

Automobile Path Dependence in Phoenix:
Driving Sustainability by
Getting Off of the Pavement and Out of the Car
by
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ABSTRACT

A methodology is developed that integrates institutional analysis with Life Cycle Assessment (LCA) to identify and overcome barriers to sustainability transitions and to bridge the gap between environmental practitioners and decisionmakers. LCA results are rarely joined with analyses of the social systems that control or influence decisionmaking and policies. As a result, LCA conclusions generally lack information about who or what controls different parts of the system, where and when the processes' environmental decisionmaking happens, and what aspects of the system (i.e. a policy or regulatory requirement) would have to change to enable lower environmental impact futures.

The value of the combined institutional analysis and LCA (the IA-LCA) is demonstrated using a case study of passenger transportation in the Phoenix, Arizona metropolitan area. A retrospective LCA is developed to estimate how roadway investment has enabled personal vehicle travel and its associated energy, environmental, and economic effects. Using regional travel forecasts, a prospective life cycle inventory is developed. Alternative trajectories are modeled to reveal future "savings" from reduced roadway construction and vehicle travel. An institutional analysis matches the LCA results with the specific institutions, players, and policies that should be targeted to enable transitions to these alternative futures.

The results show that energy, economic, and environmental benefits from changes in passenger transportation systems are possible, but vary significantly depending on the timing of the interventions. Transition strategies aimed at the most optimistic benefits should include 1) significant land-use planning initiatives at the local and regional level to incentivize transit-oriented development infill and urban densification, 2) changes to state or federal gasoline taxes, 3) enacting a price on carbon, and 4) nearly doubling vehicle fuel efficiency

together with greater market penetration of alternative fuel vehicles. This aggressive trajectory could decrease the 2050 energy consumption to 1995 levels, greenhouse gas emissions to 1995, particulate emissions to 2006, and smog-forming emissions to 1972. The potential benefits and costs are both private and public, and the results vary when transition strategies are applied in different spatial and temporal patterns.

DEDICATION

For my son, Daniel. May he learn to love cars in the same way that my dad, John, taught me when he made me work for, pay for, and fix up that 1965 Ford Mustang in 1991. But with that love, may he also carry a deep respect for the engineering that goes into the machines, the social, political, and economic implications of the choices we make in our daily lives, and the environmental impacts of all of the above.

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CHAPTER 1

RESEARCH PROPOSAL: ROADMAP TO EVALUATE AND BREAK AUTOMOBILE PATH DEPENDENCE IN METROPOLITAN AREAS

1.1 Introduction.

Historic investments in transportation infrastructure have produced an emergent behavior that requires unsustainable institutional, economic, and environmental commitment. That level of commitment becomes a path dependency, preventing the future accomplishment of established goals for sustainable transportation. In Arizona, the Long-Range Transportation Plan (LRTP) points out that the state faces \$89 billion in transportation requirements through 2035, while projecting only \$26 billion in revenue (ADOT, 2011c). The aggressive plan centers on investment choices that preserve infrastructure and expand existing systems while addressing diverse travel needs in the region. As recently as April of this year, the Mayor of Phoenix said in his state of the city address that “we cannot be a great city without a great transportation system, and our current system needs to grow” (Stanton, 2012). The economic realities associated with expanding transportation systems do not seem to reconcile with the optimistic sustainability goals of the region, such as the statewide goal to “reduce Arizona’s future greenhouse gas emissions to the 2000 emissions level by the year 2020, and to 50 percent below the 2000 levels by 2040” (City of Phoenix, 2008). Despite an implicit need to grow transportation infrastructure to meet the demands a population that will likely double by 2040 (Morrison Institute for Public Policy, 2011), Arizona’s Department of Transportation summarizes their 2013-2017 strategic plan by making priorities that “will focus our limited resources on preserving and modernizing what we already have [in order] to protect the taxpayer

investment in the existing transportation system” (ADOT, 2011b). This dichotomy begs the question, what is sustainable passenger transportation, or at the very least what does it mean to Phoenix? Furthermore, has Phoenix already committed itself to energy consumption and environmental impacts that make future sustainability goals unattainable?

This study joins theories of “lock-in” and path dependence with concepts of and plans for sustainable mobility. Path dependence theory has roots in social sciences and mathematics, and explains how suboptimal outcomes occur in complex systems because of sensitivity to initial conditions, self-reinforcing feedback mechanisms, or dependence on historic decisions (Arthur, 1988; Garud & Karnoe, 2001; Liebowitz & Margolis, 1995). Growth in roadway infrastructure in the U.S. has paralleled growth in automobile travel over many decades (Cervero, 2003; FHWA, 2012; Newman & Kenworthy, 1989; Noland & Cowart, 2000). Private automobile travel is one of the least energy efficient modes of passenger transportation and accounts for one of the largest sectors of non-point-source pollutant emissions in the U.S. (Chester, Horvath, & Madanat, 2010; EPA, 2010). Cities nationwide are advocating for reduced automobile transportation in the name of sustainability goals. Sustainability is a concept with multiple definitions, but common explanations of sustainable transportation center on meeting the mobility needs of today with the least negative impacts to ensure that future generations can also meet their mobility needs (Banister, 2008; Black, 1996; Chang & Chen, 2009; Ryley & Ison, 2007; Yazzie & Ellen Greenberg, 2012). Path dependence in transportation planning and decision-making is a barrier that directly prevents metropolitan regions from achieving sustainable transportation goals. This research will use the life cycle assessment (LCA) framework to quantify the economic costs and energy and environmental effects of infrastructure path

dependency and develops an expanded institutional analysis and LCA (IA-LCA) framework¹ to identify transition strategies that enable alternative and sustainable² future transportation options.

The primary research question is: **What are the intervention points and strategies for overcoming institutional, economic, and environmental barriers to transition cities from path-dependent automobile-oriented growth to passenger transportation infrastructure growth that is sustainable in the future?** By identifying intervention points and corresponding transition strategies that are beneficial over their life cycle, stakeholders at all levels can make more informed decisions and realize the comprehensive and definitive impacts from moving towards more sustainable passenger transportation. While this study focuses on Phoenix, urban locations worldwide struggle with decisions about sustainable transportation and these results provide a methodological framework with which to look at any large transportation infrastructure, assess and evaluate future transportation decisions, and inform the establishment of sustainable transportation goals.

1.2 Background.

Before tackling such questions, it is important to frame the overlapping concepts of sustainability, sustainable development, sustainable transportation, and sustainable mobility. The Brundtland Commission established the widely-adopted definition of sustainable development – development that “meets the needs of the present without compromising the

¹ In this dissertation, the term *framework* is used to describe a “way of thinking” or a “lens” through which one views and defines the situation. The term *methodology* is distinct from *framework*, and a methodology describes what is done or how it is done.

² Sustainable transportation, as defined in this research, is discussed in Section 1.2 of this chapter and in the institutional analysis (Chapter 3). The future trajectories modeled here are not deemed sustainable per se, but are characterized as more sustainable than the status quo due to economic, energy, and environmental benefits.

ability of future generations to meet their own needs" (The World Commission on Environment and Development, 1987). Generalized definitions of sustainability as a noun, or the associated adjective sustainable, traces back to the Brundtland concept and usually includes factors associated with intergenerational equity, minimal impact on natural resources, sustained benefits or utility, and system endurance or resilience. Adapting such definitions towards transportation, researchers describe systems that satisfy "current transport and mobility needs without compromising the ability of future generations to meet those needs" (Black, 1996). In the last two decades of discourse over sustainable transportation, the criteria and concepts attached to sustainable transportation have become complex and nearly impossible to fulfill, sometimes including communication and security (Banister, 2008; Black, 2005; Chin, 2010). Black (2005) points out that there is a balance to be established between defining sustainable transportation by only one criterion (e.g. reducing automobile travel) and including so many criteria that initiatives will never succeed and the losers will be the very societies who needed or wanted better systems. This research deliberately distinguishes between mobility as a process and transportation as a system. Banister (2008) distinguishes mobility as a derived benefit in that the value comes from getting to or from one location to the other, and this is at a very personalized or behavioral level. Thus sustainable mobility refers to concepts of the process of movement and the derived benefits to individuals (Banister, 2008; Maddison et al., 1996). Sustainable transportation on the other hand refers to physical infrastructure systems, with components of natural resource consumption, pollution, fiscal costs, and human health and environmental impacts (Black, 2005).

As cities face population growth and reach farther and farther for non-local natural resources, transportation infrastructure is a major component that not only enables growth

and expansion but also contributes to social and environmental impacts of the city, constrains urban capacity, and shapes basic human welfare. Sustainable development is a concept that is worthy of pursuit, but one that can never be physically attained without removing the very beings that consume resources (Allenby, 2005; Braungart, McDonough, & Bollinger, 2007; Halog & Manik, 2011). Modern urban societies clearly do not intend to take humans out of the equation, but the optimal solution seems to be in attaining a manageable amount of growth and development without breaking the system and without diminishing the functions or utilities that are essential to the welfare of the socio-ecological system. This research concentrates on passenger transportation infrastructure in the Phoenix metropolitan area, evaluates levels of path dependence, or “lock-in,” towards the automobile-oriented status quo, and compares transition strategies and alternatives against the status quo to reveal the possibilities and limitations for more sustainable transportation in the region.

Urban policymakers, planners, and stakeholders all have established visions of sustainable transportation systems in the future and at some level have ideas about transitions strategies to get there, but reconciling those long-term normative anecdotes with short-term budgetary, technological, and logistical requirements is elusive. Phoenix³ is not an entirely unique urban metropolis – it is made up of several “edge” cities (Garreau, 1991) that enjoy a certain amount of autonomy while also identifying themselves with the whole region. What is unique about Phoenix is that the city is relatively young, growing quickly to

³ Throughout this research, the Phoenix metropolitan area will be referred to simply as Phoenix, and the data modeled for this area are defined as the cities, towns, municipalities, and native lands that comprise Maricopa County. Specific references to the City of Phoenix will be explicitly stated (e.g. City of Phoenix, City of Mesa). During the conduct of this research, the Maricopa Association of Governments (the Metropolitan Planning Organization) was expanded to include regions from adjacent counties, but the work presented here simplifies the Phoenix metropolitan area as it was defined in 2011, just within Maricopa County.

become a metropolitan area in the post-World War II decades and during the heyday of automobiles and highways (Collins, 2005; Gammage, 1999; Gober, 2005). It also has a cooperative collaboration called the Maricopa Association of Governments (MAG) that is very active and well-respected in the region. MAG becomes the collective voice of the metropolitan region, so long as it does not overstep its welcome amongst its member localities. Sustainability goals, environmental improvement targets, and even growth and development strategies are not coherent for Phoenix. Outsiders looking in are likely to ask why politics at all levels plays a major role in decision outcomes, and why there are barriers to achieving sustainability goals, especially when initiatives are often framed as “win-win.” Political factors are likely a part of the explanation for why optimal or more efficient decisions are or are not made with respect to infrastructure and sustainability (Rittel & Webber, 1973; Rose, 1989; Wachs, 1995; Winner, 1986). Wachs (1995) details such political forces as budgetary constraints, consensus-building, competing interests at different levels of government, and many others that are clearly present in Phoenix.

1.2.1 Phoenix, Arizona from 1950 to Present. Phoenix, Arizona experienced rapid post-war growth coupled with the automobile age, and public investment in transportation infrastructure has escalated over time together with private spending on automobile use. Historic trends in infrastructure systems investment resulted in travel behavior that requires indefinite institutional, economic, and environmental commitment. The regional population is forecast to double by 2050 (Arizona Department of Administration, 2010) while the LRTP describes a \$63 billion budget gap through 2035 (ADOT, 2011c).

Located in the desert southwest United States, Phoenix now covers roughly 10,000 square miles and consists of 25 cities and towns and three sovereign Native American reservations. Phoenix grew in a location relatively isolated from other major cities. As a

result, the growth patterns and infrastructure systems are relatively uncomplicated compared to cities of similar size and with longer histories (e.g. Boston or San Francisco). MAG is the designated Metropolitan Planning Organization (MPO) for regional planning in the areas of transportation, air quality, water quality, and human services (MAG, 2012b). While the MAG member agencies cooperate on regional planning, the cultural and historic norms in the region foster a strong sense of autonomy and bottom-up leadership structure (Collins, 2005; Gammage, 1999; Gober, 2005; Ross, 2011; Yazzie, 2012), and Arizona is a “home rule” state where the constitution grants incorporated cities with the ability to govern themselves in keeping with state and federal laws. Several local, state, and federal initiatives focus on reducing transportation impacts or improving environmental quality, but there are no cohesive and broad-reaching documents to guide regional environmental or sustainability goals⁴. Without such guidance, transportation planners who are developing long-range regional transportation plans have trouble justifying changes based on environmental improvements. In 2010, MAG began an 18-month project named the Sustainable Transportation and Land Use Integration Study (ST-LUIS) to develop recommendations that both transportation and land use planners can integrate into their long-range plans (MAG, 2011b). Working papers from the ST-LUIS project define sustainable transportation for Phoenix as possessing a range of options for users, good access and affordability for

⁴ The Governor of Arizona signed Executive Order 2006-13 (Napolitano, 2006), reiterating the role of the state’s Climate Change Advisory Group (CCAG) and establishing GHG emissions reduction goals for the state. The CCAG published reports and went to work establishing strategies for meeting these goals, but in 2010 the new Governor signed a subsequent Executive Order 2010-14 (Brewer, 2010). This new Executive Order did not specifically supersede 2006-13, but set new priorities for regional interaction on GHG emissions goals by emphasizing the importance of the economy. The CCAG is not mentioned in Executive Order 2010-14, and the Governor’s approach to climate change is to advocate for Arizona’s voice in matters of regulatory requirements to ensure that the state economy is not negatively affected relative to jobs, growth, and the economy in other states and other countries. Executive Order 2010-14 expired in 2012 and the CCAG no longer meets.

users, high regional connectivity that promotes economic development, and all with minimal impact on air quality, habitat, and natural resources (MAG, 2011b). The final report from this comprehensive study details three years of stakeholder engagement, public panels, scenario modeling, toolbox and strategy development, and final recommendations (MAG, 2013b).

Streetcars and widespread use of public transit steadily declined from the 1950s-onward, but in 2008 a new light rail system began operating in the Cities of Phoenix, Tempe, and Mesa and ridership quickly exceeded initial predictions (MAG, 2012a). The recent Light Rail Transit (LRT) success has led to more political and economic support for expansion that would create a more regional light rail network and a more robust multi-modal transit system (MAG, 2012a). Recent impacts of the recession on Phoenix's housing construction industry coupled with the success of high-capacity transit has piqued interest in shifting the automobile-focused financing of infrastructure towards more multi-modal planning (MAG, 2012a, 2013b).

Passenger automobile travel and roadway infrastructure in Phoenix has grown significantly since 1950, and the increases cannot be explained by population growth alone. Both population and regional transportation spending (adjusted for inflation) increased by an order of magnitude, from 330,000 people and \$3,000 per mile public transportation spending in 1950 to nearly four million people in 2012 and \$30,000 per mile public transportation spending (Arizona Department of Administration, 2010; FHWA, 2012). The increases in automobile traffic follow a steeper trend, from one billion annual vehicle miles travelled (VMT) in 1950 to 30 billion in 2012 (FHWA, 2012). The retrospective LCA modeled in Chapter 2 details these historic trends from 1950-present in Phoenix.

Phoenix road infrastructure has been constructed ahead of and in concert with sprawling “edge” (Garreau, 1991) growth⁵. Half of the current roadways were constructed after 1979 at the edges of the urbanized area. These “fringe” roads, or the suburban housing developments that required roadway infrastructure, can explain at least part of the rapid VMT increase because they are located in isolated clusters far from job centers, public transit corridors, and basic human services.

Regional Transportation Improvement Program (RTIP) documents detail existing goals for transportation in the region, to include employer travel reduction programs, encouraging bike travel, reduction of particulate matter emissions, reduction of greenhouse gas emissions, and reduction of natural resource consumption and environmental impact (MAG, 2011a, 2013a). As the Phoenix metropolitan region grows, economically, geographically, and by population, its transportation infrastructure must grow with it. The challenge will be in meeting local, regional, state, and federal environmental and sustainability goals in the process⁶.

1.3 Literature Review.

This research combines frameworks established in social sciences, environmental sciences, and engineering. Each concept is defined in turn in this literature review.

1.3.1 Sustainability Problems. Sustainability problems, by definition, are complex problems that involve adaptive interactions between the natural environment and social systems (Wiek, Ness, Schweizer-Ries, Brand, & Farioli, 2012) and do not have distinct

⁵ A geographic analysis of roadway deployment is included in the retrospective LCA in Chapter 2.

⁶ The institutional analysis (Chapter 3) discusses new federal requirements for transportation plans to address sustainability. These new requirements are still being defined, but have been introduced initially under the Moving Ahead for Progress in the 21st Century Act (MAP-21).

solutions but instead must be managed as the system and the problem itself evolves over time (Allenby, 2007; Innes & Booher, 1999; Wiek, Ness, et al., 2012). Previous work describes several different levels and forms of complexity, from strong to weak, static to dynamic, and tame to wicked (Allenby, 2012; Ritchey, 2011; Rittel & Webber, 1973). The most common definition for complexity in relation to sustainability problems is that of wicked complexity. Wicked problems occur in organizations or ecosystems where elaborate system interactions cause any attempts at solving one part of a problem to result in other problems that may make the situation worse. There is no way to solve a wicked problem (Rosenhead, 1996), and there is a level of reflexivity that occurs in the very way the problem is defined and viewed (Allenby, 2009). The solutions that are proposed depend heavily on how the system is defined and why the questions are being asked in the first place. Managing complexity in an attempt to create sustainability solutions can only be characterized as better or worse (Ritchey, 2011; Rittel & Webber, 1973) and usually involve a degree of self-organization, adaptation, or organizational learning (Innes & Booher, 2000; Huber, 1991; Wiek, Ness, et al., 2012).

1.3.2 Sustainable Transportation. Transportation is characterized widely as a sustainability problem (Amekudzi, Jotin Khisty, & Khayesi, 2009; Banister, 2008; Black, 1996, 2005; Boschmann & Kwan, 2008; Litman, 1999). Mobility is a basic human need in modern urban areas, and every mode of passenger transportation has associated energy and environmental impacts that increase in magnitude as urbanization increases. Most of the benefits from mobility are not a direct result of transportation, but a derived benefit from getting to or from a location (Maddison et al., 1996). The infrastructure that enables this mobility is largely provided through public activity, and the individuals who benefit from the infrastructure do not pay the true cost of the system (Litman, 1997; Maddison et al., 1996;

Rothengatter, 1994). Efforts to make transportation more sustainable are often difficult to reconcile with social demands for mobility, fiscal constraints, regulatory requirements, and the physical limitations of the natural environment (i.e. there are externalities associated with all forms of transportation) (Banister, 2008; Black, 1996; Cohen, 2010, 2012; Köhler et al., 2009).

Transportation researchers generally concur that sustainable mobility and the future of passenger transport centers on reducing passenger vehicle traffic and increasing the proportion of public transportation, to include biking and walking (Akerman & Hojer, 2006; Banister, 2008; Chang & Chen, 2009; Cohen, 2012; Litman, 1999; Low & Astle, 2009). With population increases imminent, budgets constrained, and natural resources stressed, MAG in particular is trying to figure out how to provide transportation services for the least fiscal cost and with the fewest environmental impacts (Arizona Town Hall, 2009; MAG, 2010; Yazzie & Ellen Greenberg, 2012). Curtailing the amount of per-passenger travel might seem the most efficient way to accommodate increased populations, but it is easier for planners and decision-makers to enact technical solutions or incremental changes instead of those that involve radical and widespread changes in the behavior of individual travelers (Köhler et al., 2009; Wachs, 1995). MAG is beginning to integrate technical solutions with behavioral change in both transportation and land use planning as part of the ST-LUIS study, which is the only consolidated guidance developed thus far in Maricopa County that defines sustainable transportation. The final report was completed in 2012, presented at public outreach events, and accepted by MAG in 2013 (MAG, 2013b). The working definition of sustainable transportation and land use, from ST-LUIS reports, focuses on multiple transportation options, walkability, safety, equitable access, and energy efficiency (MAG, 2011b, 2011c, 2013b).

1.3.3 Path Dependence. Path dependence, sometimes termed “lock-in,” is a subset of institutional analysis, and basically describes “self-reinforcing mechanisms” that cause a particular decision to be made “even though better alternatives exist” (Arthur, 1988; Low & Astle, 2009; Martin & Sunley, 2006). It can be a way of answering questions about why planners and policymakers make inefficient or faulty choices in urban transportation systems. Some transportation researchers alternatively explain failed or ineffective decision-making by accounting for politics, perceptions, economics, and regulatory or technical constraints (Boarnet, 1995; Chang & Chen, 2009; Litman, 1997; Newman & Kenworthy, 1989; Pflieger, Kaufmann, Pattaroni, & Jemelin, 2009; Richmond, 1998; Unruh, 2002; Wachs, 1995). Even the terminology for the phenomenon, path dependence, is rooted in a metaphor about transportation. Metaphor is a powerful tool in establishing saliency in any scenario development, goal establishment, or visioning exercises (Selin, 2006), and describing a lack of control along some sort of path or road is a way to convey both the passage of time and the established nature of the direction the situation is heading. Since decision-making and policy does not actually function like a trip on a path, it is important for the actors in the transportation system to gain more comprehensive perspectives of the impacts of past and future decisions. One way to give control back to decision-makers may be to use LCA to quantify both a priori commitment to transportation infrastructure and the opportunities for savings or reduced impacts through alternatives or transition strategies. Organizational learning literature (Huber, 1991) defines institutional learning as when an entity gathers and processes information and then the realm of possible behaviors is expanded (i.e. behavior change does not actually have to occur, but the option of behavior change is now a possibility). Huber (1991) points out that organizational memory is the way that knowledge is carried into the future, and path dependence literature (Garud & Karnoe, 2001; Porac,

Rosa, Spanjol, & Saxon, 2001; Rao & Singh, 2001; Tiberius, 2011; Van Looy, Debackere, & Bouwen, 2001) posits that entrepreneurs can break path dependence by path creation where efforts are made to enable a different possibility or create a need for a new product or behavior. Once a new path is competitive with the status quo, then the realm of possible behaviors or choices is expanded and institutions then have the possibility of changing (Huber, 1991; Porac et al., 2001; Tiberius, 2011).

