High
5				Medium
6				Low
7			Mix	High
8				Medium
9				Low
10		NPV (SOE)	Tax	High
11				Medium
12				Low
13			Toll	High
14				Medium
15				Low
16			Mix	High
17				Medium
18				Low
19	Regional	BCA (SOE)	Tax	High
20				Medium
21				Low
22			Toll	High
23				Medium
24				Low
25			Mix	High
26				Medium
27				Low
28		NPV (SOE)	Tax	High
29				Medium
30				Low
31			Toll	High
32				Medium
33				Low
34			Mix	High
35				Medium
36				Low
37	Hybrid (50)	BCA (SOE)	Tax	High
38				Medium
39				Low

40			Toll	High
41				Medium
42				Low
43			Mix	High
44				Medium
45				Low
46		NPV (SOE)	Tax	High
47				Medium
48				Low
49			Toll	High
50				Medium
51				Low
52			Mix	High
53				Medium
54				Low
55	Hybrid (25)	BCA (SOE)	Tax	High
56				Medium
57				Low
58			Toll	High
59				Medium
60				Low
61			Mix	High
62				Medium
63				Low
64		NPV (SOE)	Tax	High
65				Medium
66				Low
67			Toll	High
68				Medium
69				Low
70			Mix	High
71				Medium
72				Low
73	Municipal	BCA (SOE)	Tax	High
74				Medium
75				Low
76			Toll	High
77				Medium
78				Low
79			Mix	High
80				Medium
81				Low
82		NPV (SOE)	Tax	High
83				Medium
84				Low

85			Toll	High
86			Toll	Medium
87			Toll	Low
88			Mix	High
89			Mix	Medium
90			Mix	Low
91	Link	n/a	Tax	High
92	Link	n/a	Tax	Medium
93	Link	n/a	Tax	Low
94	Link	n/a	Toll	High
95	Link	n/a	Toll	Medium
96	Link	n/a	Toll	Low
97	Link	n/a	Mix	High
98	Link	n/a	Mix	Medium
99	Link	n/a	Mix	Low
100	National	IRR (Concession)	Toll	High
101	National	IRR (Concession)	Toll	Medium
102	National	IRR (Concession)	Toll	Low
103	Link	IRR (Concession)	Toll	High
104	Link	IRR (Concession)	Toll	Medium
105	Link	IRR (Concession)	Toll	Low