Previous work on path dependence in transportation does not weigh alternatives against existing auto-oriented systems but generally focuses on historical analysis (Arthur, 1988; Cowan & Hultén, 1996; Meyer, 1999; Unruh, 2002). For example, studies explore the concept that roads and highways enable urban sprawl patterns (Bruegmann, 2005) or why electric cars were not widely adopted in the 1990s (Richard, 2011). Much of the research on sustainable mobility recognizes that the status quo in urban transportation is unsustainable and then focuses on vehicle technology or roadway policy solutions to break the cycle (Khayesi & Amekudzi, 2011; Parry, Walls, & Harrington, 2007; Schot, Hoogma, & Elzen, 1994). Innes and Booher (2000; 1999) outline organizational learning strategies as a way to manage sustainability problems; the strategy is to develop system performance indicators that inform the public about health and environmental issues, program indicators that inform policy-makers on the performance of their policies, and rapid feedback indicators that inform individuals and single actors about the immediate effects of individual actions (Innes & Booher, 2000). In order to transition towards sustainable transportation infrastructure, theories of organizational learning can be applied to breaking path dependence in transportation planning and combined with concepts of managing sustainability problems as complex adaptive systems (Gifford & Stalebrink, 2002; Van Looy et al., 2001).

The previous work on transportation path dependence makes conclusions about the barriers preventing transitions to more sustainable systems, but researchers define and characterize these barriers subjectively and anecdotally (Boschmann & Kwan, 2008; Cohen, 2010; Steg & Gifford, 2005). While these concepts for transitions are valuable to planners and decision-makers, it is difficult to apply these concepts to immediate budgetary and policy decisions (Steg & Gifford, 2005; Wachs, 1995). Other work outlines and quantifies the “true cost” of transportation, using LCA methods to make comprehensive and holistic comparisons between different modes of transportation or different technologies (Litman, 1997; Maddison et al., 1996; Michalek et al., 2011), but these studies do not link the results to normative or geographically-specific goals for sustainability. Sustainability researchers propose that an essential component in addressing problems in a complex system such as urban transportation is building the decision-making capacity of individual players in the system (i.e. passengers and decision-makers) so that the system itself adapts incrementally and evolves away from the lock-in (Innes & Booher, 1999; Köhler et al., 2009). According to Innes and Booher (1999), complex problems require that appropriate indicators be developed to evaluate the problem, then collaboration and community deliberation can lead to positive change if new leadership allows for bottom-up adaptations. LCA studies, if developed in ways that stakeholders and decision-makers find useful, can result in developing indicators that will be catalysts for both passengers and decision-makers to close the gap between normative sustainability goals and institutional inertia towards the status quo.

1.3.4 Life Cycle Assessment. LCA is a framework for looking at environmental causes, effects, and impacts from products or processes from cradle to grave (ISO, 2006), and depending on the design, LCA results can be used to inform manufacturers, engineers

and designers, decision-makers in industry and government, scientists and academics who measure, evaluate, and regulate products or processes, and even those who market such products or processes. The system boundary of an LCA is chosen based on the scope of the study, and defines the dimensions (geographic, temporal, technical, etc.) of the analysis (Baumann & Tillman, 2004). Inventorying (LCI), costing (LCC), and impact assessment (LCIA) are methods within the LCA framework that can be tailored to the specific purpose or application of a study (i.e. a corporation may prefer a simple LCC while an environmental conservation organization may want an LCI) (ISO, 2006). In the case of passenger transportation, most studies are LCIs (Baron, Tuchschnid, Martinetti, & Pepion, 2011; Yang, Mccollum, Mccarthy, & Leighty, 2009), some are LCCs (FHWA, 1998, 2002; Jansson, 2008; Kim et al., 2010), and there is a distinct gap in the literature for transportation research that integrates both (Chester & Horvath, 2009; Chester, Horvath, & Madanat, 2010; Eckelman, 2013; Eisenstein, Chester, & Pincetl, 2013). Typically an LCI of passenger transportation would be useful to regulators, public interest groups, environmental and conservation officials, and possibly local and regional managers or officials. Without the economic component of a transportation analysis, an LCI alone is not sufficient to influence decision-making for regional transportation planners, transportation review committee members, and several levels of elected officials who manage their portion of a fiscal budget (Beimborn, 2006; Eisenstein, Chester, & Pincetl, 2013; Taylor, 2004). When integrated appropriately, with logical and matching system boundaries, LCI and LCC together can facilitate more comprehensive and constructive information, transition strategies, and solution opportunities for problems as complex as sustainable passenger transportation. The accuracy of the results are not always as important as the differences between alternatives or

scenarios and the conversation and deliberation that is generated by looking at the problem in new ways (Beimborn, 2006; Huber, 1991; Innes & Booher, 1999).

Transportation life cycle studies have focused on specific vehicle types (Chester & Horvath, 2012a; Chester et al., 2010; Cooney, 2011; Givoni, 2007; Michalek et al., 2011) and broader transportation systems (Chester & Horvath, 2012b; Graedel & Allenby, 1997; Maddison et al., 1996)⁷. When LCC and LCI system boundaries are commensurate, LCC can reveal aspects of the system that dominate costs (e.g. cement mixing and temporary construction to divert traffic) or that limit the possible extent of the project (e.g. Department of Transportation suppliers can only produce limited amounts of aggregate per month and regulations and costing precludes out-of-state aggregate purchases) while LCI reveals aspects of the system responsible for differing amounts of material flow (natural resources or emissions) and details externalities that are not normally included in decision-making (e.g. ozone non-attainment impacts from construction, water quality impacts from paving land in watershed areas, urban heat island effects, etc.).

LCC can supplement conclusions from LCI and vice versa. Integrating the two reveals processes or portions of the material flow that may exceed regulatory standards (e.g. particulate matter or pollution emissions) and could either prevent project approval or put federal funding at risk⁸. The additional benefits (sometimes intangible to decisionmakers) of a transportation project revealed through LCI can also generate support for alternative

⁷ Maddison et al. (1996) admit that their approach is not an LCA (pg 13) because it is not cradle-to-grave, but it does use similar methods for inventorying “costs” and also points out that “before confronting road users with the true costs of their activities we first have to work out what the costs are: (pg 11). In their methodology, they inventory the inputs and outputs for road transport (air pollution, noise, congestion, etc.) and assign economic values to these externalities in order to compute the “true cost” of transport. While not strictly an LCA, it does combine detailed input/output inventory of externalities with costing.

⁸ The Clean Air Act of 1990 allows federal funding to be withheld from transportation projects based on nonattainment of planning goals and pollution emissions standards (Johnston, 2004).

transportation projects that might otherwise be dismissed as too costly (Wachs, 2009). A General Accounting Office (GAO) report on transportation planning in the United States found that transportation planners who consider ecosystem conservation in their plans see positive benefits, and recommended that all MPOs perform such integrated planning (GAO, 2004). LCIA can be a decision support tool for both land use and transportation planning (Eckelman, 2013)⁹.

1.3.5 Transformational Sustainability Research. This research defines sustainability transition strategies as plans or tactics that enable a human-environment system to alter its current (or expected) trajectory to a more sustainable state (Wiek, Ness, et al., 2012; Wiek, Withycombe, & Redman, 2011). Transformational sustainability research calls for changes in individual behavior and governance within complex systems and across multiple disciplines over time and space (Wiek et al., 2011). To break the path towards an undesirable future state and to determine sustainability solutions, more desirable (normative) future states are identified, the paths leading to those states are termed transition strategies, and the detailed actions that must be taken to execute those transition strategies are intervention points (Wiek et al., 2011). Conducting participatory research, selecting the appropriate data sources and boundaries, engaging the stakeholders, and contextualizing the solutions in time and space are all factors necessary for successful institutional and behavioral changes towards sustainability (Blackstock, Kelly, & Horsey, 2007).

⁹ Eckelman (2013) states that transportation LCAs often treat the land use patterns as fixed, and focus on the short term benefits and costs. Work completed during this research (Chester et al., 2013; Kimball et al., 2013) looks at both geographic and temporal changes to evaluate a consequential LCA for a metropolitan area.

Building adaptive capacity¹⁰ in transportation planning institutions is a means for enabling sustainable transportation in the future and it requires bridging disconnects between normative desires for sustainable transportation and quantitative regulatory and fiscal constraints that are inherent in urban systems (Holmberg & Robert, 2000; Köhler et al., 2009). Viable opportunities for achieving more sustainable systems can be revealed by investigating the levels of historic automobile-oriented path dependence in a city's passenger transportation infrastructure, identifying the commitment towards that status quo into the future, reconciling that commitment against future sustainability goals, and then evaluating equivalent levels of commitment for intervention points and transition strategies that may break the path dependence. This research evaluates a suite of transition strategies by modeling growth as transit-oriented development (TOD) infill on vacant lots along Phoenix's light rail transit (LRT) line¹¹. The results show large marginal benefits from the combined transportation and land use effects of building a dwelling unit as TOD infill rather than allowing business-as-usual (BAU) growth at the urban periphery (Kimball, Chester, Gino, & Reyna, 2013). MAG Transportation Policy Committee members, transportation planners, consultants, and Valley Metro officials have expressed interest in this study and indicate that it would be useful in their planning efforts, and the results corroborate previous studies about the benefits of LRT in Phoenix (Chester, Nahlik, Fraser, Kimball, & Garikapati, 2013; Golub, Guhathakurta, & Sollapuram, 2012).

¹⁰ Adaptive capacity is the ability of a system to evolve or adapt in response to stresses or shocks, and is sometimes termed resilience (Anderies et al., 2004; E. Ostrom, 2005; Scoones, 1998). Blackstock et al. (2007) describe sustainability as relying on "enhancing social capital and the collective capacity to respond positively to sustainability challenges."

¹¹ Different scenarios are modeled as "future trajectories" along with policy and planning transitions. Each trajectory is described in Section 1.4.3.

1.4 Methods.

This research is a mixed-methods interdisciplinary approach, using qualitative methods to evaluate institutional structures and policy, and quantitative methods to evaluate historic path dependence and reconcile policy targets with future commitments. The research follows four steps, conceptualized in Figure 1.1.

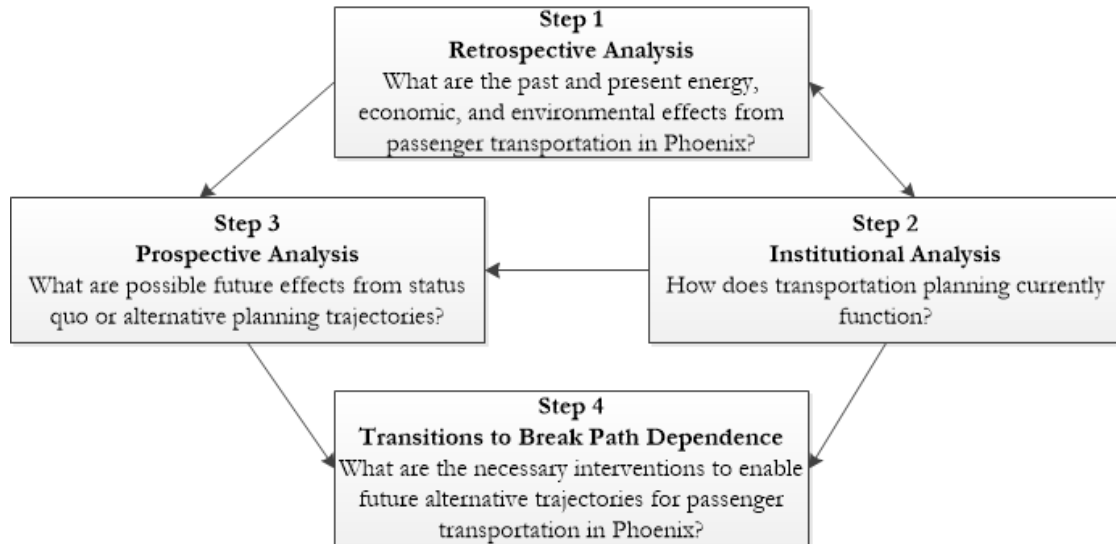


Figure 1.1. Conceptual Diagram of Research Methodology

1. **Retrospective Energy, Economic, and Environmental Analysis.** A historical life cycle energy consumption, economic costs, and air emissions inventory will be developed for vehicle manufacturing, vehicle operation, fuel production, and roadway construction and reconstruction.
2. **Policy Review and Institutional Analysis.** The significant influences that interact in the regional transportation system will be mapped, and barriers will be identified that prevent transitions towards more sustainable transportation options.
3. **Prospective Analysis and Trajectory Development.** Current and future light rail deployment will be assessed and tested against the future scenarios to see whether those strategies are beneficial and by how much.
4. **Synthesizing Transition Strategies and Intervention Points for Breaking Automobile Path Dependence.** The energy, economic, and environmental analysis results will be joined with the institutional analysis to match realistic transition strategies with identified barriers and the parts of the system most capable of affecting changes towards sustainable passenger transportation.

1.4.1 Retrospective Energy, Economic, and Environmental Analysis. The economic and environmental analysis assesses critical processes and develops life cycle indicators for Phoenix’s passenger transportation systems (i.e. the vehicle well-to-wheels cycle and the infrastructure “quarry-to-street” cycle) and evaluates the historic fiscal and environmental costs (i.e. the “sunk” impacts and influence by institutions) so that perceptions of automobile path dependence can be linked with more resolute data that are significant to the decision-making process. The geographic boundaries of the institutional analysis correspond with the Phoenix metropolitan area (defined here as Maricopa County) because regional transportation planning occurs at this scale and the Maricopa Association of Governments is designated by law as the MPO for transportation. The environmental analysis evaluates activities and effects that occur both inside and outside the region (e.g. auto manufacturing occurs outside Phoenix, but tailpipe emissions are localized). The system boundaries are shown in Figure 1.2, and are commensurate with processes and products that have been modeled in existing literature with LCA tools (ANL, 2011; Bare, Norris, Pennington, & McKone, 2002; Chester & Horvath, 2009; Chester et al., 2013; FHWA, 1998; Kimball et al., 2013).

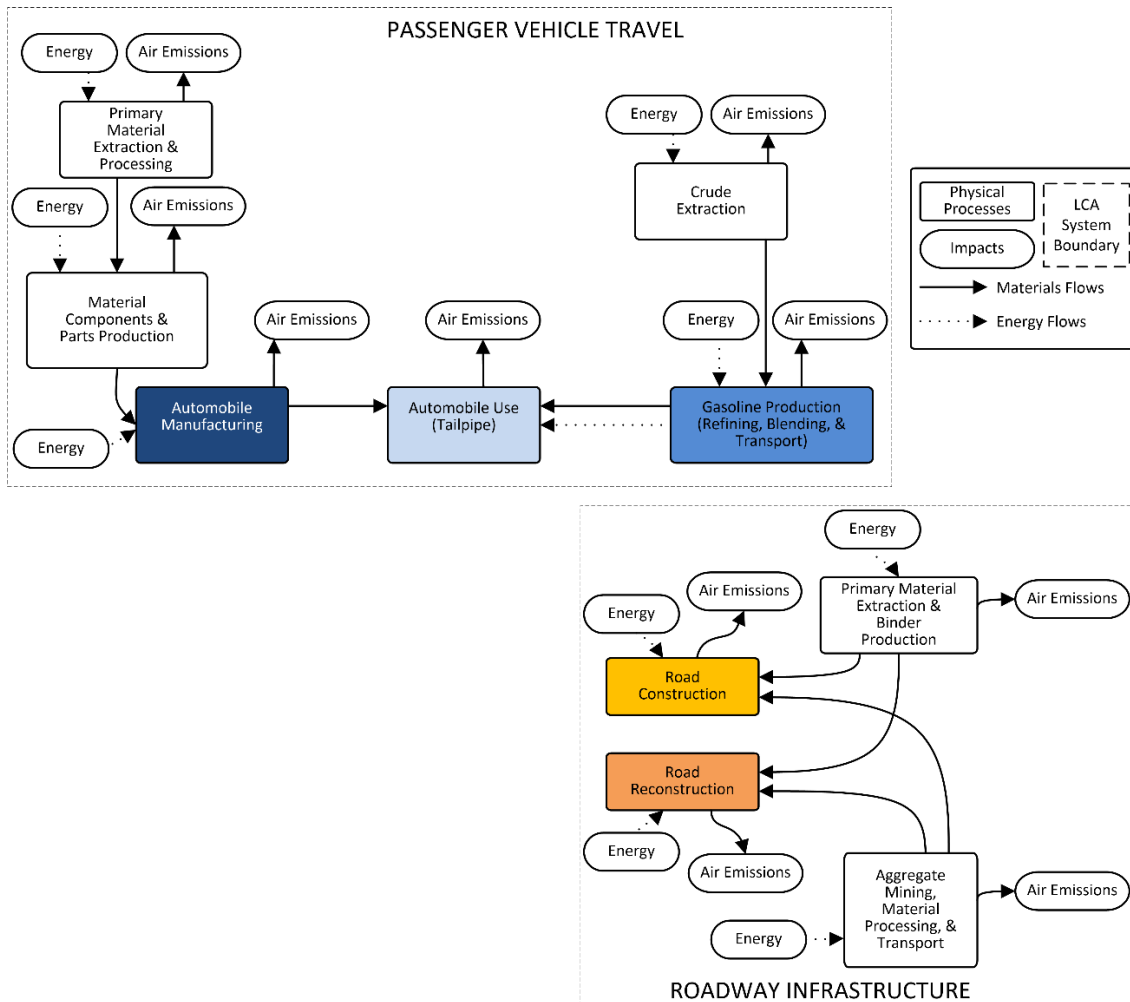


Figure 1.2. Life Cycle Assessment (LCA) System Boundary.

The PaLATE and GREET models are used to evaluate the energy and environmental flows of the shaded boxes in Figure 1.2. The Pavement Life Cycle Assessment Tool for Environmental and Economic Effects (PaLATE) (Horvath, 2003) are used to model the effects from roadway construction and reconstruction (periodic maintenance and resurfacing/repaving). The PaLATE tool has been modified and updated by work completed here at Arizona State University to incorporate the latest technical and academic data. The Greenhouse Gases, Regulated Emissions, and Energy use in Transportation, (GREET) models are used to analyze the vehicle cycle and fuel/electricity

cycles (ANL, 2007, 2011). GREET was developed at Argonne National Laboratories and is the state of the art for tracking energy use and emissions from primary sources (fuel or raw materials) to operational end-use (tailpipe or plug). Automobile use impacts (tailpipe emissions, automobile manufacturing, and oil extraction and gasoline production) are calculated with GREET based on the VMT from the Federal Highway Administration (FHWA) statistics. No transit-based LCA tools have been developed to date, so a process-based LCA approach is used to calculate the effects from LRT systems operating in the region, as in Chester et al. (2010) and Kimball et al. (2013).

Rather than conducting a simplified top-down study of passenger transportation in the United States, this study is a bottom-up historical assessment obtaining geographically-specific and scale-appropriate data that will be useful to regional transportation planners and decision-makers. Historical statistics are collected for roadway and passenger transportation system (including public transit) construction, maintenance, operation, and use from 1950-2010 as reported by the Federal Highway Administration and the Federal Transit Authority (FHWA, 2012; FTA, 2012). Transportation planning documents (Regional Transportation Plans, Transportation Improvement Plans, Highway Management System reports, etc.), regional budgets, and travel survey data are collected to gather a comprehensive accountability of historic travel behavior and actions. Current reference data on construction and maintenance of transportation infrastructure are used to project future commitments. Complete descriptions of data inputs are included in the LCA methodology in Chapter 2.

Cost data are necessary for this study in order to couch the results within every aspect of sustainability (i.e. the three pillars of social, environmental, economic) and to signify the results for planners and decisionmakers whose actions are often constrained and

driven by economics. The types of costs considered here are public costs (federal, state, and local spending on passenger transportation infrastructure) and private costs (vehicle purchase, fuel purchases, and public transit ticket purchases). These costs are correlated in this research to the different institutional players (e.g. passengers, Department of Transportation (DOT), city government) to gather insights on the positive and negative externalities inherent to the transportation system.

The FHWA statistics are annual reports reaching back to 1945 and reporting transportation infrastructure and travel characteristics at the state level (and more recently at the metropolitan city level). These statistics provide region-specific values for consolidated expenditures on public and private roadways (after 1960 this can be split into capital and maintenance), total miles of roadway, spending on new construction, VMT (only after 1960), and private and commercial motor fuel usage. At the national level, the FHWA statistics list annual numbers of passenger vehicles registered, VMT per passenger car, average fuel consumption per car, and average fuel economy (in miles-per-gallon) for passenger cars. From these data, Arizona-specific annual averages can be computed for miles-per-capita infrastructure, per-capita infrastructure spending, spending-per-mile of roadway, spending-per-mile on new construction, spending-per-mile on maintenance, and passenger VMT-per-mile of roadway. The U.S. Bureau of Labor and Statistics inflation calculator is used to convert all historic economic figures into current 2012 dollars (BLS, 2012), and census data are used for estimates of population statistics (Arizona Department of Administration, 2010; US Census Bureau, 2011).

The roadway statistics reported by the FHWA are only resolvable to the state level, therefore data must be collected that more accurately represent the miles of roadway in the Phoenix metropolitan area. Historic statistics do not exist that provide miles of roadway in

the Phoenix over time (Whelan, 2012). The state and regional Geographic Information Systems (GIS) map databases contain metadata on most sections of roadway, but in general the dates associated with a roadway are the dates that the section of roadway was added to the database rather than the date that the roadway was first constructed (ADOT, 2011a). The only accurate road inventories that can be used as primary data sources are those years of databases since GIS maps have been created and managed (for Maricopa County this is within the last decade). Building ages (the year of building construction) from the County Assessor database (Maricopa County, 2012) are used as a proxy, assuming that the roadways were initially constructed just before the buildings were constructed. This road age proxy methodology was developed by Fraser and Chester (2013). The road age proxy data are cross-referenced with the FHWA statewide statistics for quality assurance (as well as linking the sections of roadway with statistics on new construction spending).

Data on public transit in Phoenix are much more dispersed. In 1947, streetcars gave way to privatized bus systems for public transit, then in 1971 the city of Phoenix contracted an agreement with a private bus operator to control and organize transit operations (Abbitt, 1990). From 1971 to 1984, the City Manager's Office controlled the organization, and after that an official public transit department began. Each of the other cities in Maricopa County had different forms of public transit over the years (bus and paratransit), and in 1993 Valley Metro was created to join local governments in the funding and management of public transit. The Federal Transit Agency's (FTA) National Transit Database reports historic statistics on transit funding, extent of services (miles of bus routes, number of buses), usage, and operations and maintenance from 1996 (FTA, 2012). The FTA public transit data (from

nine separate transit operators in Maricopa County) are included in the LCA from 1996-onward¹².

Travel characteristics such as annual VMT, travel mode choices, and passengers per vehicle are collected from the FHWA statistics series (FHWA, 2012). In earlier versions of the FHWA statistics, the VMT are reported state-wide, but in more recent reports (1989-onward) the data are specific to the metropolitan statistical region and will correspond more directly with Maricopa County. Prior to 1989, state-wide statistics must be used as proxies and metropolitan-level VMT are calculated as a proportion of the state population (Arizona Department of Administration, 2010; FHWA, 2012). These travel characteristics are used in the LCA tools to model energy consumption, economic costs, and environmental effects.

Precise information on pavement design and reconstruction schedules are built into the PaLATE model. Historic Department of Transportation research documents are used to approximate the periodic maintenance schedules and the pavement design characteristics (AASHTO, 2011; City of Phoenix, 2009; Smith et al., 2005). MAG's transportation planning documents and a review of the Arizona Department of Transportation (ADOT) Maintenance Management System are used¹³.

The result of the retrospective LCA model (Step 1) is a comprehensive inventory of the historic passenger transportation fiscal and environmental effects in Phoenix from 1950 to present-day. Such a large-scale temporal assessment of passenger transportation has yet to be conducted for a major metropolitan city. The inventory includes roadway

¹² The lack of pre-1996 data does not skew the total model because the economic and environmental effects from all of the post-1996 transit is lost in the “noise” of all the other effects in the system. In early iterations of this research, transit was not included, and the decision was made to add the statistics to assuage any questions about trade-offs from transit versus automobile travel. Kimball et al. (2013) and Chester et al. (2013) corroborate the conclusion that transit effects are negligible compared to automobile effects.

¹³ roadways are now surveyed annually for quality and safety to determine maintenance needs (MAG, 2010).

infrastructure, vehicle manufacturing, fuel production, and vehicle operation for passenger transportation systems over the last six decades. Step 4 (Synthesizing Transition Strategies and Intervention Points for Breaking Automobile Path Dependence) correlates the results of the Prospective LCA (Step 3) with the Institutional Analysis (Step 2) to create a list of recommended strategies for transitioning away from automobile path dependence.

1.4.2 Policy Review and Institutional Analysis. The Institutional Analysis and Development (IAD) framework (E. Ostrom, 2005, 2011) is used to understand the institutional structure that leads to the transportation decisions and financing creating automobile path dependence. The analysis identifies barriers that significantly impact viable alternative strategies so that research efforts can be focused more appropriately towards transformational intervention points. IAD is a social sciences framework that takes both visible (buildings, infrastructure, people) and invisible (rules, norms, strategies, organizations) pieces of a complex system and maps the interactions to better understand key variables in the structure of the system and the effects of those key variables over time. The Phoenix passenger transportation system in this research is mapped as a social-ecological system (SES), that is, a network of people and processes (Anderies, Janssen, & Ostrom, 2004). The analysis is constructed from reviewing regional transportation planning documents and published policies and goals regarding passenger transportation and sustainable transportation (Arizona Town Hall, 2009; Collins, 2005; Yazzie & Ellen Greenberg, 2012). A simplified version of this analysis (Figure 1) is expanded and improved in Step 4

(Synthesis) by mapping the key players and the published requirements, expectations, and goals.

The insights from this institutional analysis gives context to the retrospective LCA (Step 1) results and provides focus for relating the results directly to sustainability transitions (see Step 4: Synthesizing Transition Strategies and Intervention Points for Breaking Automobile Path Dependence). Each of the results from the quantitative analyses (steps 1 and 3) are correlated directly or indirectly to this institutional analysis to provide functionality aimed at actually transforming the system (Blackstock et al., 2007).

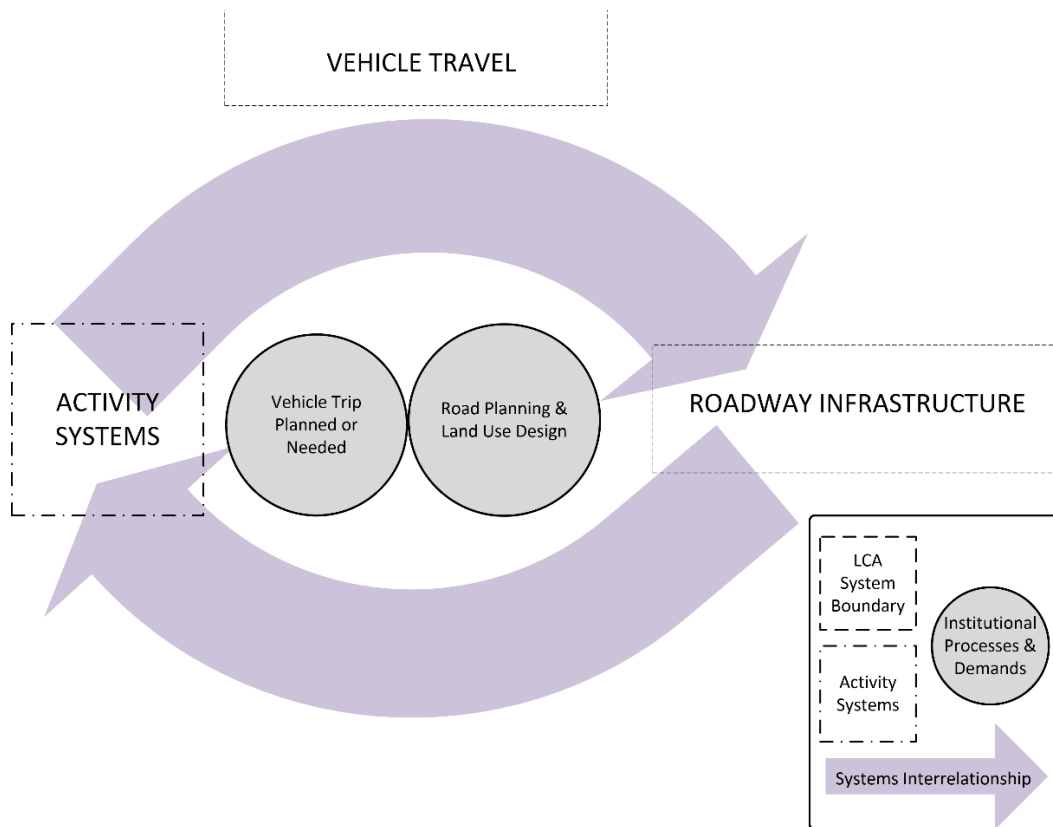


Figure 1.3. Basic Conceptual Map of Passenger Transportation Systems. Adapted from Manheim (1979).

The specific roles of each institution are defined (i.e. the MAG Transportation Policy Committee writes the Regional Transportation Plan), and the types of interactions are

described (i.e. updates to the Regional Transportation Plan require a conformity analysis to verify that the plan meets requirements for air quality improvements). The IAD is a reference guide to pair with the results from the Energy, Economic, and Environmental Analysis (Steps 1 and 3) in developing methods for assessing and breaking automobile path dependence (Step 4). A conceptual map (an expanded version of Figure 1.3) is produced in Step 4 that details the connections and interactions between different types and levels of institutions in the passenger transportation system.

1.4.3 Prospective Analysis and Trajectory Development. The retrospective life cycle effects are projected into four future trajectories¹⁴ that bound the possible outcomes (continued growth of auto-oriented infrastructure with no institutional change and halted infrastructure and land growth with significant policy change). The trajectories are correlated with recommended transition strategies (in Step 4) at plausible intervention points (time horizons) that will set the conditions to enable breaking BAU path dependence. Page (2006, p. 114) points out that it is possible to test the influences of positive and negative externalities in path dependence, and that “if a decision-maker discounts the future... early choices may determine or restrict later choices... what appears suboptimal ex post need not have been suboptimal ex ante.” Transportation planners of the 1950s did not set out to make plans that resulted in unsustainable systems, but they may have acted differently had they made informed connections between their planning and policies and the effects we now label as externalities. The LCA model is projected through 2050 to show different levels of

¹⁴ The trajectories are, in fact, model scenarios. However, the term “scenario” is not used to name the future conditions because peer-reviews of submitted journal articles and interviews with transportation planners clearly indicated that the term implies very specific travel modeling that was not conducted in this research. While the MAG data used to project the Business as Usual (BAU) conditions are considered a “scenario,” the assumptions applied to the models to create alternative trajectories were not formed by conducting scenario development as a transportation planner would carry out.

future commitment to the existing infrastructure (either continued low-density geographic growth or densified and limited geographic growth). The three alternatives trajectories are evaluated to offer insights about the tradeoffs and barriers involved in breaking the Business as Usual (BAU) automobile path dependence, and are titled Plateau, Integrated Transportation and Land Use (ITLU), and Sustainable Phoenix. The trajectories are summarized in Table 1. The Plateau trajectory assumes that the BAU trend will continue through the currently-projected planning horizon (the year 2031) and then the existing infrastructure will be leveraged to allow population growth without geographic land use growth (i.e. transit-oriented development and infill in existing urban areas). The ITLU trajectory models the same changes as the Plateau trajectory (maximizing land use with existing transportation infrastructure) but assumes that the changes will begin 13 years earlier in the year 2018 (after the current transportation budget is executed). The Sustainable Phoenix trajectory assumes a more aggressive suite of policy and technical changes that begin in the year 2018.

Table 1.1. Summary of Future Trajectories in Prospective LCA.

Trajectory	Changes
BAU: Business as Usual	None – continues 1950-2010 trend through 2050
Plateau	Transit-Oriented Development (TOD) infill accommodates growth from 2031-onward. No new roads constructed after 2031.
ITLU: Integrated Transportation and Land Use	TOD infill accommodates growth starting in 2018. No new roads constructed after 2018. Major real-estate developments planned outside the urban core area resume after exhausting TOD infill market.
Sustainable Phoenix	TOD infill accommodates growth from 2018-2050. No new roads constructed after 2018. New markets for TOD developed before existing market is exhausted. Automobile fuel economy doubles the BAU projection by 2050 (100 miles per gallon fleet average). Gasoline tax increased incrementally through 2035 to match California’s current gasoline tax. Price on carbon added to gasoline price incrementally through 2050.

The model results demonstrate which trajectories have fewer potential environmental impacts, and where there are lower costs. This information can be communicated to regional transportation planners to feed long-range planning, and is tuned appropriately for integration into the multi-criteria decision analysis (MCDA) tools which are already used by transportation planners (Halog & Manik, 2011; Johnston, 2004; Kennedy, 2013; Shiftan, 2003; Yazzie, 2013). The value of the trajectories is in communicating comprehensive information that is aligned with the institutional culture and strategic understanding of the planners and decision-makers so that their choices are expanded to include alternatives that can compete with the path dependence towards automobile-oriented infrastructure.

The prospective LCA tests whether or not new strategy recommendations, if successfully implemented¹⁵, will produce benefits that warrant or justify breaking the automobile path dependence. For example, the recommended strategy of TOD infill along the Phoenix LRT system is tested against status quo growth to measure the range of costs and benefits resulting from the trajectory outcome. The specific results from this analysis can then be communicated directly to the institutions (key decision-makers or managers of the institutions) correlated with the strategy in Step 4 (see Section 1.4.4) who can integrate this information into future policies, plans, and decisions.

1.4.4 Synthesizing Transition Strategies and Intervention Points for Breaking Automobile Path Dependence. The prospective energy, economic, and environmental analysis results from Step 3 will be linked in this step with the IAD framework results (Step

¹⁵ It is important to remember that the trajectories model strategy outcomes as “what if” rather than “how.” The institutional correlations made in Chapter 4 discuss how the conditions could be set to make the trajectory outcomes possible.

2) to develop insights that will motivate organizational learning, system adaptation, and sustainability transformations. The resulting methodology is termed IA-LCA. Transition strategies are coupled with specific institutions at distinct intervention points to stimulate debate among planners and policy-makers while they are in the process of performing their institutional functions (i.e. while they are doing planning and crafting policy). The IA-LCA synthesis also reveals which energy, economic, or environmental effects are directly or indirectly controlled by transportation planning institutions, and therefore reveals opportunities for changing the business-as-usual trajectory. The value in advancing traditional LCA methods with the IA-LCA is in showing a city or region that achieving more sustainable transportation systems is not just about putting in TOD (for example), but it is so much more and reaches across temporal, spatial, and institutional divides.

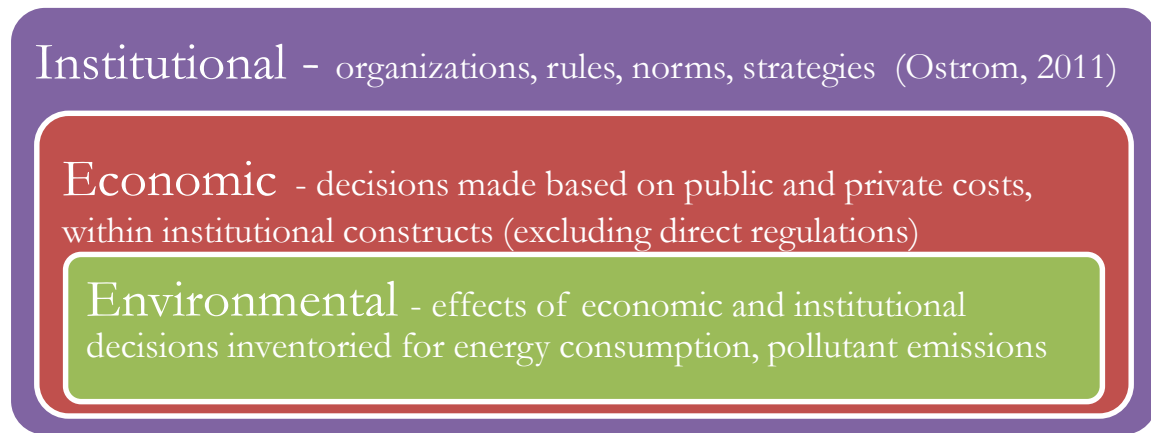


Figure 1.4. Sustainability Perspective of the IA-LCA. Barriers such as policy constructs (e.g. federal funding mechanisms) have a direct influence on the perceived economic costs of transportation infrastructure and the infrastructure itself (construction, reconstruction, and subsequent passenger travel) results in environmental effects. Mapping the correlations between barriers and the effects on the system is crucial for putting the results of this study in context for planners and decisionmakers.

The IA-LCA method addresses breaking path dependence from three overlapping and interacting perspectives (synonymous with the social, economic, and environmental

pillars of sustainability): institutional, economic, and environmental (see Figure 1.4). The feedback loops inherent in creating automobile path dependence (Arthur, 1988; Foxon, 2002; Innes & Booher, 1999; Tiberius, 2011) can be linked to the historic outcomes (not causal links but correlative links), and these connections (as identified in Step 2, Institutional Analysis) imply an automobile-oriented status quo into the future. This research identifies the feedback loops and mechanisms that are reinforcing the path dependence (institutional analysis). The economic effects of the decisions made by and through the institutions (economic analysis) then result in environmental effects that can be inventoried (environmental analysis). In Step 3 (the prospective LCA) the transition strategies are tested and the trajectories linked directly or indirectly to institutions so that decisionmakers and planners can break the path dependence (at specific intervention points) by designing and implementing alternatives that are competitive with the status quo. This is not to say that decisionmakers would “pick winners and losers” or even that they would discourage automobile-oriented infrastructure. Instead, the way to break path dependence is to create a new path that is possible because it can compete with and has the same or better benefits and costs as the status quo (Garud & Karnoe, 2001; Huber, 1991; Innes & Booher, 1999; Tiberius, 2011). Planners and decisionmakers who understand the comprehensive and long-term effects from either automobile-oriented infrastructure or non-automobile alternatives can enable sustainable transitions as long-range transportation plans are updated, regulatory compliance reports are completed, and budgets are approved.

The environmental analysis overlaps with both the institutional and the economic analysis. The inventories of environmental effects are important to establish a baseline, but the value in enabling transitions comes from looking at these trends over time in light of institutional requirements (both policy goals and regulations), social pressures and

expectations (e.g. carbon footprinting, or marketing demands for “greener” transportation), and economic constraints (Black, 2005; Innes & Booher, 1999; Kemp, Rip, & Schot, 2001; V. Ostrom, Tiebout, & Warren, 1961). The energy and environmental analysis baselines provide a BAU trend against which alternatives can be measured and compared. Any alternatives must be able to compete with the effects from future status quo (automobile-oriented) growth. The environmental effects of either the BAU or the alternative can then be directly compared for the benefit of decision-making.

The literature on organizational learning (Gifford & Stalebrink, 2002; Huber, 1991; Oasis Consulting Services, 2006) and transformational sustainability research (Allenby, 2000; Han, Fontanos, & Fukushi, 2012; Innes & Booher, 1999; Wiek, Farioli, Fukushi, & Yarime, 2012) both converge on the idea that building new knowledge is not enough to affect change in complex social-ecological systems. The real change happens when the players in the system (here it is planners and decisionmakers, and indirectly the policymakers and individual passengers) use that new information to increase the range of possible decisions and build the capacity (of both the decision-makers and the system users) to make different decisions with this new information. This research not only identifies the factors that have led to historic automobile-oriented path dependence, but also quantifies those barriers in relation to future alternatives so that those alternatives can be more directly compared and considered (and then possibly designed and implemented to better compete with the status quo).

The combined IA-LCA synthesizes strategy recommendations for breaking automobile path dependence. Each recommendation is correlated with the life cycle economic and environmental benefits and costs (e.g. road construction, vehicle manufacturing, etc.), discloses the institutional transitions that must be surmounted to enable

that trajectory, and identifies the institutions (e.g. policies, individuals, regulations) to which the transition strategies must be addressed. For example, a recommendation might be for land use planners (the zoning commissions) and the transit committee within the MPO (for MAG, this would be the MAG transit committee, Valley Metro, and the Regional Public Transportation Authority) to advocate for land use changes that enable TOD infill along Phoenix's existing LRT line, with the benefits coming from reduced energy consumption and greenhouse gas emissions over many decades (from more efficient high-density dwellings and reduced automobile travel). The potential benefits from the trajectories are tested against the future BAU projections (i.e. the status quo path dependence) in Step 3 (the prospective LCA).

1.5 Significance of This Research.

This research demonstrates a methodology for testing a sustainability transition strategy against automobile path dependence in a way that is quantitative, regionally-specific, and scale-appropriate. Previous research on transportation lock-in and path dependence relies heavily on intuition, common understanding, lore, and metaphor (Arthur, 1988; Low & Astle, 2009; Newman & Kenworthy, 1989; Unruh, 2000). Transportation planners and decision-makers are constrained by real and present physical factors (budgets, regulatory requirements, land-use policy, etc.) that require justification by quantitative assessment. In keeping with theories on breaking path dependence (Innes & Booher, 2000; Garud & Karnoe, 2001; Page, 2006; Tiberius, 2011), this methodology aligns place-based institutional analysis with process-based energy, economic, and environmental analysis to generate intervention strategies tuned to and primed for the planners and decision-makers. Until now, the state of the art environmental assessment has operated without discussion of who

can make the environmental improvements happen (Baumann & Tillman, 2004; Carlsson Reich, 2005), and interdisciplinary research is one way to bridge this gap. Combining empirical research with institutional insights to identify barriers to sustainability transitions meets the intent of innovative solutions-based sustainability research (Lang et al., 2012; Wiek, Ness, et al., 2012). Armed with the quantitative insights on the benefits and costs of transition strategies, planners and decision-makers will expand the realm of possible actions to become more flexible and adaptive in the face of sustainability challenges. This methodology cannot guarantee a change towards sustainable transportation, but it can facilitate the process of *path creation* rather than *path dependence*, and can become a transition science for transportation sustainability.

Metropolitan regions across the globe are facing increased urbanization, limited natural resources, and a desire to ensure sustainable systems long into the future. Transportation systems account for a large component of urban metabolism, but are so complex that they are often distilled into generalized concepts (e.g. individual cars are bad, public transportation is good) that leave planners and decision-makers with difficult choices as they commit to future infrastructure and scant analytical tools to evaluate the comprehensive and long-term impacts of those choices (e.g. how to decide whether adding more lane-miles is better than expanding a public transit systems). This study proposes a method by which cities can evaluate their specific level of commitment to business-as-usual infrastructure and then use that information to assess their own sustainability goals and to weigh transition strategies in quantitative comparisons that are useful to decision-makers.

The results of this study are not directly applicable to all cities, nor are they meant to be a specific prescription for Phoenix. The study is meant to capture an accurate state of current systems and then demonstrate a view of the ranges of possibilities and opportunities

that decision-makers can weigh against continually-evolving sustainability goals. The concepts and the methodology can be applied to other urban metropolitan areas, provided that they incorporate geographically-specific physical attributes, institutional constructs, and sustainability definitions. Urban planners and leaders worldwide can use this methodology as a way of identifying and then quantifying harmful, costly, and destructive path dependencies, while at the same time evaluating the efficacy of their sustainability goals and the viability of transition strategies to meet those goals. The insights from this methodology will identify intervention points in planning and decision-making that can be matched directly with regionally-specific and scale-appropriate strategies for breaking path dependence.

1.6 Theoretical and Empirical Contributions.

This research will expand the current practices and methods of sustainability assessments, which typically inventory rather discrete factors in the system¹⁶ (Carlsson Reich, 2005; Gibson, 2006; Guinée et al., 2011; Xie, 2012). Phoenix was recently awarded a 2.9 million dollar Sustainable Communities Grant from the U.S. Department of Housing and Urban Development which is meant to incorporate land use and transportation planning towards smart growth and more sustainable communities (HUD, 2011). This study complements the research funded by the HUD grant while also building directly upon the results from the ST-LUIS framework study (MAG, 2013b). If the results can be adequately communicated to the key decision-makers, then their capacity for transitioning to more

¹⁶ For example, Maricopa County has goals for sustainable transportation and emissions reductions, but those goals are only for County Government operations and not for activities that happen in the private or commercial sectors (Burgess, Brumand, & Walker, 2011).

sustainable operations will be increased. Additionally, the region-wide quantitative information can better inform policymakers as they establish future sustainability goals¹⁷.

LCA and environmental analysis techniques are becoming more widely used in product or technology comparisons, or in assessing the complete impacts of an action or process. However, these techniques have strong potential to be applied in policy-making and in addressing complex sustainability problems (Baumann & Tillman, 2004; Carlsson Reich, 2005). Combining institutional analysis and life cycle assessment has been proposed in the literature (Carlsson Reich, 2005; Givoni & Banister, 2013; Salhofer, Wassermann, & Binner, 2007), but to date has not been executed¹⁸. Burnett (1980) used institutional analysis to study trip-chaining (i.e. linking multiple trips during a distinct departure from home or work), but only used the information to justify why trips should not be generalized as a singular movement from one point to another when conducting travel studies. De Marchi et al. (2000) used institutional analysis to study water issues in Sicily, but only used the institutional insights as data that became values in a multi-criteria decision assessment (MCDA). Bond et al. (2001) conducted a Strategic Environmental Assessment (SEA) for sustainable development projects and used institutional analysis to assign values to social aspects of development and then built those values into the MCDA. Andrews and Swain (2001) used the results of two LCAs on computers to justify the negative environmental impacts of the institutions in the New Jersey government that are responsible for purchasing office computers in state agencies. This research is a methodological proof-of-concept,

¹⁷ The institutional analysis in Chapter 3 discusses the existence and scope of sustainability goals in the region, of which there are no clear specifications. The point of this research is not to criticize the lack of sustainability goals, but if there were sustainability goals in a region then this methodology will help in figuring out how to get there.

¹⁸ And certainly it has not been attempted at a regional scale or across temporal scales.

combining institutional analysis and LCA for the first time at a metropolitan scale over 100 years. The IA-LCA demonstrates that life cycle views, when integrated with institutional analysis, can facilitate comprehensive long-term decision-making and planning in metropolitan areas while also revealing unintended consequences and hidden benefits.

1.7 Chapter Organization.

The subsequent chapters of this dissertation separate the work into the LCA (Chapter 2), the institutional analysis (Chapter 3), and the integration of the two into the IA-LCA proof of concept (Chapter 4). The research questions addressed in each chapter are:

- What are the past and present energy, economic, and environmental effects from passenger transportation in Phoenix, and what are the possible future effects from status quo or alternative planning trajectories? (Chapter2)
- How does transportation planning currently function in Phoenix? (Chapter 3)
- What are the necessary interventions to enable future alternative trajectories for passenger transportation in Phoenix? (Chapter 4)

CHAPTER 2

LIFE CYCLE ENERGY, ENVIRONMENTAL, AND ECONOMIC EFFECTS FROM PASSENGER TRANSPORTATION SYSTEMS IN PHOENIX, 1950-2050

2.1 Introduction.

A methodology is developed for metropolitan planners and decisionmakers to quantify historic automobile path dependence and assess sustainability interventions that reduce future transportation environmental impacts by identifying cost-effective strategies for new infrastructure investment. The LCA framework is used to inventory historic economic and environmental effects from passenger transportation (roads and vehicles). The retrospective LCA is then used to project future trajectories (a prospective LCA) for the region and to assess their viability and performance against sustainable transportation goals (the combined institutional analysis and LCA, or IA-LCA).

Although path dependence is an ex post social and institutional construct, the possibility of quantifying the concept using a regional transportation system is explored using LCA, a framework for analyzing products, processes, services, and activities, and the complex systems in which they reside, over their lifetime (e.g. from raw material extraction through manufacturing, transportation, packaging, use, and disposal). The selection of system boundary, model design, and trajectory development is performed concurrently with institutional analysis (see Chapter 3), and the combined IA-LCA results are analyzed together (see Chapter 4) to deduce intervention points for sustainable transportation transition strategies. The LCA described in this chapter is a proof-of-concept case study on passenger transportation systems in metropolitan Phoenix, Arizona (see Chapter 1 for background).

2.2 The Growth of Automobile Travel in Phoenix since 1950.

Passenger automobile travel and roadway infrastructure in Phoenix¹⁹ has grown significantly since 1950, and the increases cannot be explained by population growth alone. Both population and regional transportation spending (adjusted for inflation) increased by an order of magnitude, from 330,000 people and \$3,000 per mile public transportation spending in 1950 to nearly four million people in 2012 and \$30,000 per mile public transportation spending (Arizona Department of Administration, 2010; FHWA, 2012). The increases in automobile traffic follow a steeper trend, from one billion annual VMT in 1950 to 30 billion in 2012 (FHWA, 2012). Figure 2.1 shows the annual per capita trends, where the miles of roadway to support each person has decreased as VMT per person increased.

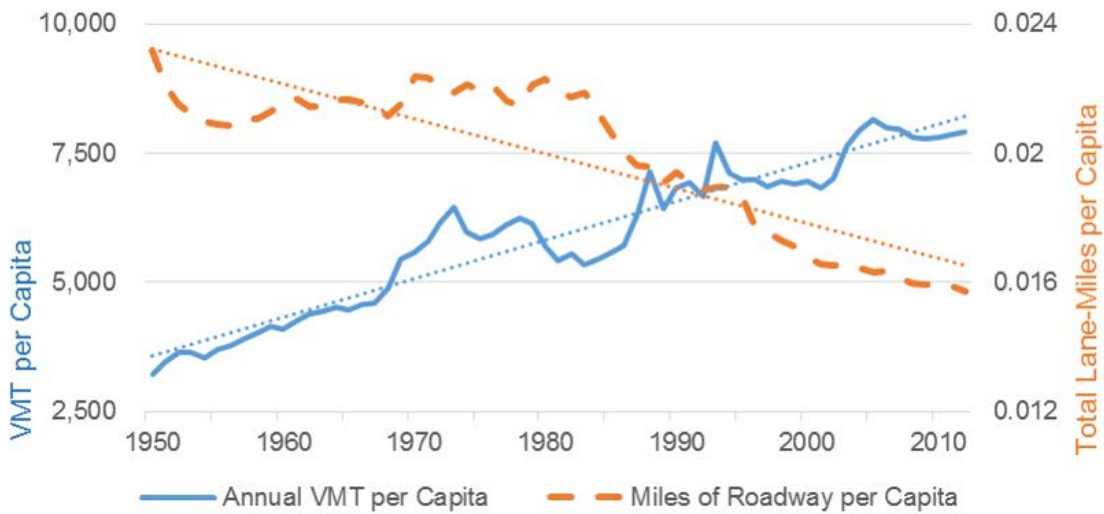


Figure 2.1. Phoenix per Capita Vehicle Travel and Road Infrastructure. Vehicle miles traveled (VMT) per capita (in blue) rise steadily from 1950 to 2012, while the miles of roadway per capita (in orange) decrease. If trends continue, the region faces congestion and infrastructure capacity issues.

¹⁹ Recall from Chapter 1 that the Phoenix metropolitan region is simply referred to as Phoenix, whereas specific cities or municipalities are titled “the City of ...” as in the City of Phoenix.

Individual travel behavior, travel times, economic prosperity, and fuel prices influence VMT (Cervero, 2002; Hansen & Huang, 1997; Marchetti, 1994), and the supply of infrastructure (road and other transportation networks) can be viewed as an underlying factor with indirect impacts. The construction of roads creates more travel route choices, induces more travel, and increases trip distances (Cervero, 2003; Hansen & Huang, 1997). In Phoenix, prior to 1980, each new mile of roadway construction was matched region-wide with 26,000 new VMT per year. From 1980-1990, a boom period for both population growth and roadway construction, each new mile of roadway construction was coupled with 190,000 new VMT. Post-1990 changes in VMT per mile decreased, with each new mile of road construction adding 93,000 new VMT. While there may always be a necessity for new road construction, and VMT changes can be influenced by economic conditions or technology innovations, the historic trends in Phoenix show a relationship between new road deployment and vehicle travel. As Phoenix prepares for the next four million people, regional agencies are researching growth alternatives and approving initiatives and goals for sustainable transportation and land use planning (see Chapter 3).

Roadway construction patterns in Phoenix are sporadic, following boom-bust cycles in both land use and transportation funding, but over the last six decades the region has averaged 330 miles of new roadway per year. The influence of urban sprawl cannot be ignored, and there is ample evidence to suggest that passenger VMT nationwide have increased over time because trip distances have increased (Pisarski, 2006). Phoenix is a relatively young urban area that does not have significant geographic limits to growth, and has growth as a collection of “edge cities” who both collaborate in regional governance and planning and compete with each other for resources and profit (Garreau, 1991). The road infrastructure has been constructed ahead of and in concert with this growth, as shown in

Figure 2.2. Half of the current roadways were constructed after 1979 and most of these new roads are further than 12 miles from the center of Phoenix. Consider that the national average home-to-work trip distance was 12 miles in the year 2000 (Pisarski, 2006), and the contribution of urban sprawl to increased VMT in Phoenix is obvious. The urban planning and lifestyle mantra in Phoenix also encourages low-density land use (Gammage, 1999; Gober, 2005; Heim, 2001; Ross, 2011), and currently 59% of dwelling units in Phoenix are single-family homes (Maricopa County, 2012). Phoenix is projected to double its current population by 2050, and the previous doubling (from 1980-2010) occurred by population density changes primarily in peri-urban or “fringe” areas (Rex, 2000).

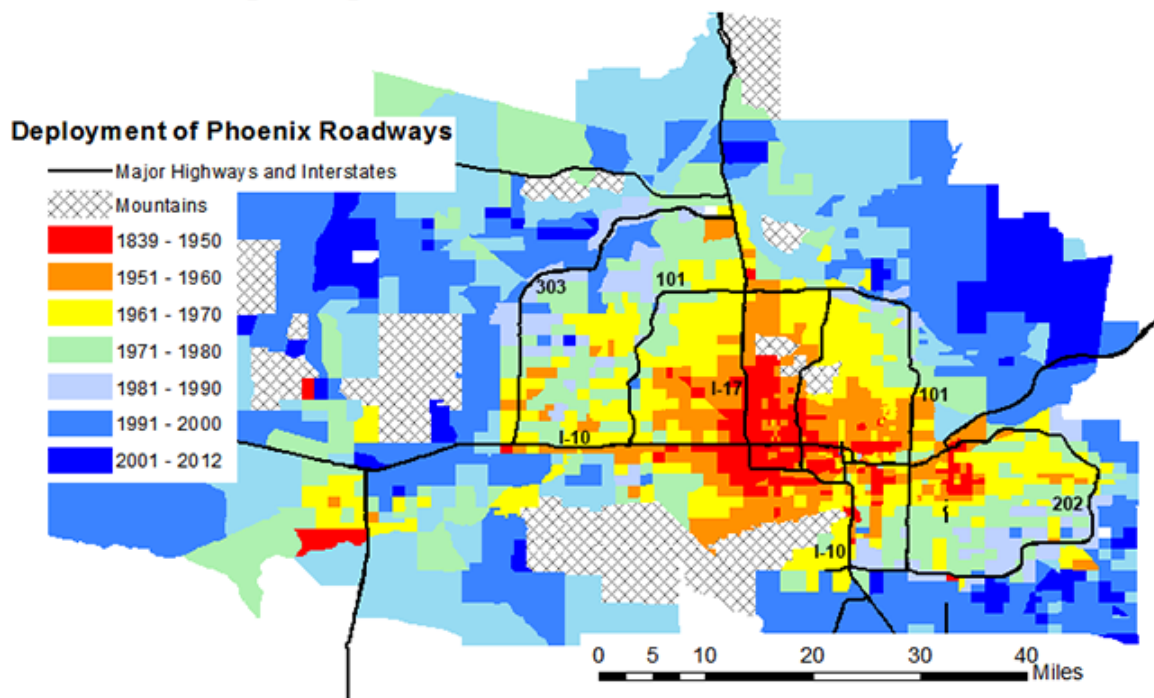


Figure 2.2. Roadway Construction in Phoenix from 1950 to 2012.

2.3 System Boundary Design.

The geographic extent of the system must match the scope of the problem, but also include processes outside of the geographic area that are compulsory to the system. In

choosing the geographic system boundary (the Phoenix metropolitan area), passenger transportation systems in Phoenix generally occur within the politically-defined metropolitan region. Non-local (long distance) travel does originate or terminate in Phoenix, but a conscious decision is made to limit the geographic extent of passenger travel and focus completely on local travel (origin and destination both within the metropolitan region). This decision is primarily made because the transportation planning is organized at the metropolitan area scale, and a majority of the passenger travel occurs at the metropolitan scale. For this same reason, the geographic scale was not appropriate at a national level or a single city in the region. For simplicity, the Phoenix metropolitan area is equated with the political boundary of Maricopa County²⁰.

Understanding the scope of the problem is necessary to establish the temporal scale of the LCA model, in this case the 100-year period spanning 1950 to 2050. Phoenix grew into a metropolitan area at approximately the time automobile travel became mainstream, and statistical data on automobile travel were regularly collected beginning in 1945. Studying a region so closely-linked with automobile-oriented travel allows more targeted conclusions to be drawn from historic transportation activities. Pre-1900 Phoenix is not directly relevant to current transportation trends, and by the year 2000 the automobile-oriented travel norms were heavily embedded in the cultural landscape (Collins, 2005; Gammage, 1999; Gober, 2005)²¹. Studying Phoenix from 1950 (the primary “age of the automobile”) is logical since

²⁰ In 2013, the Maricopa Association of Governments was expanded to include portions of adjacent counties, and the generalization used in this research should be carefully considered and updated in future versions of this work.

²¹ Gammage (1999) explains that “the existing development pattern in metropolitan Phoenix essentially requires that every household have an automobile” and that low-density growth combined with work and leisure lifestyle changes have increased traffic congestion in the region (despite the common conception that low-density development eases congestion). Phoenixians often complain about traffic congestion, but in reality Phoenix is ranked very low in terms of congestion severity compared to other major metropolitan areas (TTI, 2012).

the general sentiment for solving transportation sustainability problems in urban regions is to shift travel to more efficient modes (or eliminate motorized personal vehicle travel), the most obvious target being a reduction in automobile travel (Buehler, 2010; Buhler, 2011; Decicco & Mark, 2010).

Passenger transportation occurs in multiple modes (e.g. automobile, bus, rail, air, bicycle, and walking), and the system boundary must specify which mode(s) of transportation are included in the LCA model. In Phoenix, the shares of passenger travel occurring in each mode of transportation have varied over time, but since the 1950s a majority of local passenger travel has been via automobile. For this reason, and because a majority of regional transportation planning involves motorized vehicles, the system boundary is narrowed to passenger automobile travel and the infrastructure supporting passenger vehicles²². Other modes of travel are important and should not be ignored, but restricting the LCA model to one mode of transportation reduces the complexity and allows a structure to be established where multiple modes of transportation could be incorporated at a later time.

Selecting an appropriate system boundary for the LCA is crucial for matching the model to the scope of the problem. The concept of transportation planning for sustainable systems includes travel demand, behavior, and infrastructure. Many other transportation processes could have been included in the LCA model, such as automobile dealerships, maintenance shops, car-wash facilities, and maybe even drive-thru food sales. However, the data availability combined with a need for a simplified model drives the decision to restrict the LCA processes to roadway construction, roadway maintenance/reconstruction, vehicle

²² Public transit is excluded.

manufacturing, fuel production, and vehicle operation. The processes that are not included in the LCA model are acknowledged in Table 2.1.

Table 2.1. LCA Processes. The table is a review of those processes included and not included in the LCA model of passenger vehicle transportation in Phoenix from 1950-2050.

PROCESSES INCLUDED IN LCA MODEL	PROCESSES EXCLUDED FROM LCA MODEL
Roadway Construction	Bridge/Overpass Construction
Roadway Maintenance/Reconstruction	Drainage Channel Construction
Automobile Manufacturing	Sound Wall Construction
Gasoline Production	Freeway Management (signs, cameras)
Automobile Operation	Roadside Landscaping
	Traffic Signal Construction (lights, meters)
	Utilities Construction/Expansion
	Street Sweeping Operations
	Freight Travel
	Bus Travel
	Public Transportation Infrastructure (stations/facilities)
	Bank Financing (facilities/operation/expenses)
	Automobile Insurance (facilities/operation/user expenses)
	Automobile Licensing/Registration (facilities/operation/user expenses)
	Fuel Distribution Infrastructure (gas stations)
	Automobile Sales Infrastructure (dealerships)
	Automobile Maintenance Infrastructure (service facilities, car washes, parts shops)

An extensive literature review placed the research in context with other works, informed the selection of data sets and LCA modeling tools, and assessed the validity of the topic. The literature review spanned the major topics that intersect in this research problem: transportation planning, life cycle assessment of transportation systems, complex systems analysis, path dependence (or “lock in”) in social systems, and transformational sustainability research. After reviewing the literature to establish background and ensure that the work is relevant and unprecedented, subject-matter experts were canvassed for advice and to validate

the research topic. The literature review became the basis for the research proposal, together with a framework for the LCA model.

Figure 2.3 shows the analytical system boundary for the IA-LCA. Life cycle processes can be generalized as the extraction and processing of raw materials, the production and transport of materials, and the construction and reconstruction (maintenance) of the roads. Passenger vehicle travel (the automobile life cycle phases) includes the upstream energy and material flows (raw material extraction, processing, and transport) for automobile manufacturing and gasoline production, and automobile operation (at the tailpipe). Roadway and travel emissions inventories are combined and then grouped into environmental impact categories.

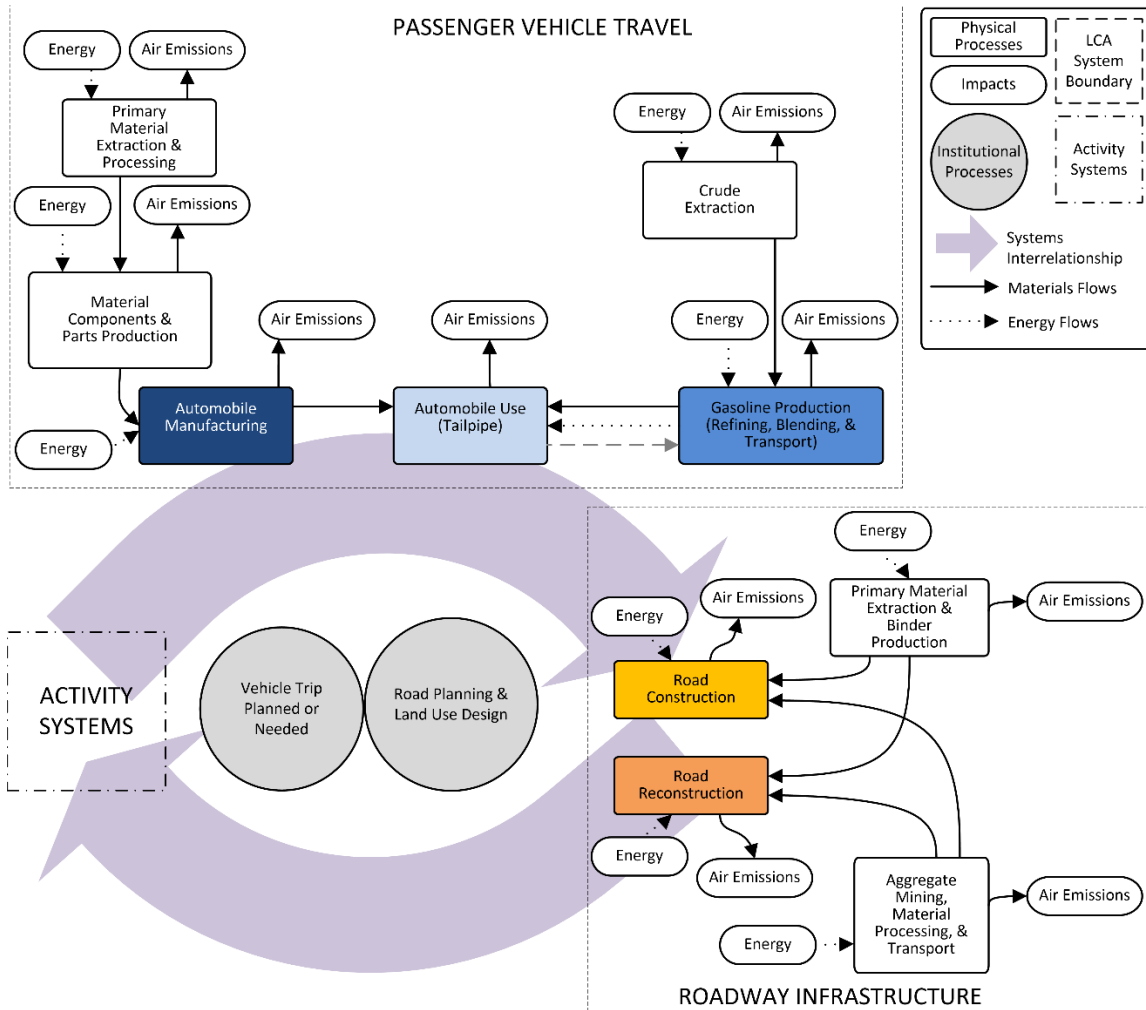


Figure 2.3. The IA-LCA System Boundary. Shaded process boxes are LCA phases.

2.4 LCA Model Framework.

Numerous LCA tools have been developed for the analysis of a variety of products and processes (by multiple agencies and researchers), and selecting the structure of the LCA model ultimately establishes the perspective and utility of the results. The research proposal was developed concurrently with the literature review and the generation of the LCA model framework. A review of the state-of-the-art LCA tools (and in most cases a trial use with sample data) was conducted to inform the selection of the tools that are used in the final LCA model. The important factors to consider while selecting LCA tools are data

availability (the data inputs required for the tool are obtainable by the researcher), transparency of computations within the tools, and data outputs (the results are relevant to the question).

A preliminary assessment was developed²³ to test the LCA tools to determine whether the final LCA model would be feasible, and to establish the model framework. The quantitative results from the LCA are interpreted using potential impact factors, also from state-of-the-art environmental impact assessment tools. The impact categorization tool must be selected in the same way LCA tools are selected: data input requirements are met, calculations are transparent, and output results are relevant to the question. The emphasis on transparent calculations is important if the results need to be explained in detail, especially if conclusions must reference a specific part of a process to be useful to decisionmakers²⁴. After a working LCA model is established, the research proposal is completed and a final LCA model is constructed concurrently with institutional analysis.

The historic energy consumption, economic spending, and environmental impacts of Phoenix's transportation infrastructure is modeled as the construction and reconstruction of roadways and automobile travel (vehicles, fuel, and vehicle use). The PaLATE tool is used to model the energy consumption and environmental effects from the roadway construction

²³ Preliminary data collected to build an initial model included representative road construction designs, simple reconstruction schedules, and automobile travel data (from FHWA statistics) for one year in each decade from 1950 through 2010.

²⁴ One assessment tool may be a "black box" system where data inputs are converted to an indexed impact category but the user cannot see the weights given to each of the inputs. Another assessment tool may be a conversion factor where the user knows exactly what calculations are applied to each input, and the resulting impact categorization can be traced back to more or less significant factors. For example, emissions from a process may be causing potential smog impacts, but understanding which specific emissions have a greater potential impact (within the model) is important for decisionmaking. If Process X emits 2 tons of nitrous oxides and 100 tons of methane, it is important to be able to discover that reducing the methane emissions by 100% would have the same effect on smog impacts as reducing the nitrous oxide emissions by just 3%. A "black box" impact categorization would not give you that same resolution and would limit the extent of insights to be gained from the complete LCA model.

and reconstruction processes (Horvath, 2003). The four major roadway classifications (local, arterial, state highway, and interstate highway) are modeled with PaLATE and the outputs are expressed as life cycle energy consumption and emissions per mile of road, which is later joined to a GIS database for Phoenix. Reconstruction includes surface-layer repaving and total reconstruction, which over time exceed the impacts from initial construction. Roads are evaluated at regular intervals to ensure proper maintenance and serviceability, based on category and traffic volumes, but unless a road is retired permanently it will require indefinite reconstruction. Road classification and lengths are from regional roadway GIS databases (ADOT, 2011a) and roadway design manuals are used to determine cross-sectional areas that define how wearing layers and sub-bases are constructed (AASHTO, 2011; City of Phoenix, 2009). Construction and reconstruction schedules are based on Arizona DOT publications (Arizona DOT, 2012; Smith et al., 2005). To understand the historic commitment to automobile infrastructure, it is important to establish how roadways were deployed. For most cities, it is possible to identify when (in general) neighborhoods were constructed, however, the specific years in which roadway links were constructed is not typically cataloged. The years of initial roadway link construction are estimated with a GIS spatial analysis of building records from county assessor data (Maricopa County, 2012). The building assessor data are grouped into U.S. Census tracts and roads are assigned an initial construction year based on the average building age minus one standard deviation. This spatial analysis method²⁵ assumes that the roads were built when the buildings were placed. Historic aerial photos were used to validate the results by roughly identifying decades in

²⁵ The method was pioneered by Fraser and Chester (2013), and was originally tested on Los Angeles, California.

which neighborhoods (and their roadways) were constructed (see Figure 2.2 for a graphical presentation of this GIS analysis).

The travel phases are modeled by inventorying the passenger automobile use that occurred region-wide, categorized by automobile operation (driving the car), gasoline production (making and transporting the fuel), and automobile manufacturing (building the car). The Motor Vehicle Emission Simulator (MOVES) model (EPA, 2012) is used to inventory automobile operation effects, and the automobile manufacturing and gasoline production effects are assessed using the GREET models for vehicles and fuel cycles (US Department of Energy, 2010). Freight traffic and passenger vehicles with more than two axles are not included, and vehicle manufacturing only models sedans (not light duty trucks). The FHWA reports county-level annual VMT determined from fuel sales, from 1989 to present for the Phoenix metropolitan area (FHWA, 2012). Figure 2.4 shows annual VMT in Phoenix since 1950. Pre-1989 values are computed as a percentage of the statewide gasoline consumption based on population and the national average fuel economy of passenger cars (EIA, 2013a; FHWA, 2012). Automobile manufacturing is calculated based on a 160,000-mile vehicle lifetime (US Department of Energy, 2010) and the number of vehicles that would be manufactured to drive the total number of VMT each year.

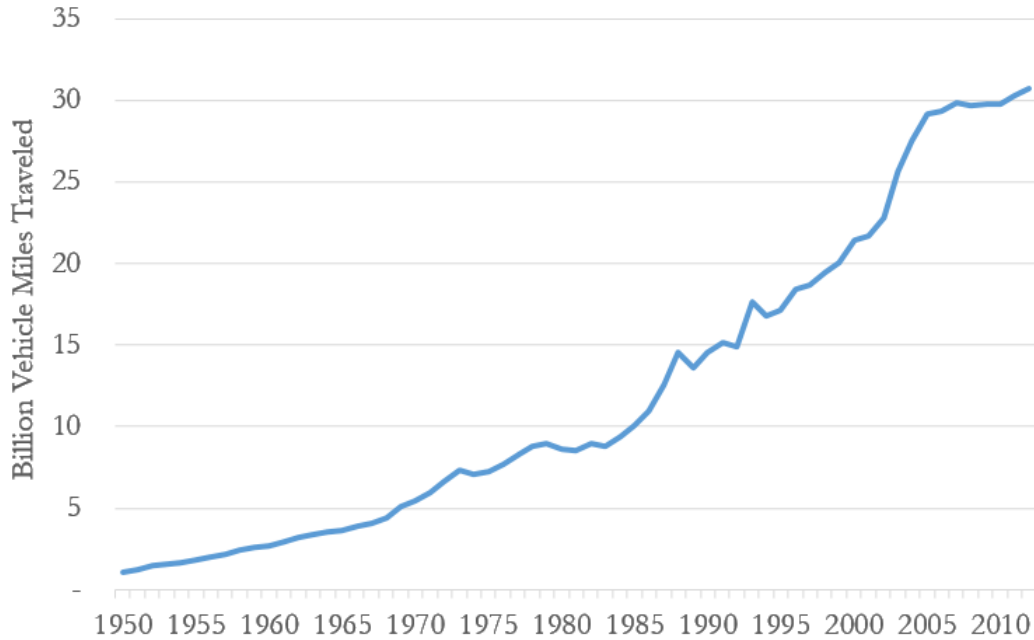


Figure 2.4. Annual Vehicle Miles Traveled (VMT) in Phoenix, 1950-2012.

The air emissions are characterized into three mid-point impact categories that are relevant to Phoenix using the U.S. Environmental Protection Agency’s (EPA) impact assessment method, the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) (Bare, Norris, Pennington, & McKone, 2002; Bare, 2011). The mid-point impact categories are measures of human health and environmental impact stressors. Global warming potential (GWP), human health respiratory potential (respiratory), and photochemical smog formation potential (smog) are assessed. GWP impacts are calculated in carbon dioxide-equivalent units (kg CO₂e) by multiplying emissions inventories by the TRACI factors for greenhouse gas emissions (CO₂ at a factor of 1, CH₄ at 25, and N₂O at 298). Potential respiratory impacts are expressed in units of particulate matter of size 10 microns and smaller (kg PM₁₀e), using TRACI factors for particulate emissions (PM_{2.5} at 1.7 units, SO₂ at 0.17, and NO_x at 0.03). Smog-forming emissions are

calculated in ozone-equivalent units (kg O_{3e}) using the TRACI factors for CH₄ (0.01 units), CO (0.06), Volatile Organic Compounds (VOC) (3.6), and NO_x (25).

The life cycle costing results combine public and private spending resulting from all phases of passenger transportation each year. Spending on roadways (capital outlay and maintenance disbursements by all units of government) are considered public and spending on automobile travel is private (the retail automobile and gasoline purchases). To avoid double-counting, gasoline production spending is not included and it is assumed that those costs are passed on to the private consumer with the price of gasoline. Construction (including right-of-way) and maintenance costs per mile (Arizona DOT, 2011; FHWA, 2012) and gasoline and vehicle purchase prices (EIA, 2013a; FHWA, 2012) are converted to 2012 fiscal rates (US Bureau of Labor and Statistics, 2012).

An assessment of the historic financial and environmental commitments is constructed for roadway construction and automobile travel. The retrospective LCA is used as a baseline to establish a BAU future and to assess long-term patterns contributing to path dependence. Future trajectories are designed using proposed solution strategies, and the results from the trajectories are evaluated to determine the benefits for breaking the BAU path. The LCA model is a system of linear equations that inventory the energy and environmental life cycle effects and the economic spending for each year of roadway infrastructure and passenger travel activity from 1950 to 2012. After 2012 three future trajectories are tested through 2050. The generalized functional forms are:

$$\begin{aligned}
\text{Roadway Construction: } RC_{t,r,p} &= f(C_{t,r} D_r OC_{r,p} SC_{t,r}) \\
\text{Roadway Reconstruction: } RR_{t,r,p} &= f(C_{t,r} R_{t,r} D_r OR_{r,p} SR_{t,r}) \\
\text{Automobile Manufacturing: } TAM_{t,p} &= f(VMT_t AL OAM_{t,p} SAM_t) \\
\text{Gasoline Feedstock: } TGF_{t,p} &= f(VMT_t GFE_t OGF_{t,p}) \\
\text{Automobile Operation: } TAO_{t,p} &= f(VMT_t GFE_t OAO_{t,p} SAO_t) \\
\text{Total Energy Consumption: } EC_{t,energy} &= f(RC_{t,r,energy} RR_{t,r,energy} TAM_{t,energy} TGF_{t,energy} TAO_{t,energy}) \\
\text{Emissions Inventory: } E_{t,p} &= f(RC_{t,r,p} RR_{t,r,p} TAM_{t,p} TGF_{t,p} TAO_{t,p}) \\
\text{Potential Global Warming Impacts: } IGWP_t &= (I_{CO_2} \times E_{t,CO_2}) + (I_{CH_4} \times E_{t,CH_4}) + (I_{N_2O} \times E_{t,N_2O}) \\
\text{Potential Respiratory Impacts: } I_{Resp}_t &= (I_{PM_{10}} \times E_{t,PM_{10}}) + (I_{PM_{2.5}} \times E_{t,PM_{2.5}}) + (I_{SO_2} \times E_{t,SO_2}) \\
&+ (I_{NO_x} \times E_{t,NO_x}) \\
\text{Potential Smog Impacts: } I_{smog}_t &= (I_{CH_4} \times E_{t,CH_4}) + (I_{CO} \times E_{t,CO}) + (I_{VOC} \times E_{t,VOC}) + (I_{NO_x} \times E_{t,NO_x}) \\
\text{Public Spending: } PuS_t &= SC_t + SR_t \\
\text{Private Spending: } PvS_t &= SAM_t + SAO_t
\end{aligned}$$

where

RC = Roadway construction (e.g., miles of local roads constructed)
C = Miles of roadway constructed (pre-2012 from assessor data spatial analysis, post-2012 from trajectory variation)
D = Roadway design (e.g., dimensions and pavement design)
OC = Outputs per mile of road construction (e.g., CO₂ emissions, PM₁₀ emissions)
SC = Spending on roadway construction (e.g., capital outlay)
OR = Outputs per mile of road reconstruction and repaving (e.g., CO₂ emissions, PM₁₀ emissions)
SR = Spending on roadway reconstruction and maintenance (e.g., maintenance outlay)
VMT = Annual vehicle miles traveled (pre-2012 from FHWA statistics, post-2012 from MAG travel models and trajectory variations)
AL = Automobile lifetime (e.g. 160,000 miles)
OAM = Outputs per vehicle for automobile manufacturing
SAM = Spending on automobile manufacturing (retail spending for vehicles required to drive VMT)
GFE = Automobile gasoline fuel economy (in miles per gallon)
OGF = Outputs per gallon of gasoline (e.g., CO₂ emissions, PM₁₀ emissions)
OAO = Outputs per VMT of automobile operation (e.g., CO₂ emissions, PM₁₀ emissions)
SAO = Spending on automobile operation (retail purchase of gasoline used to drive VMT)
RR = Roadway reconstruction (e.g., miles of local road resurfaced)
R = Reconstruction frequency (e.g., surface repave and total reconstruction schedule)
TAM = Travel automobile manufacturing
TGF = Travel gasoline feedstock (e.g., gasoline refining)
TAO = Travel automobile operation (e.g., tailpipe emissions)
I = Environmental impact potential factors (e.g. TRACI factors)
r = Roadway category (local, urban collector, state/federal, interstate)
p = Pollutant (energy consumption, CO, CO₂, CH₄, PM₁₀, PM_{2.5}, N₂O, NO_x, SO₂, VOC)
t = Time-series (annual)

Table 2.2 lists the data inputs together with their references. The inputs are categorized in the table to note whether they are used for travel (T) or roadway (R) life cycle phases, or for environmental impact characterization (I).

Table 2.2. Data Inputs and References.

Category	Input	Reference
R	Miles of Roadway	ADOT (2011a)
R	Pavement Life Cycle Emissions	PaLATE (Horvath, 2012)
R	Repave/Reconstruction Schedule	ADOT(Smith et al., 2005)
R	Road Construction and Reconstruction Schedules	ADOT (Arizona DOT, 2012)
R	Roadway Designs	City of Phoenix (2009), ADOT (Arizona DOT, 2012)
R	Roadway Spending	FHWA Statistics Series (1950-2011) (FHWA, 2012)
R	Year of Road Construction	Maricopa County Assessor (Maricopa County, 2012), U.S. Census Tracts (US Census Bureau, 2011)
R, T	Projected Land Development	MAG (2012)
R, T	Fiscal Conversion Rates	U.S. Bureau of Labor and Statistics (BLS, 2012)
T	Automobile purchase prices	U.S. Energy Information Administration (EIA, 2013a)
T	Region-specific gasoline prices	EIA (2013b)
T	Fuel Production (Feedstock) Emissions and Energy	GREET 1 (ANL, 2011)
T	Fuel Emissions and Energy	MOVES (EPA, 2012), EPA (2013a)
T	Automobile Fuel Economy	FHWA Statistics Series (1950-2011) (FHWA, 2012), EIA (2013a), EPA (EPA, 2013a)
T	Gasoline Combustion Properties	EPA (2013a)
T	Vehicle Miles Traveled (VMT)	FHWA Statistics Series (1950-2011) (FHWA, 2012), MAG (MAG, 2013d)
T	Population	U.S. Census (Arizona Department of Administration, 2010)
T	Automobile Manufacturing Emissions and Energy	GREET 2 (ANL, 2011)
T	Automobile Fleet Age Distribution	NHTS (DOT, 2011)
T	Induced travel elasticity for fuel price	Su (2011), Cervero and Hansen (2013)
T	Induced travel elasticity for fuel efficiency	Su (2011), Litman (2013)
T	Induced travel elasticity for infrastructure	Cervero (2003), FHWA statistics series, (1989-2012) (FHWA, 2012), Cervero and Hansen (2013), Litman (2013)
I	Environmental Impact Factors	TRACI (Bare, 2011)

The specific years in which roadway links were constructed is not typically cataloged for whole regions²⁶. The years of initial roadway link construction for this research are estimated with a GIS spatial analysis (see Section 2.4 and Fraser and Chester (2013)) of building records from county assessor data (Maricopa County, 2012). There are likely flaws in using this methodology over long time periods because land use designs and transportation policies change over time. Roads circa 1950 were more likely to be paved *after* the buildings were constructed and the opposite is likely true in more recent history²⁷. Historic aerial photos were used to validate the results by roughly identifying decades in which neighborhoods (and their roadways) were constructed. Table 2.3 summarizes the cumulative lane-miles of roadway in Maricopa County, by decade, determined using the GIS spatial analysis.

Table 2.3. Miles of Roadway Constructed by Decade in Phoenix.

Year	Center-Line Miles Constructed (This Year)	Total Lane-Miles in Maricopa County (Thousand)
1950	340	7.7
1960	320	14
1970	530	22
1980	680	34
1990	360	41
2000	590	52
2010	23	61

²⁶ Through personal interviews with transportation researchers and with state, county, and university librarians, the absence of road age statistics became evident. Whelan (2012) recalls that the FHWA contacted state DOTs to gather details as the 50th anniversary of the national highway system approached. The state agencies had trouble gathering information on the historic deployment of roadways, and relied on paper copies of old annual reports that happened to be stock-piled by long-term employees. Only recently have the 1945-present Highway Statistics Series data been available in digital form, and the pre-1995 data are scanned copies of paper reports. Those interviewed on the topic suspected that transportation agencies are primarily concerned with the system they have now, and historic information is only marginally valuable for very specific uses.

²⁷ It is also true that automobile travel occurred on unpaved roads throughout the region, and still does both here in Phoenix and in other metropolitan areas in the Southwest U.S. (e.g. Tucson, Albuquerque).

2.5 Future Passenger Transportation Trajectories.

The retrospective LCA establishes a baseline metric to compare future growth trajectories. For planners the question is how to accommodate growth in Phoenix and whether the resulting transportation systems will impact environmental quality while cities, MPOs, and households experience increased transportation costs. Three trajectories are designed to test the effects of different future transportation activity, from the continued automobile-dependent trends (a business as usual, or BAU trend) to policies that reduce VMT and increase transit access (a plausible better-case and an optimistic best-case). A geographic boundary is established to differentiate between more dense “urban core” growth (considered inside the highway 101/202/303 loops as shown in Figure 2.2) and less dense “fringe” development (outside the core). Household travel characteristics in the urban core reflect shorter trip distances and access to the regional transit system and fringe growth is considered automobile-oriented with longer trip distances and more household VMT.

The prospective conditions selected for the LCA model are called trajectories instead of scenarios because the methodology is not the same as scenario development (as understood by transportation and land use planners). The BAU trend pulls data inputs from future scenarios that have been developed by planning agencies, technology experts, and economic forecasters. In the initial design of future trajectories only two paths were designed, the “Plateau” trajectory (where BAU trends continue through the year 2031 and then alternative technologies and policies change the status quo) and the “Integrated Transportation and Land Use” (ITLU) trajectory (where BAU trends continue through 2017 and then alternatives to the status quo take effect). No “worse case” trajectory was

developed because the BAU trend was already dismal²⁸ and modeling a trajectory worse than BAU is not constructive in the attempt to change the status quo for the better.

During the design of future trajectories an ancillary project (Chester, Nahlik, Fraser, Kimball, & Garikapati, 2013; Kimball, Chester, Gino, & Reyna, 2013) provided details on the mechanisms that might allow conditions to change in the region, namely transit-oriented development (TOD). Data inputs for the Plateau and ITLU trajectories were gathered after completing two project iterations that tested the transportation and land use changes possible when placing new TOD dwelling units in Phoenix, and validating the concept with published studies on the topic (Gehrke & Srivastava, 2011; MAG, 2013b). The results from the first iteration of the LCA model demonstrated that these changes alone were not enough to meet commonly-referenced goals for improving transportation emissions. Therefore an additional and more aggressive trajectory was developed, called “Sustainable Phoenix.”

2.5.1 Business as Usual (BAU) Trend: Automobile-Oriented Growth. Current real estate development models forecast the planned and approved major developments in Phoenix through 2040 (Maricopa Association of Governments, 2012) and traffic demand models project future vehicle travel through 2031 in each transportation analysis zone (TAZ) (MAG, 2013d). In the BAU trajectory, geographic analyses of the development and traffic models are used to project new road construction through 2040 and increased travel miles through 2031. The major developments are analyzed to determine the number of dwelling units they would accommodate and the amount of new roads that would be constructed in each TAZ to complete those developments. Recently-completed developments are used as

²⁸ Published planning documents warn that current trends are unsustainable (ADOT, 2011b; MAG, 2010, 2011a, 2013a).

analogs for the new developments, assuming that the household density and road networks will mimic current designs. The population growth predictions match within 3.1% the capacity of these developments through 2040, assuming a household size of 2.7 persons per household (US Census Bureau, 2011). The travel predictions through 2031 also show increased VMT originating from the areas of these new developments, on pace with the population growth predictions²⁹. The trends (from 2031 onward for VMT and 2040 onward for new households) are projected beyond the MAG predictions on a linear trajectory out to 2050. The U.S. Census Bureau (2010) population predictions are used as a check to validate the assumptions for regional population growth.

There is no expectation that these BAU trends will continue indefinitely, particularly if influences other than those considered here begin to change population growth and travel behavior (job availability, economic stability, fuel prices, technology advancements, changes in travel times, etc.). Existing literature extrapolates peak travel trends at both the national and regional levels in the U.S. (Goodwin & Van Dender, 2013; Millard-Ball & Schipper, 2011; Sivak, 2014), and it is assumed that Phoenix infrastructure growth and travel behavior will one day plateau as well. Cultural analyses of Phoenix point to Los Angeles as a foreboding analog (Gammage, 1999; Gober, 2005; Ross, 2011), and recent work by Fraser (2013) indicates that Los Angeles reached a saturation point where the infrastructure simply does not support increased travel. There are physical limits to the amount of travel that infrastructure can enable because there are only so many miles of roadway that can be

²⁹ These matching data are not a surprise since travel models use city land use plans as data inputs. The four-step travel model typically employed by regional transportation planners is (1) trip generation, (2) trip distribution, (3) mode choice, and (4) trip assignment. In the first step, trip generation, demographic data and economic and social factors are collected to model the activity systems in a region (see the dashed box in the system boundary diagram at Figure 2.3).

constructed and financed between homes and activity centers, and hours in the day that travelers are willing and able to commit to moving. For Los Angeles, the plateau in travel corresponds to 0.11 VMT per lane-mile per capita (Fraser & Chester, 2013), and in the Phoenix BAU trend this ratio of travel to infrastructure and population is 0.079 in 2050³⁰. There is likely a plateau in travel that will occur in Phoenix's BAU future, and the concept should be incorporated into any further projections that take the modeling beyond 2050. The BAU trajectory takes an initial step to explore the relationship between embedded infrastructure and emergent behavior, and the next two trajectories test some of the possible benefits from breaking the automobile path dependent trends by constraining low-density auto-oriented outward growth.

2.5.2 Plateau Trajectory: Quelling Automobile-Oriented Growth by 2031. In the "Plateau" trajectory the MAG travel and real-estate development models are used through 2031³¹, then no additional fringe infrastructure growth is modeled. Growth will plateau in this trajectory because land use policies will discourage major suburban housing developments beyond what has already been approved, and associated roadways to support that land use will not be constructed. As a result, regional VMT will decrease from BAU because new households after 2031 will be in urban core locations where travel matches those households currently in the core. Phoenix urban core households traveled 21,000 miles by automobile in 2012 and those outside drove 27,000 miles per year (MAG, 2013d).

³⁰ Fraser is still perfecting this analysis, and there is a nuance to using a statistic like this because road capacity is highly-dependent on the time of day. Peak travel times carry a majority of the VMT (by definition), so even with "saturated" infrastructure there are likely very few cars on the roads at midnight. Los Angeles is half the geographic size as Maricopa County, and already has double the population. The L.A. road network currently has less lane-miles than Maricopa County and more people.

³¹ If 2031 seems like an odd pint-point, the year is chosen specifically because the MAG future travel models are for the year 2031. Since this research has been completed, MAG has updated the models to project out to 2040, but the data are still being processed and is not available yet to update the models in this research.

The cities of Phoenix, Tempe, and Mesa have already zoned areas along the LRT corridor for TOD and expect that the travel efficiencies and economic development benefits (Cervero, Ferrell, & Murphy, 2002; TRB, 2009) will be realized as new households and jobs are infilled in urban core areas with access to public transportation, basic services, and jobs. In this trajectory, regional VMT will not increase as rapidly as the BAU trend because there will not be new roads to increase daily capacity. FHWA statistics are used to calculate lane-mile supply-demand elasticity for each roadway category from 1990-2011, and the results are consistent with Cervero and Hansen (2013). These elasticities are applied to the annual increase in VMT from 2032 onward, and together with the reductions from household location the region-wide annual increases in VMT are 460 million VMT per year instead of the 780 million per year for the BAU trend. The new TOD will reduce VMT even more through both transit mode-shifts and reductions in household auto travel (Chester et al., 2013), reducing annual VMT by 49% (14,000) per TOD household. The ST-LUIS market study (Gehrke & Srivastava, 2011) suggests that Phoenix can accommodate (through job location and land availability) 485,000 TOD households, which is just enough to meet the population growth projections from 2032-2050. This plateau may not hold indefinitely, as policies and planning strategies could change over time to allow fringe development again, and beyond 2050 the projections will change for transportation, land use, and population.

2.5.3 Integrated Transportation and Land Use Trajectory: Immediate Action.

The ITLU trajectory expands on previous work (Chester et al., 2013; Kimball et al., 2013) and assumes that the recommendations of the ST-LUIS study (MAG, 2013e) are embraced by all cities within the next few years. As a result of aggressive land use policy changes and transportation initiatives, growth in the region is focused on achieving the characteristics

defined as sustainable by stakeholders in the ST-LUIS report (MAG, 2011b, 2013e): TOD and urban infill, access to multi-modal transportation systems, access to jobs and services, and walkable communities. After 2017 it is assumed that no fringe growth happens and no new roadways are constructed (with the exception of the approved interstate highway expansions). Road reconstruction will continue on the region's 65,000 lane-miles of road, and regional VMT will decrease as a result of more centrally-located households and increased use of transit services. TOD infill will accommodate all new population growth up to 485,000 new households (Gehrke & Srivastava, 2011), and after that the household growth will occur in the urban core (inside the 101/202/303 highway loops as seen in Figure 2.2) but not in a TOD. These new non-TOD urban core households will drive less because they will have shorter trips than fringe households, but will still primarily drive automobiles³². Household size is assumed to stay constant at 2.7 residents (Arizona Department of Administration, 2010). The difference between fringe and urban core household VMT (6,000 per year) is calculated from the MAG 2031 travel model by assigning all trips to the origin TAZ, computing the VMT per household in each TAZ, and then averaging the result for TAZs inside and outside the urban core. The region-wide annual increase in VMT after 2017 is calculated by reducing the BAU-projected VMT growth (780 million per year) by the same "no new road construction" factor used in the Plateau trajectory after 2032 (to 460 million per year). As a result, total VMT in the region reduce

³² For further information on densification without transit access, see Chatman (Chatman, 2013).

rapidly while TOD growth happens but then regional VMT begin to increase again when the new households are automobile-dependent.

Growth in this trajectory is slowed over time because the induced effect of new roadway construction is avoided and the new TOD households reduce their annual VMT by more than the region-wide increase in per-capita (household-equivalent) VMT. TOD households are essentially offsetting the regional growth in VMT, and from 2017-2031 the reduced travel benefits from TOD infill in Phoenix are able to accommodate new growth and reduce annual travel. After 2031 the VMT begin to increase again because the supply of TOD infill runs out. If new TOD infill opportunities are created, through expansion of the LRT system or introduction of high-capacity transit routes, then the post-2031 calculations in this trajectory could be reconfigured to reflect continued VMT reduction.

2.5.4 Sustainable Phoenix Trajectory: Immediate and Aggressive Action. This trajectory takes a “back-casting” approach and adjusts future VMT projections, as well as applying fuel price and fuel efficiency elasticities³³ and increased adoption of electric vehicles, to get emissions reductions as close as possible to 1990 levels (a common target year for other regions aiming to reduce emissions). The trajectory is unrealistic based on recent trends, and overly optimistic, but represents a best-case or “utopia” trajectory. The analysis will be valuable during the development of policy goals so that they are more closely-aligned with achievable results. As the Department of Energy (DOE) recently concluded,

³³ The concept of an elasticity is that for every 1% increase in one factor, another factor will increase or decrease by a certain percentage in response to (or in correlation with) that change. In this trajectory, changes in fuel prices will result in slightly decreased travel as people respond to more expensive gasoline, but also changes in vehicle fuel efficiency (i.e. getting more miles to the gallon) will motivate people to drive a little more because it makes each mile a little less expensive. For a reference on these elasticities for travel, Litman (2013) provides a good literature review.

California's optimistic policy goals (80% below 1990 per capita emissions) are not achievable by the 2050 target date (Greenblatt, 2013). The overwhelming conclusion from the Greenblatt (2013) report is that population growth will still drive overall emissions upward. An argument for quelling population growth in Phoenix is not the intent of this research, therefore MAG's population predictions are held as de facto inputs even in this utopian trajectory.

In this trajectory, population predictions match all other trajectories, with Phoenix reaching nine million people by 2050. After 2017 (the end of the currently-programmed budget cycle), every new resident who moves to Phoenix is accommodated by a TOD household and drives the number of annual VMT corresponding with the Chester et al. (Chester et al., 2013) Phoenix-specific TOD travel modeling. Additionally, the trajectory assumes that the residents who currently live in Phoenix (the 2012 population) do not increase their annual household VMT as might be expected in a BAU trend. No new road construction occurs after the year 2017.

The trajectory models gasoline tax increases that are phased-in at two cents per year through 2035 to match California's current gasoline taxes. The idea of matching California's gasoline taxes has been suggested with some debate at MAG transportation committee meetings (MAG, 2013c, 2014), and would be an additional 36 cents per gallon by 2035. A "price on carbon" is also modeled as a phased-in increase of gasoline prices based on the CO₂ content of gasoline (EPA, 2013a) and the proposed legislation for carbon taxation (EPA, 2010). The price on carbon would be \$20 per ton by 2020, and \$75 per ton by 2050. The elasticity value used to calculate the reduction in VMT in response to a one percent rise

in gasoline price is -0.10%, which is the midpoint between a high California-based study (Cervero & Hansen, 2013) and a low U.S.-based study (Su, 2011).

Vehicle fuel efficiency is modeled as exceeding the current projections (EIA, 2013a; NHTSA, 2012) and doubling the fleet-wide economy to 100 miles per gallon by 2050. Increased fuel efficiency results in increased automobile travel (Cervero, 2002; Fulton, Noland, Meszler, & Thomas, 2000; Hymel, Small, & Dender, 2010; Su, 2011), and an average elasticity value³⁴ is applied to the modeled gas mileage to add back in the increased VMT in this trajectory.

A “road construction” elasticity is calculated from the FHWA (2012) statistics for the Phoenix metropolitan area. Existing literature on induced demand from new lane-miles of roadway estimate that a one percent increase in the lane-miles of highway roads (in California from 1976 to 1997) corresponds with a 0.59% increase in VMT (Cervero & Hansen, 2013). Elasticities specific to Phoenix are computed based on the 1989-2011 statistics in the FHWA series, and separate elasticities are calculated for each road type (highway, arterial, collector, and local). The elasticity calculated for highways in Phoenix ranged from 0.14% to 1.7% (an average of 0.90%). This average falls within the range of literature values, so the same calculation method is applied to each road type to get a specific elasticity from the lane-miles of roadway that would be built in the BAU trajectory. The “no new roads” VMT reductions are subtracted from the total annual VMT modeled in the trajectory.

³⁴ The literature on induced travel from fuel efficiency ranges from 0.064% to 0.0004% (Litman, 2013; Su, 2011). While this is a large range, using the high or low elasticity instead of the average did not significantly change the VMT projections.

The Sustainable Phoenix trajectory is a direct result of the iterative process of conducting the institutional analysis (see Chapter 1) and then validating the completeness of the LCA. If the institutional analysis had been completed independently and before the LCA framework was established, the policies and interactions that are explored would have been limited because data dependencies would not be clear. For example, the importance of city and developer actions in constructing local roads might not have been explored if the LCA model had not revealed the connection between future land development plans and the number of miles of local roadways (and the corresponding quantities of vehicle miles traveled). If the LCA model were completed before the institutional analysis, the final results would have been less useful because the model would not have incorporated context-specific insights such as modeling a more aggressive Sustainable Phoenix trajectory.

2.6 Final LCA Model Results.

Building the final LCA model required significant time investment gathering detailed and accurate data and incorporating the IA-LCA iterative processes outlined in Chapter 1. The data availability determined the resolution of the historic data (annual travel statistics), and that annual interval is carried forward for the prospective trajectories. Wherever possible, location-specific and period-appropriate technical data are used for inputs (e.g. road designs, vehicle technology). Financial data are indexed to the most recent year of complete data (2011) for the entire model. This allows reasonable comparison of historic and prospective model results.

The prospective trajectories are compared to the BAU trend. It is important not to carry forward dynamic aspects of the model by creating forecasting from LCA results. The BAU projection from economic results might not correspond to a BAU projection for

emissions. Literature sources that independently project future values for the data inputs (e.g. vehicle fuel efficiency, gasoline prices, and population) are used to fill in the model in future years, and the future trajectories are designed by manipulating these data predictions according to the conditions modeled in each trajectory.

The final LCA model is built simultaneously with the institutional analysis research (see Chapter 3). This is important because institutional insights informed the selection of specific data inputs for the LCA model. In conducting the institutional analysis, relationships with the transportation planners in the institutions led to gaining access to more credible data for the LCA model. Because the data inputs for the LCA model match the data used by the transportation planning organization (e.g. population predictions, land use patterns, travel demand models), the model will be more coherent and salient for decisionmakers in the planning institution. Future trajectories are also modeled to be associated with realistic scenarios that have been proposed by the institution.

Infrastructure systems enable automobile use, and small costs in roadway construction are accompanied by large costs in private spending and environmental impacts. Figure 2.5 shows historic trends in roadway construction and VMT through 2012 and forecasts future trajectories through 2050. Roadway construction plateaus in the trajectories when fringe real-estate development ceases, at which point the existing infrastructure accommodates new automobile travel demand. VMT results, however, are dependent on variance in household travel based on location as well as the availability of developed land. In the Plateau trajectory, VMT can level off in 2031 if TOD infill begins and each new TOD household drives 49% fewer VMT (Chester et al., 2013). The 560,000 new households³⁵ that

³⁵ This is based on the population predictions between 2031 and 2050, and 2.7 persons per household (Arizona Department of Administration, 2010).

infill Phoenix’s urban core from 2031-2050 collectively avoid 60 billion VMT through 2050 compared to BAU travel trends. The ITLU trajectory capitalizes on these avoided VMT 14 years earlier (in 2017), but since there is only market demand (jobs and real estate) for 485,000 TOD households in the urban core (Gehrke and Srivastava, 2011), the population growth after 2032 is placed in households that are again reliant on automobile travel. The cumulative effects of infilling TOD households earlier, and the lower household VMT for urban core homes, result in 140 billion VMT avoided from 2018-2050. The sooner a VMT is avoided the larger the energy, environmental, and economic benefits are when compounded through 2050. The Sustainable Phoenix trajectory increases the potential savings by affecting existing travel demand (through price and technology travel elasticities) and developing new markets for TOD. In this most aggressive trajectory, a cumulative 240 billion VMT are avoided through 2050.

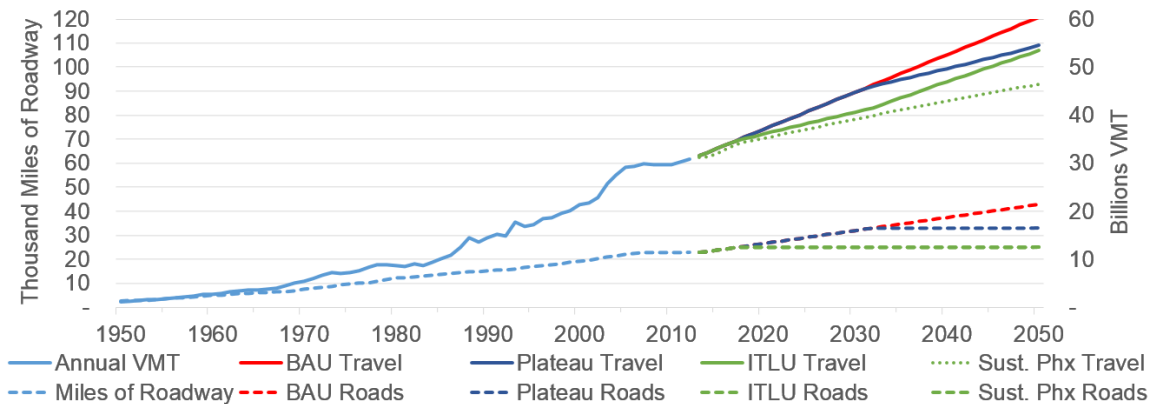


Figure 2.5. VMT and Roadway Construction in Phoenix, 1950-2050.

If growth occurs as predicted by regional planning agencies (MAG, 2013d; Maricopa Association of Governments, 2012), Phoenix can be expected to construct 20,000 miles of new roadway (or roughly 40,000 lane-miles) and annual VMT will double by 2050. The road construction and VMT in each trajectory reveal critical points when land use strategies reach

their limit (e.g. the market supply of TOD) and how population growth contributes to regional VMT totals over time. The plateau trajectory shows that by placing new growth in TOD infill locations, VMT growth is stunted and Phoenix avoids building 9,900 miles of roadway. To maintain the plateau would require creating new market demand for TOD by 2048 and ensuring that policies aimed at restricting fringe growth remain in effect through 2050 and beyond. In the ITLU and Sustainable Phoenix trajectories Phoenix avoids building 18,000 miles of roadway and all of the associated reconstruction and maintenance. A critical point for the ITLU trajectory occurs in 2027 when the market for TOD is exhausted and VMT growth picks up again, although at a smaller rate because urban core households drive less than the fringe households in the BAU trajectory.

2.6.1 Economic Effects. Small changes in public dollar expenditures may induce large changes in user costs. Figure 2.6 shows that public spending over the last six decades has been 1.2% to 35% (average 9.7%) of the combined spending in any given year and this percentage is decreasing as region-wide VMT increase. In the Plateau trajectory every avoided dollar in public spending results in two dollars of avoided automobile spending

(gasoline and automobile purchases), starting in 2031. The ratio increases every year to 11:1 private to public savings by 2050.

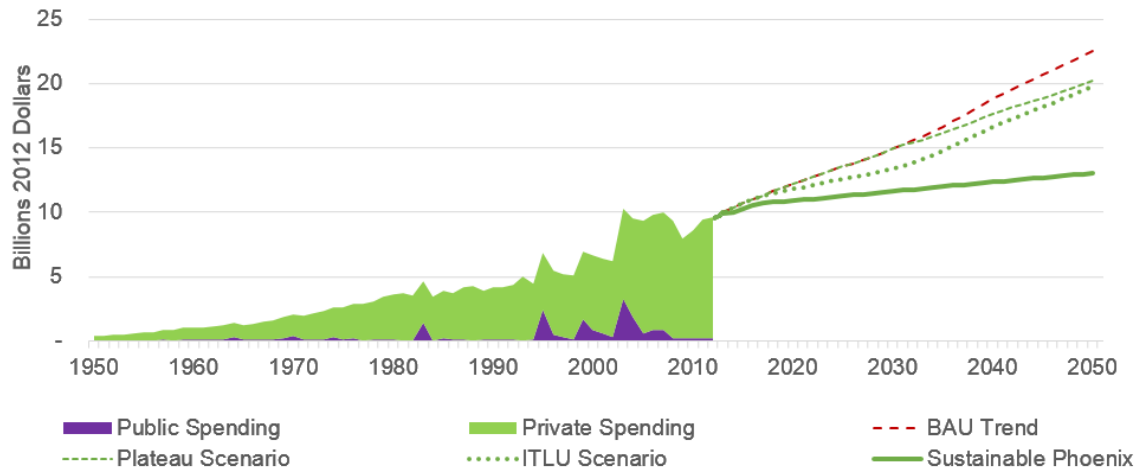


Figure 2.6. Phoenix Public and Private Spending, 1950-2050.

Reductions in public expenditures coupled with reductions in user expenditures are the result of increasing density by concentrating urban growth where infrastructure exists and the resulting lower household VMT travel due to access to high-capacity transit. These user cost “savings” are not necessarily direct user benefits because each household that reduces VMT by mode-shifting will still spend a portion of their budget on alternative transportation options (e.g., transit fares, bicycle purchases). However, a fraction of the avoided VMT are from shorter trip distances compared to fringe travel behavior, and those are direct user cost savings³⁶. By making infrastructure investment changes earlier in the ITLU trajectory, a 9:1 private to public savings starts in 2018 and steadily increases to 11:1 by 2050. The avoided roadway spending is not necessarily a direct public benefit either, since providing alternative transportation options to the public is expensive (e.g. bike/walk paths, transit expansion, increasing transit frequency). Creating the 20-mile light rail transit

³⁶ In the Plateau trajectory the urban core households are estimated to reduce VMT by 22% from trip reduction.

system in Phoenix cost \$1.4 billion in 2008, but this amount of public spending is saved by avoided road construction and operating costs in the ITLU trajectory by the year 2020. The economic results show that significant changes in user costs happen when public dollars are diverted away from roads.

Greater long-term economic savings are possible from more immediate public spending changes that emphasize TOD. Reconstruction costs in the Plateau and ITLU trajectories flatten when no new roads are constructed. In the Plateau trajectory this annual reconstruction cost is \$260 million starting in 2031 and \$200 million for the ITLU trajectory starting in 2017. The cumulative economic benefits (in avoided spending compared to BAU through 2050) in reconstruction costs alone from the Plateau trajectory are \$680 million and \$2.1 billion from the ITLU trajectory. The cumulative public spending avoided in the ITLU trajectory through 2050 is \$5.8 billion, and the cumulative private automobile spending avoided is \$140 billion. While the public and private spending on other forms of transit must be considered together with this information, these results provide a metric against which public-private partnerships (such as the Phoenix public transit system) can be measured for economic viability.

The Sustainable Phoenix trajectory, while overly optimistic, saves a cumulative \$29 billion in public spending and \$160 billion in private spending. Calculating the avoided roadway infrastructure costs against the upfront costs of public transit expansion can produce faster “payback” timeframes than expected, but must be accompanied by institutional changes in infrastructure funding mechanisms. The IA-LCA could easily be expanded to provide a benchmark for evaluating proposals for alternative infrastructure or technology projects (e.g. transit infrastructure expansion, automobile manufacturing improvements, etc.). Increasing gasoline taxes that directly increase private automobile

transportation costs might seem unpalatable to voters and policymakers, but the resulting private savings from reduced automobile travel are significant and should be better communicated to citizens as they make decisions about where to live and how to travel.

2.6.2 Energy Consumption and Environmental Effects. Life cycle energy consumption and GWP, herein referred to as greenhouse gas (GHG) emissions, results show that while automobile operation dominates, the contribution from infrastructure is significant, and from 1950-2012 every unit of energy and GHG embedded in roadway construction and reconstruction enabled 17-times more emergent units. Figure 2.7 shows that roadway construction and reconstruction combined, from 1950-present, account for an average of 2.9% of life cycle energy and 3.2% of GHG, while automobile operation alone is 82% and 79% respectively. The avoided roadway construction/reconstruction emissions in the alternative trajectories are almost negligible (1%) compared to the energy and GHG emissions avoided from reduced VMT, assuming that households in the core and fringe follow the travel forecasted in MAG models (MAG, 2013d). Annual energy and GHG in the whole life cycle system are reduced by another 6.1% (Plateau) to 9.1% (ITLU) compared to BAU, and as high as 47% for Sustainable Phoenix by 2050. The ITLU trajectory, cumulatively through 2050, results in 732 PJ of avoided energy consumption and 52 million metric tons (mmt) of avoided CO_{2e} emissions. Upstream automobile life cycle phases are significant. For every ton of GHG emissions in automobile operation, 0.19 tons of CO_{2e} are emitted to extract, process, and deliver the gasoline (production) and 0.14 tons are emitted in automobile manufacturing. Over the last six decades, passenger transportation in Phoenix has resulted in life cycle consumption of 6,600 PJ of energy and 470 mmt of CO_{2e}

GHG. The Navajo Generating Station (a 2,250 megawatt coal power plant in Arizona) would require 106 years to generate this amount of energy running at full capacity.

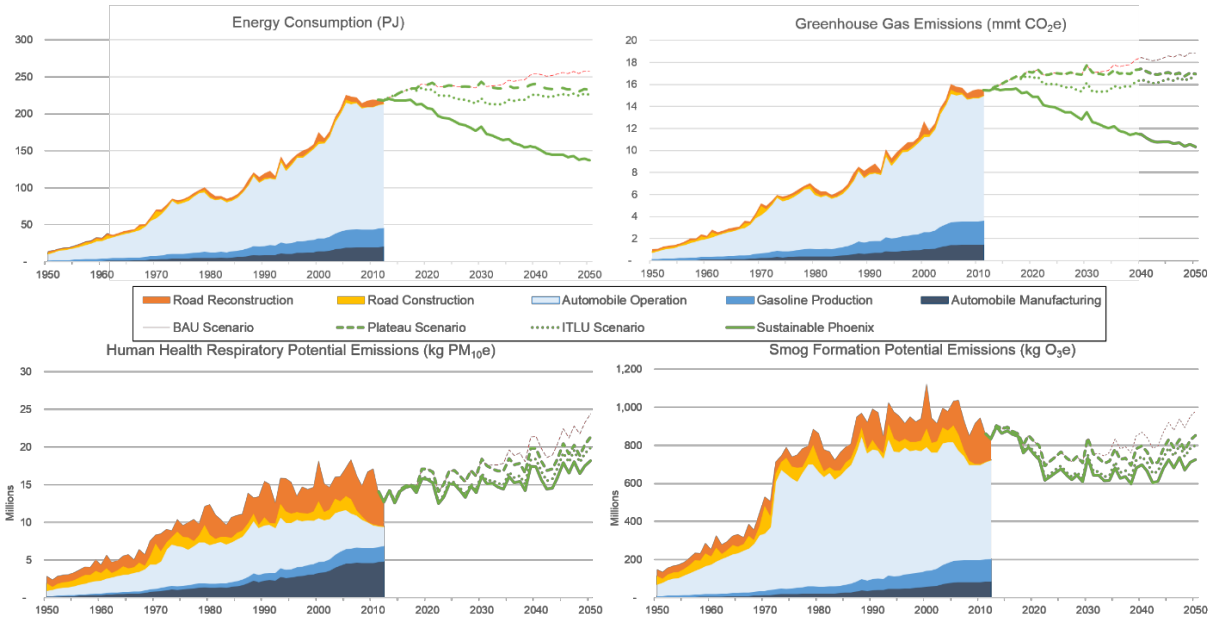


Figure 2.7. Phoenix Passenger Transportation Annual Energy Consumption and Environmental Effects, 1950-2050. Automobile operation dominates the results, and road reconstruction, automobile manufacturing, and gasoline production are significant.

Respiratory and smog emissions are spread across all life cycle phases due to a variety of direct and upstream processes. Environmental and air quality initiatives in recent decades have been fairly successful in limiting the particulate matter emissions from internal combustion engines and vehicle operation (EPA, 2013b), and the model results for respiratory emissions (Figure 2.7) demonstrate that automobile operation represents a comparatively smaller share of the life cycle emissions than in energy and GHG. While the automobile phases taken together still outweigh the roadway phases, roadway construction represents 36% of the total life cycle respiratory emissions (on average through 2012). From 1970-2000 automobile operation was 47% of respiratory emissions, but after the year 2000 vehicle manufacturing increases proportional to the other phases and automobile operations

decreased to 27%. Newer manufacturing processes aimed at increasing fuel efficiency and improving safety have required more wrought aluminum parts which require bauxite mining, a process high in PM₁₀ emissions (Wang, Wu, & Elgowainy, 2007). Reducing road construction and VMT in the Plateau, ITLU, and Sustainable Phoenix trajectories do not result in the same benefits as in energy and GHG, and the primary benefits are gained from a combination of avoided VMT and fewer automobiles manufactured. Emerging EPA standards may reduce automobile emissions more in the near future (EPA, 2014), making a focus on roadway construction/reconstruction emissions a logical next step in the reduction of total system emissions.

Smog-forming emissions in Phoenix passenger transportation primarily result from the life cycle processes of automobile operation and roadway construction. Automobile operation accounts for 64% of life cycle smog emissions and 26% is from roadway phases. Significant potential exists for avoided emissions, mainly from fewer tailpipe and gasoline production emissions. Roadway construction emissions remain relatively constant in all future trajectories, primarily because the re-construction of old roads is still necessary regardless of new policies that limit the creation of new roads. The embedded roadway infrastructure will continue to require maintenance and reconstruction indefinitely, but the sooner new road construction can be avoided the more cumulative benefits can be achieved through 2050. In the Plateau trajectory, 34 million kg of PM_{10e} respiratory emissions and 1.5 billion kg of smog-forming emissions will have been avoided from 2031-2050. The ITLU trajectory doubles those savings at 80 million avoided kg PM_{10e} from 2017-2050 and 3.5 billion avoided smog-forming emissions. The Sustainable Phoenix trajectory avoids 105 million kg of PM_{10e} respiratory emissions and 4.7 billion kg of smog-forming emissions, but

depends on technology and regulatory changes that are partially beyond local control (i.e. vehicle technology and gasoline content).

2.7 Relationship to Sustainability Goals.

The results show that energy and environmental benefits from changes in passenger transportation systems can contribute to the achievement of sustainability goals. The Arizona Climate Change Advisory Group (CCAG) concluded that reductions in air pollution improve environmental quality, human health, and economic prosperity (CCAG, 2006). The Sustainable Phoenix trajectory through 2050 avoids a cumulative 2,500 PJ energy consumption (by removing 240 billion cumulative VMT from the road), 177 mmt CO_{2e} GHG, 105 million kg PM_{10e}, 4.7 billion kg O_{3e}, and \$160 billion in public and private automobile-oriented spending. These reductions would bring the life cycle footprint of passenger transportation in Phoenix to 1995 GHG emissions levels and 1972 smog, while respiratory emissions would be higher than today (but not any higher than 2006 levels). The energy savings from reduced roadway construction and automobile travel could be as high as 120 PJ annually by 2050. This would be twice the energy-content equivalent of the annual net electricity generation from the Navajo Generating Station coal-fired power plant.

The Sustainable Phoenix trajectory demonstrates that several extreme changes must take place if Phoenix, or the State of Arizona, were to adopt emissions targets similar to California's 2050 goals. Barring policy changes that would not be popular in Phoenix, such as a growth boundary or population-limiting strategies³⁷, any sustainability goals aimed at quelling transportation emissions should be developed using comprehensive and prospective

³⁷ This is not to suggest birth-rate policies, only migration policies that might apply to new residents moving into the area.

LCA methods such as those formulated in this research. Policymakers can focus on reducing the impacts from processes that are in their direct control and have significant local environmental effects, such as the particulate emissions from roadway construction. These policy and planning changes do not guarantee results, but set the conditions that make alternative future trajectories possible.

A path to stabilize air quality emissions from transportation in Phoenix is possible. The Arizona Department of Environmental Quality (Maricopa County, 2008a, 2008b) estimates the current Phoenix particulate emissions at 92 Gg PM_{10e}/yr and the smog-forming emissions at 3.8 Tg O_{3e}/yr. In the BAU trajectory, local (automobile operation and both road phases) PM_{10e} emissions increase by 52% (to 3.7 Gg PM_{10e}/yr) due to increasing reconstruction. Smog emissions decrease significantly through 2020 from new vehicle emission control technologies but then return to today's levels by 2050 as hot-mix asphalt plant emissions and direct emissions during roadway construction accelerate with new roads. Local air quality will improve from technology advancements that are already projected in BAU conditions. Local smog emissions decrease by 16% (2050 versus 2013, to 0.58 Tg O_{3e}/yr) because the emissions from increased automobile travel are smaller than the remote emissions (gasoline production and automobile manufacturing), and a majority of the emissions reductions in the BAU trajectory result from improving gasoline combustion. By reducing roadway construction and VMT after 2031, the Plateau trajectory at 2050 would decrease local particulate and smog emissions by 16% from BAU (1.8 Gg PM_{10e}/yr and 0.90 Tg O_{3e}/yr). In the ITLU trajectory at 2050, local respiratory emissions and smog emissions decrease by 27% and 23% respectively (3.0 Gg PM_{10e}/yr and 0.13 Tg O_{3e}/yr) due to avoiding major road construction and significantly reducing annual VMT. Phoenix is already designated as a particulate nonattainment area, and the ITLU trajectory would allow

population growth through 2050 without further increases in local PM emissions. The Sustainable Phoenix trajectory could reduce local particulate emissions by 28% from BAU (3.1 Gg PM_{10e}/yr) and local smog-forming emissions by 28% lower than BAU (0.16 Tg O_{3e}/yr). A summary of the cumulative results through 2050 is at Table 2.4.

Table 2.4. Cumulative Retrospective and Prospective LCA Results. The columns listing “savings” over BAU are calculated by taking the 2050 cumulative BAU value and subtracting the trajectory 2050 value. Values are rounded to two significant figures.

	Cumulative Energy Consumption (EJ)	Savings over BAU (EJ)	Cumulative GHG Emissions (mmt CO _{2e})	Savings over BAU (mmt CO _{2e})	Cumulative Respiratory Emissions (Tg PM _{10e})	Savings over BAU (Tg PM _{10e})	Cumulative Smog Emissions (Pg O _{3e})	Savings over BAU (Pg O _{3e})	Cumulative Spending (Billion 2012 \$)	Savings over BAU (Billion 2012 \$)
Retrospective Inventory, 1950-2050	6.6		470		680		44		340	
BAU Trend, 1950-2050	16		1,100		1,400		75		940	
Plateau Trajectory, 1950-2050	16	0.29	1,100	21	1,300	34	73	1.5	910	23
ITLU Trajectory, 1950-2050	15	0.73	1,000	53	1,300	80	71	3.4	880	55
Sustainable Phoenix Trajectory, 1950-2050	13	2.5	960	180	1,300	110	70	5.7	780	160

Breaking automobile path dependence for a regional transportation system requires institutional innovations that being with small changes in the way decision-makers assess actions and outcomes (Innes & Booher, 1999). The benefits and costs of alternative future trajectories are quantified in this prospective LCA, the institutions that have direct and indirect influence on the regional transportation system are framed in the institutional analysis in Chapter 3, and the combined IA-LCA (Chapter 4) correlates the specific institutions with transition strategies that would set the conditions enabling each trajectory towards transportation sustainability.

CHAPTER 3

INSTITUTIONAL ANALYSIS OF PHOENIX PASSENGER TRANSPORTATION SYSTEMS

An institutional analysis of the passenger transportation systems was conducted for the Phoenix metropolitan area, circa 2011. Section 3.1 is an overview of the framework used to conduct the institutional analysis. Section 3.2 is a summary of the current regulatory and political system for transportation planning in metropolitan Phoenix. Section 3.3 describes and defines each of the decisionmakers, authority levels, people, and institutions that act in the system. The next two sections use these institutions to outline the financial systems (Section 3.4) and the political systems (Section 3.5). After establishing the background and describing the system (Sections 3.1 through 3.5), Section 3.6 establishes a future normative state by summarizing the sustainable transportation goals, regulations, and targets specifically documented in transportation planning and policy documents. The analysis in this chapter is then combined with the LCA (Chapter 2) to synthesize a final IA-LCA model and results in Chapter 4. The IA-LCA links the institutions to the sustainable transportation goals by describing the intervention points and transition strategies that would alter the “business as usual” passenger transportation trends and move the Phoenix metropolitan area closer to sustainable transportation systems.

3.1 Overview of the IAD Framework.

The Institutional Analysis and Development (IAD) framework (E. Ostrom, 2005, 2011) maps and defines both visible (buildings, infrastructure, people) and invisible (rules, norms, strategies, organizations) pieces of a complex system to better understand key variables in the structure of the system and how those key variables and interactions affect

the system over time. Social systems are complex, have many levels and scales, and can be difficult to study. Using an IAD framework allows researchers to focus on a specific part of a larger system, where all other parts of the system are held constant and deductions can be established about the roles and responsibilities of isolated sets of interactions or participants. This method of isolating parts of a system (a common example from economics is a single marketplace), simplifies the research and enables researchers to define and investigate relationships, roles, and interactions amongst and between the participants and institutions in a social system.

The IAD framework defines institutions as both visible entities (formal organizations, infrastructure, or physical places) and invisible concepts (rules, norms, and strategies). Visible and formal institutions do not need definition but the terms *rules*, *norms*, and *strategies* are used in specific context according to the IAD framework (E. Ostrom, 2005, 2011). *Rules* are “shared prescriptions” that participants understand and are enforced in the system, *norms* are “shared prescriptions” that are accepted by participants according to the conditions within the system (so-called do’s and don’ts), and *strategies* are plans that participants make to take actions (or to interact) using the rules, norms, and physical or material conditions within the system. The setting that is the subject of analysis is termed the *action arena*. Figure 3.1 is a diagram of the action arena. A glossary at the end of this section summarizes the definitions of several terms and how they are used within the IAD framework.

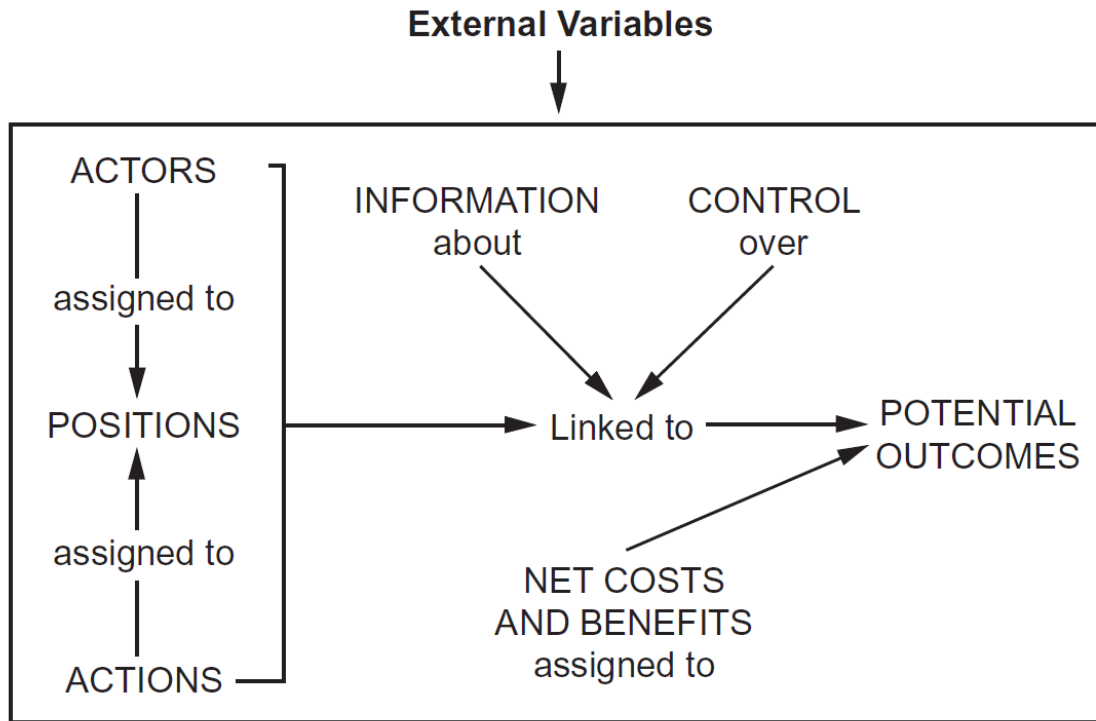


Figure 3.1. The Action Arena in the IAD Framework. Taken from Ostrom (2011). External variables can be biophysical conditions, attributes of the community, or rules-in-use. The arrows represent causal or correlating links.

This research does not modify the IAD methodology, but expands its application by matching it with the quantitative analysis (Life Cycle Assessment, LCA) results as a means of providing societal context that is necessary for comprehensive sustainability research. The institutional analysis does not answer questions in a research problem, it only identifies and characterizes aspects of the situation that are related to or interact with the actions, actors, or outcomes in the social system experiencing the problem. Quantitative models, LCA in this research, complements the institutional analysis framework and allows conclusions to be made about the problem situation (E. Ostrom, 2005). Infrastructure systems are uniquely situated for socio-economic study because the services provided (in this research it is passenger transportation infrastructure) can be considered a common-pool resource but the system also must perform on certain levels and at certain scales as a competitive market. As

a common-pool resource, it is difficult to exclude users from using infrastructure systems, free-rider problems exist, and users are not required to pay the true cost of the service (E. Ostrom, 2005; V. Ostrom, Tiebout, & Warren, 1961). As a competitive market, physical space is finite, different agencies (and municipalities) compete for funding (at several different levels), and users interact in supply and demand relationships based on private benefit/cost considerations. This research examines metropolitan-level passenger transportation infrastructure, but does not attempt to categorize the nature of the resources and services provided. Instead, the purpose of the analysis is to match the results of the quantitative assessment (LCA) with institutions that could be intervention points for sustainability transition strategies (the IA-LCA). Table 3.1 outlines how the IAD framework relates to transportation planning systems in this research.

Table 3.1. Applying the Institutional Analysis Framework Categories to Regional Transportation Planning Systems. See Section 3.1.1 for term definitions.

Institution Type	How it Applies to Transportation Systems
Formal Institution	What are the organizations that conduct transportation planning? Who are the decisionmakers, and under what formal authority? How are the formal institutions changed, laws updated, or requirements met in accordance with formal structures?
Strategy	What tactics or plans are programmed for transportation systems? What precepts are employed to do transportation planning?
Norm	What are the generally-accepted precepts within the transportation community? What are the “group-think” logics applied to transportation planning actions? What are the shared meanings understood by decisionmakers and stakeholders? What are the behavioral consistencies demonstrated by the users of the transportation system?
Working Rules	What rules affect ongoing transportation planning? How do these rules influence planning outcomes?
Boundary Rule	How do people or other institutions participate in transportation planning? Who is able to participate, and who is considered a decisionmaker or stakeholder?
Position Rule	How are the decisionmakers and stakeholders designated within transportation planning organizations? Under what

Institution Type	How it Applies to Transportation Systems
	authority are the planners and policymakers acting when they conduct transportation planning?
Scope Rule	What are the limits of possible transportation plans? What are the budget and planning requirements that dictate possible outcomes of transportation planning? Who is responsible for the effects resulting from planning outcomes (i.e. what is internal to the system and by default the other effects are externalized)?
Authority Rule	Who is given specific authorities for transportation planning (and executing the plans), and what are those authorities? What institutions govern the designation of these authorities, and how are those authorities decided?
Aggregation Rule	What conditions or forums must come together to allow transportation planning actions to occur? What collective actions by which institutions must take place before a decision becomes final?
Information Rule	Who must report what information to who (and how)? What information does not have to be disclosed publicly in transportation planning actions? How is information required to be maintained (or determined/collected) to be used for transportation plans and decisions?
Payoff Rule	What are the benefits and costs of transportation planning in the current system? What are the incentives and disincentives for transportation planning actions? Who pays for transportation systems, and what revenues are used to fund them?

This research defines sustainability transition strategies as plans or tactics that enable a human-environment system to alter its current (or expected) trajectory to a more sustainable state (Wiek, Ness, Schweizer-Ries, Brand, & Farioli, 2012; Wiek, Withycombe, & Redman, 2011). Through scenario development, modeling, and stakeholder engagement future desirable states are identified and then back-casted to reveal the intervention points that are required for (or would facilitate) the system to change over time (Wiek et al., 2011). The current path is typically unsustainable, as is true for passenger transportation systems in the Phoenix metropolitan area, and maintaining an unsustainable trajectory is consistent with theories of “lock-in” or path dependence. To break the path dependence and determine

sustainability solutions, more sustainable future states are identified, the paths leading to those states are termed transition strategies, and detailed actions that must be taken to execute those transition strategies are intervention points (see Figure 3.2 from Wiek et al. (2011)).

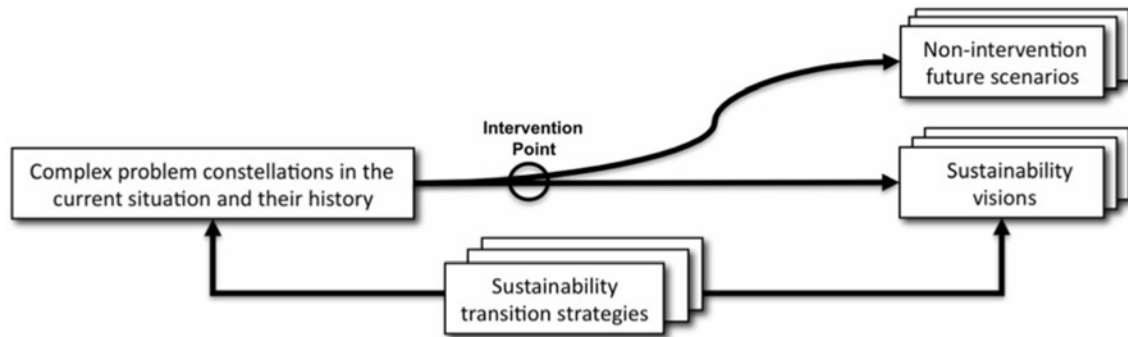


Figure 3.2. Transformational Sustainability Research. Conceptual diagram from Wiek et al. (2011) showing how sustainability transition strategies can be executed at intervention points to alter current (non-intervention) paths and instead arrive at a new (more sustainable) future.

Path dependence, sometimes termed “lock-in,” is a subset of institutional analysis that theorizes “self-reinforcing mechanisms” causing particular decisions to be made “even though better alternatives exist” (Arthur, 1988; Low & Astle, 2009). Transportation planners and policymakers in retrospect explain inefficient or faulty choices by accounting for politics, perceptions, economics, and regulatory or technical constraints (Boarnet, 1995; Chang & Chen, 2009; Litman, 1997; Richmond, 1998; Wachs, 1995). Institutional analysis studies on transportation systems and path dependence (Low & Astle, 2009; Porac, Rosa, Spanjol, & Saxon, 2001; Rao & Singh, 2001) acknowledge those constraints but also identify organizational memory and professional culture as components contributing to path dependence. Because decision and policy making does not actually function like a trip on a

path³⁸, it is important for the actors in the transportation system to gain more comprehensive perspectives of the impacts of past and future decisions. Organizational memory (Huber, 1991) can carry both good and bad knowledge into the future. Institutional learning (Huber, 1991) is necessary for organizations experiencing “lock-in” to change, and this occurs when an entity to gather and processes information and then the realm of possible behaviors is expanded (i.e. behavior change does not necessarily occur, but the option of behavior change is now possible). Entrepreneurs often break path dependence by path creation where efforts are made to enable a different possibility or create a need for a new product or behavior (Garud & Karnoe, 2001; Porac et al., 2001; Rao & Singh, 2001; Van Looy, Debackere, & Bouwen, 2001). Once a new path is competitive with the status quo, then the realm of possible behaviors or choices is expanded and institutions then have the possibility of changing (Huber, 1991; Porac et al., 2001; Tiberius, 2011).

This research will inform sustainability solutions and enable organizational change by using the IAD framework to conduct an institutional analysis of regional transportation planning in Phoenix and linking benefits and costs with transition strategies for the sustainable future trajectories that were modeled in the LCA (Chapter 2). The institutional analysis is a methodological demonstration and does not judge the appropriateness of the organizational structure, nor the efficiency or functionality of the regional transportation planning system. Maricopa Association of Governments (MAG), as the Metropolitan Planning Organization (MPO) for the Phoenix metropolitan area, is the subject of this

³⁸ Even the terminology for the phenomenon, path dependence, is rooted in a metaphor about transportation. Metaphor is a powerful tool in establishing saliency in any scenario development, goal establishment, or visioning exercise (Selin, 2006), and describing a lack of control along some sort of path or road is a way to convey both the passage of time and the established nature of the direction the situation is heading. In institutional analysis, Ostrom (2005) also warns that “Words are always simpler than the phenomenon to which they refer.” For a list of transportation metaphors noted during this research, see Appendix B.

analysis but the methodology is meant to be adaptable to any urban planning area in the United States. The Phoenix metropolitan area is assumed to be Maricopa County, and is henceforth referred to as simply Phoenix (specific municipalities will be titled “City of” to be precise).³⁹ The future-state visions modeled in the quantitative assessment (the LCA in Chapter 2) are not “scenarios” as used by planners and engineers, and are instead termed “trajectories” to make a distinction between scenario planning and prospective modeling. The results synthesized in this chapter are intended to be additive products to supplement and enable existing sustainability, transportation, and land use planning efforts in Phoenix.

3.1.1 Glossary of Institutional Analysis Terms.

Institution: According to the Institutional Analysis and Development (IAD) framework (E. Ostrom, 2005, 2011), an entity that structures or influences patterns of interactions in a social system. Institutions can be formal or informal organizations, rules, norms, and strategies. Institutions can be visible or invisible, and can be found in shared concepts or implicit knowledge.

Rules: According to Ostrom (2005), “shared prescriptions (must, must not, or may) that are mutually understood and enforced in particular situations in a predictable way.”

Norms: According to Ostrom (2005), “shared prescriptions known and accepted by most of the participants.” Can sometimes be synonymous with the term “values” but does not necessarily require a belief system or set of values.

³⁹ In 2012, the Phoenix metropolitan area was expanded to include portions of Pima County. This research began before the boundary change, and the quantitative analysis does not include any portions of land outside Maricopa County. It is interesting to note that at the time the MPO boundaries were expanded (by federal agencies according to updated census data), MAG extended an offer to adjacent municipalities in Pima County that they could be included in MAG’s organization. Several Pima County municipalities, and one Native American reservation accepted and are now represented in MAG committees and boards.

Strategies: According to Ostrom (2005), “regularized plans” made by participants who employ the rules, norms, and physical conditions within the action arena.

Action Arena: According to Ostrom (2005), the physical or conceptual space and time in which actions occur. The subject (or place) of the institutional analysis. An action arena can also be narrowed to a specific participant, termed an individual action arena, or to a specific number of participants, a “single” action arena.

Working Rules: According to Ostrom (2005), there are seven types of working rules, and these “affect the structure of any repetitive action situation” and have a direct effect on the action situation components. The seven types are boundary rules, position rules, scope rules, authority rules, aggregation rules, information rules, and payoff rules.

Boundary Rules: According to Ostrom (2005), a type of working rule that determines the participants (including the quantity of participants), their characteristics, how they enter and leave the situation, and what resources they have access to in the situation.

Position Rules: According to Ostrom (2005), a type of working rule that determines the various positions (which could be titles or roles).

Scope Rules: According to Ostrom (2005), a type of working rule that outlines the possible results (or outcomes) of a situation, and because there is an a priori restriction the scope rules can link specific actions to potential outcomes. In a market situation, scope rules determine the externalities that participants are able to pass on to others in the situation.

Authority Rules: According to Ostrom (2005), a type of working rule that delineates the actions of participants, and these actions can be required, allowed, or prohibited according to the authority rule. Authority rules work together with scope rules and “scientific laws about the relevant states of the world” to create action-outcome linkages.

Aggregation Rules: According to Ostrom (2005), a type of working rule that changes the “level of control that a participant in a position exercises in the selection of an action.”

Information Rules: According to Ostrom (2005), a type of working rule that affect the knowledge (or information) sets held by the participants, and also the information that they must provide to others (such as required reporting).

Payoff Rules: According to Ostrom (2005), a type of working rule that establishes the benefits and costs from specific actions in the situation, to include incentives and disincentives (or penalties).

Culture: According to Ostrom (2005), a term that generally applies to the attributes of a community (specific variables) that influence the structure of the action arena. The attributes of the culture can be preferences, distribution of physical resources, norms, behaviors, and shared understanding.

3.2 Regional Transportation Planning in Phoenix: Defining the Action Arena.

Regional transportation planning has occurred in a variety of forms since the dawn of human civilization⁴⁰. Highways and road networks have been designed and built by governments and private organizations since the days of wagon trains and the invention of trains and automobiles. Only since the post-World War II era has transportation planning been codified in law, with the establishment of the Federal Highway Act of 1963 (Johnston, 2004). More recent legal actions have motivated transportation planning laws to be updated

⁴⁰ The Roman road networks circa the 600s B.C. were a way to ensure salt and fish were supplied to the population and for Roman empire-building (Kurlansky, 2002).

so that MPOs are responsible for and accountable to their approved plans⁴¹. Today MPOs are responsible for establishing long-range transportation plans that integrate and address problems as diverse as future population growth, reduced land availability, air quality, stressed natural resource supplies, economic livelihood issues, environmental conservation, and public health and social equity concerns (Beimborn, 2006).

Transportation planning in Phoenix occurs at all levels and scales (from housing developments to national and federal programs), but this review addresses the planning occurring at the level of the MPO responsible for the region known as the Phoenix metropolitan area. Since federal legislation in the 1970s, any urbanized area with a population over 50 thousand people must form a MPO (FHWA, 2007). The MPO for Phoenix is MAG, as designated by the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and subsequently the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) (Beimborn, 2006; Johnston, 2004). SAFETEA-LU expired in 2009, but was extended 10 times through 2012. The most recent update to transportation planning regulations is the Moving Ahead for Progress in the 21st Century Act (MAP-21), which was signed into law in 2012 and restructured many funding programs and the methods by which transportation standards are evaluated. Many of the new MAP-21 requirements for MPOs are still being defined, but wherever possible are included in this institutional analysis. While MAG is required to complete many

⁴¹ California lawsuits in the early 1990s accused planners of violating the Clean Air Act, and resulted in ISTEA and subsequent regulation of transportation planning (Garrett & Wachs, 1996). The trial was completed at the same time as Clean Air Act amendments were taking place, and the court made sure to include the emerging regulatory requirements in its decision. Now federal funding can be withheld if MPOs do not meet the pollutant goals that they build into their plans (Johnston, 2004).

requirements according to state and federal law, the organization itself is not formed by state law (MAG, 2012c).

By federal law MAG as the MPO generates models, develops and updates a 25-30 year Regional Transportation Plan (RTP) and a corresponding Transportation Improvement Program (TIP), and interacts with community and government organizations to comply with established or emerging regulatory requirements (such as the Clean Air Act) and other policy or social goals (Beimborn, 2006; Handy, 2008; MAG, 2013a). Travel and transportation issues require extensive demographic analysis, land use mapping, and complex assessment of travel within and through the geographic area. The planning is prospective, meaning that it analyzes current trends and projects future demands to ensure that mobility needs are satisfied with safety, efficiency, and minimal impact on the environment (FHWA, 2007). Transportation planners are professionals from interdisciplinary backgrounds in engineering, public administration, geography, and urban planning (Beimborn, 2006).

In Phoenix, MAG (the MPO) is the focal point for regional transportation planning, and interacts with (as well as being comprised from) all levels of government and public/private organizations to execute its planning responsibilities. The conceptual diagram in Figure 3.3 outlines the major interactions between key decisionmakers in the planning process (Beimborn, 2006; Johnston, 2004; MAG, 2010, 2012c, 2013a). This conceptual diagram is not meant to be exhaustive, and there are many subtle links and additional agencies that are not included in this diagram yet play important roles in the planning process.

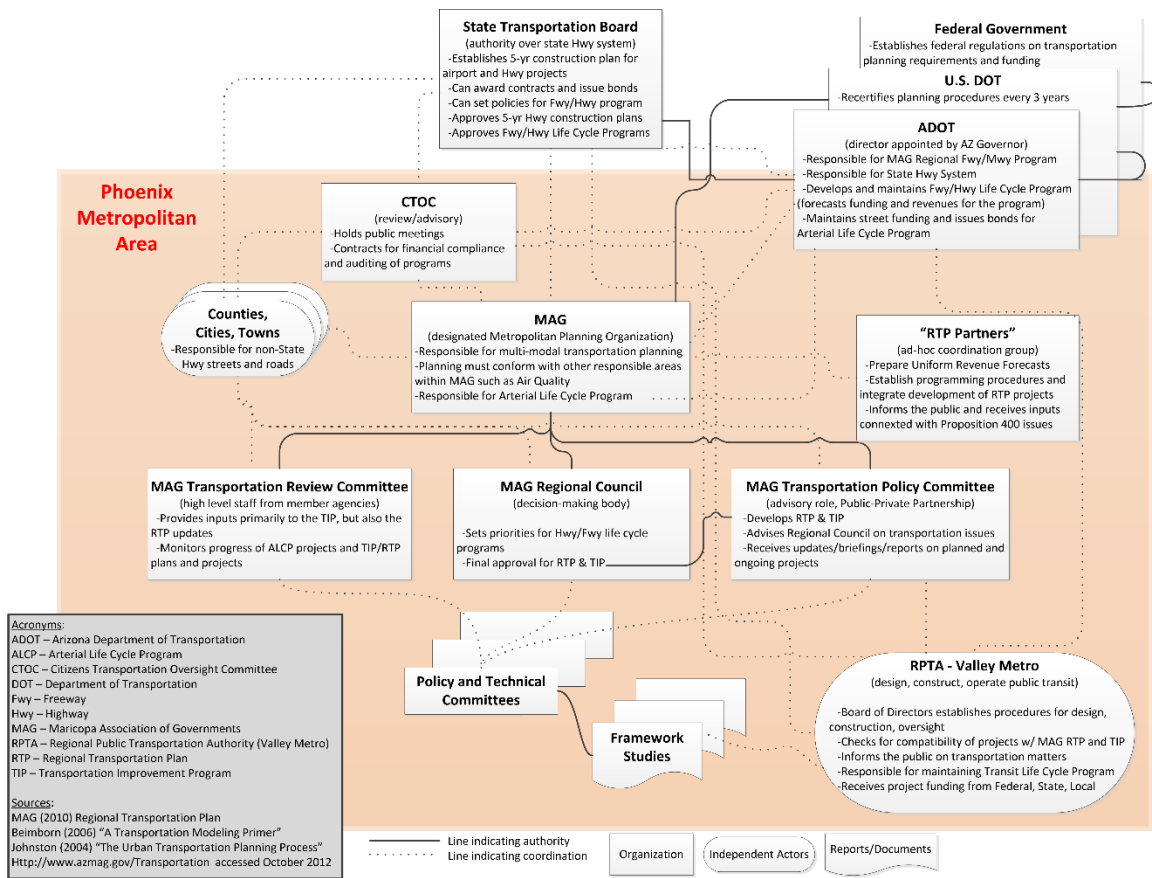


Figure 3.3. Transportation Planning in Metropolitan Phoenix.

The key documents generated in the planning process are the RTP and the TIP. MAG’s Transportation Policy Committee develops the RTP and TIP, and MAG’s Regional Council holds final approval of these documents. Many other agencies and groups have input, advisory, and compliance roles, for example the Citizens Transportation Oversight Committee, City and Town representatives on MAG committees, Regional Transportation Plan Partners, and Valley Metro. Several “life cycle programs” (not related to LCA as discussed elsewhere in this research) are developed at different levels in the planning process to ensure that construction and maintenance of the systems and services are maintained over several years or decades, and that funding and revenue streams are budgeted (MAG, 2010). Lastly, several other laws (not reflected in Figure 3.3) must be coordinated and integrated

into regional transportation planning, such as the National Environmental Policy Act (NEPA) that requires environmental assessments of new federal projects (and subsequent impact assessment if significant impacts are identified) and the Civil Rights Act of 1964 that requires consideration of effects constituting discrimination (Johnston, 2004).

While this extensive network of coordination and decisionmaking appears to accommodate a diverse group of stakeholders, politics⁴² are not reflected in the diagram. Many conflicting regulations, priorities, and institutional incentives compete at all levels of transportation planning (e.g. emissions reduction goals compete with revenue structures based on gasoline consumption, and cross-jurisdictional projects must satisfy differing priorities of several cities and organizations) to create a situation where decisions cannot be based solely on technical criteria (Wachs, 1995). Transportation planning in Phoenix is no exception. MPOs do not have a prescribed structure and must work in coordination with entities that change over time to include the public at large and elected officials at local, regional, and state levels (FHWA, 2007). The US Department of Transportation (DOT) provides federal oversight by recertifying the MPO's planning procedures every three years. Political trends and social mores do influence both the planning and execution of transportation systems, but analysis of these factors is outside the scope of this work.

The RTP and the TIP must be evaluated in a Conformity Analysis to ensure that the plans and projects comply with the Code of Federal Regulations (40 CFR Parts 51 and 93) as it relates to the Clean Air Act (MAG, 2013c). MAG must meet these conformity

⁴² A legendary example of how transportation planning can embody politics comes from the story of Robert Moses and the designs for overpasses in the New York City area in the 1950s. The claim is that Moses specifically designed the overpasses to preclude tall buses from accessing expressways and since at the time most lower-income people rode such buses, this design effectually segregated whole populations and “protected” nicer parks and beaches for the middle- and upper-class who drove cars (Winner, 1986). Wachs (1995) describes transportation planners and consultants who regularly revise estimates and models based on the implied purpose of the study.

requirements because there are areas within the MPO designated as nonattainment areas (or “maintenance areas”) for three specific air pollutants (carbon monoxide, eight-hour ozone, and particulate matter) as of 2013 (EPA, 2013). The Clean Air Act requires a general plan for the county to attain the air quality standards, and a specific plan for each individual area (an area smaller than the county, designated geographically). These general and specific plans are part of an overall State Implementation Plan (SIP) that must be generated by the state (in coordination with air quality management agencies), and approved by the EPA.

Because the Phoenix population is larger than 200 thousand, the MPO is designated as a transportation management area (MPA) and MAG must establish a congestion management process (CMP). The CMP is a systematic means of evaluating the performance of multi-modal transportation systems to reduce congestion and ensure that mobility needs are satisfied. Travel demand management is required as a component of the CMP. The MPO is able to anticipate congestion problems, test different strategies for reducing congestion, and identify past and future contributors and effects of congestion (FHWA, 2007).

The Governor of Arizona is responsible for appointing the director of the state Department of Transportation. At the state level, transportation planning has a broad focus on freeways and highways but the agency also provides assistance to MPO and local transportation agencies for funding and street and highway life cycle programs. Transportation finance is discussed separately in section 3.4. The state agency has responsibility for managing the State Highway system, and the State Transportation Board holds specific authority for this system. The State Transportation Board designs construction plans and manages contracts and bonding to fund construction and maintenance for highway projects. The board also sets policies for freeway and highway

programs, and establishes standards for construction, maintenance, and operations (in compliance with federal standards). Arizona Department of Transportation (ADOT) develops and maintains the Freeway and Highway Life Cycle Program, and the State Transportation Board holds approval authority for these plans. The Life Cycle Programs forecast funding and revenues, and are updated regularly.

MAG is one of five MPOs in the state of Arizona. The Federal Transit Administration (FTA) funds planning efforts in each state based on a population formula for each urban area. ADOT distributes the funding based in this formula, and MPOs match the funds to round out the planning budget. The state establishes guiding principles and visions for statewide transportation planning in a document titled Building a Quality Arizona (bqAZ), but the bqAZ visions and goals (currently projected through the year 2050) are not subject to fiscal constraints. The statewide long-range transportation plan (LRTP) (currently projected through 2035) is required by both federal and state law to meet fiscal constraints. The bqAZ plan is meant to be an ideal vision, whereas the state LRTP analyzes different scenarios and forecasts that would achieve baseline, alternative, and recommended levels of revenues and investments. The statewide LRTP includes all forms of transportation, including transit, bicycling, and aviation, but primarily focuses on highway systems. The MPOs coordinate and consult on the state-level planning efforts, and the state transportation planners are represented on boards and committees in the MPOs. Through coordination at all levels of transportation planning, the MPO plans (specifically the RTP and the TIP) match the state LRTP and work towards achieving the goals and visions of the bqAZ plan.

MAG maintains a special relationship with Indian Tribal governments that fall within the MPO. Federal regulations require consultation with Indian Tribal Governments on

transportation planning. As of 2011, there are three tribal lands in the urbanized area (Gila River Indian Community, Salt River Pima Maricopa Indian Community, and Fort McDowell Yavapai Nation) and each of them participate in transportation planning as full member agencies within MAG. Long-range plans and TIPs that affect Indian Tribal Lands are coordinated with the tribal representatives as part of the normal planning cycle. Separate from the MPO planning process, state and federal DOTs consult with the tribal governments on projects impacting tribal land or resources (FHWA, 2007).

Local governments are responsible for streets and roads that are not state or federal highways. Each municipality is unique and manages its roadways through collaboration with MPO, state, and federal requirements. Land use planning, housing policies, and zoning laws directly affect local transportation management (Jackson, 1985; Papacostas & Prevedouros, 1961). In Maricopa County, land developers are required to construct the infrastructure for new developments and subsequently relinquish control for operations and maintenance to the local government. The developers coordinate local roadway construction with the local government to meet design standards and congestion management planning goals, and the developments must be approved by land use planners and through permitting requirements. Because the MPO manages the Arterial Life Cycle Program (ALCP), local representatives report local road construction to the MPO for coordination and integration with the ALCP. If local conditions change, and arterial road projects programmed in the ALCP no longer satisfy local travel needs, then municipalities can request changes to the ALCP that are then approved or disapproved by a council at the MPO level.

Planning at the statewide level is a more recent federal requirement, mandated by the ISTEA in 1991. Most states adapted the planning procedures and tools already developed and in practice at local levels (Papacostas & Prevedouros, 1961). Cities across the U.S. had

established varying levels of land use and transportation planning, most of which correlated with the age of the city and the planning and growth trends at the times the city expanded (Bruegmann, 2005; Jackson, 1985; Papacostas & Prevedouros, 1961). For example, older cities were heavily influenced by European traditions of grand city plans but by the nineteenth century cities grew according to economic and technological trends like speculative fever and rail and automobile transportation capabilities (Papacostas & Prevedouros, 1961). The primary requirement for statewide planning as established in 1991 and onward is to fulfil the requirements of the Clean Air Act, and to ensure that transportation planning encompasses multi-modal transportation.

3.2.1 Connecting the Action Arena with the LCA System Boundary. To support the IA-LCA model, the action arena of the institutional analysis should correspond with the system boundary of the actions and processes modeled in the LCA, and be limited where possible to a scale that is manageable for the duration of the research period (in this case 1950-2050). Because regional transportation planning occurs at the level of the MPO and the LCA processes were modeled at the metropolitan scale, the action arena in this research is designated as Maricopa County⁴³. The LCA models processes that are both local and non-local (raw material extraction, electricity generation, use, etc.), and Chapter 2 discusses the relevance of the life cycle environmental impacts that are characterized as local effects and non-local effects. In the same way, a thorough institutional analysis must include

⁴³ The geographic scale of the LCA is simplified to Maricopa County, and at the time the research data were collected this county boundary coincided with the legally-defined Phoenix Metropolitan Area (plus the Avondale Metropolitan Area, as reported in the FHWA statistics series). In 2012, the metropolitan area was legally expanded to include portions of adjacent counties and Native lands, and MAG expanded their MPO responsibilities to include this new geography.

some organizations and players that are physically located outside of or at a higher echelon than the metropolitan transportation planning system.

3.2.2 Literature Review and Information Collection. In addition to a thorough literature review of regulations, planning documents, legal requirements, reports, and studies, information collection and “field work” was conducted by embedding⁴⁴ in transportation planning activities within the action arena. Each literature source, informal interview, and attended planning event revealed pieces of the story that details *who* does *what*, *how* they do it, *what* happens *when* and sometimes *why*. The interactions and interdependencies are revealed through a thorough understanding of the institutions that act in the action arena.

From August 2012 through February 2014, at least 40 transportation planning committee meetings and public outreach events were attended to establish roots in the action arena and fully absorb the context of the research. The primary committee meetings regularly attended were MAG Transportation Review Committee, Transportation Policy Committee, and Transit Committee. The public outreach events for the MAG Sustainable Transportation and Land Use Integration Study (ST-LUIS) framework study were also attended. In 2013, the draft Regional Transportation Plan (RTP) and Transportation Improvement Plan (TIP) were published for public review and comment, and a thorough review of those two documents was conducted to update the previous data collection. During the MAG committee meetings, the RTP and TIP were shepherded through the approval process, and no significant changes were made to the documents after the drafts were published. As a stakeholder in the regional transportation system, this researcher filed

⁴⁴ Although the details of the “embed” process are outlined in this section, the extent of the insertion into the planning process was purely at a level that was publicly available. The term should not be taken as the popular use of the word “embed” which means to ride-along or accompany the actors during all or most of their actions.

several feedback comments in the online forum that were included in the information reported to the approval committees. The committees noted the public comments, and heard directly from citizens during a formal public outreach event, but only acknowledged the comments and did not change the RTP or the TIP⁴⁵.

During eighteen months of institutional analysis data collection, informal interviews were conducted in-person and via e-mail and telephone to clarify published documents from MAG. Informative discussions were conducted with dozens of actors (past and present) in the transportation planning action arena, to include the Arizona State University subject librarian who specializes in transportation⁴⁶, the MAG librarian, the Arizona Department of Transportation (ADOT) librarian, a MAG transportation planner, a Valley Metro representative from the Transportation Policy Committee, several developers who are members of the Arizona Planning Association, and a MAG transportation programming manager. Several planning workshops and networking events were attended, organized by the local chapter of the Arizona Planning Association and the Metrophoenix chapter of the Advancing Women in Transportation (WTS) organization.

3.3 Identify and define the decisionmakers, authority levels, people, institutions (rules, norms, strategies).

The following discussion is focused at the level of the MPO, and federal, state, and local institutions are only included where they are specifically relevant to the MPO levels. Each of the decisionmakers, authority levels, people, and institutions are discussed separately

⁴⁵ Section 3.3 details the significance of these documents and their role in transportation planning.

⁴⁶ The ASU transportation librarian had previously worked for ADOT and had significant historical knowledge of state-wide changes in transportation over many decades, as well as the availability of published documents relevant to transportation planning institutions.

to define the roles, functions, and relationships to other institutions. The order of these subsections is not meant to imply levels of importance or influence.

3.3.1 MAG Transportation Policy Committee. The MAG Transportation Policy Committee (TPC) is a formal institution that serves in an advisory role and is a public-private partnership within MAG comprised of representatives prescribed by state law. The MAG TPC is chaired by the mayor of one of the member municipalities, and must include six members from businesses (of which one must be a transit business, one freight, and one construction). The state government appoints all six business representatives (three from the state Senate, three from the state House). The primary responsibility of the TPC is oversight of both the 20-year RTP and the implementation of Proposition 400 (see section 3.4.3).

3.3.2 MAG Regional Council. The Regional Council holds governing and policymaking authority for MAG. It is a formal institution. Most member agencies' representatives on the Regional Council are the city or town mayors. Other (non-municipal) members serving on the council include county governments (Maricopa and Pinal), the Maricopa County representative from the State Transportation Board (also representing ADOT), the chair of the Citizens Transportation Oversight Committee (CTOC), and the governors or presidents of the Tribal Communities.

3.3.3 MAG Transportation Review Committee (TRC). The MAG member agencies provide representatives from their staffs to serve on the Transportation Review Committee (TRC), which is a formal institution. Monthly public meetings are conducted to update MAG members on the relevant issues in transportation planning, current and prospective political and financial policies, and new or completed transportation planning studies. The TIP is assembled by the TRC, and periodic updates to the TIP are developed

within the TRC and sent to the MAG Regional Council for final approval. The TRC also provides recommendations on RTP updates and monitors the progress of programmed ALCP, and TIP projects.

3.3.4 MAG Regional Transportation Plan (RTP) Partners. The Regional Transportation Plan (RTP) Partners are an ad hoc group with a charter to coordinate the implementation of Proposition 400 (see Section 3.4.3) and transportation projects in the RTP. The agencies partnering in this group are MAG, ADOT, and the Regional Public Transit Authority (RPTA, Valley Metro). The group prepares revenue forecasts, establishes life cycle procedures (related to life cycle programs, not LCA), and both receives inputs from and provides information to the public on issues related to Proposition 400. The RTP Partners maintain a Project Information Database with updated information on the status of projects funded by Proposition 400. They also establish performance measures for evaluating the regional transportation system and individual projects within the system (MAG, 2005). While the members of the RTP Partners are decisionmakers within their own formal institutions, the RTP Partners is considered a strategy because the individuals participate in this entity as a “regularized plan” for following the structure produced by the rules and norms of the action arena (E. Ostrom, 2005).

3.3.5 Citizens Transportation Oversight Committee (CTOC). Arizona statute requires a CTOC to be established in any county with transportation sales taxes (Maricopa County has a transportation sales tax). The committee serves primarily in an advisory and oversight role for transportation issues within MAG, the RPTA, and the State Transportation Board. ADOT provides technical assistance and support to CTOC to ensure adequate coordination with all necessary transportation agencies. Each year, the CTOC is required to contract an audit of spending from the Regional Area Road Fund and

the Public Transportation Fund. Additional performance audits of spending from life cycle programs are also contracted by CTOC. As a representative of citizens' interests, the CTOC acts as a liaison for public concerns on transportation projects and issues, and holds public hearings or publishes reports as appropriate (MAG, 2005). The CTOC can be considered both a norm (for the collective ideas that the committee acts upon in representing public concerns) and a strategy (for the role it plays in performing oversight for established rules and formal institutions).

3.3.6 MAG Technical and Policy Advisory Committees. There are twelve MAG advisory committees, each formal institutions, involved specifically in transportation planning for the MPO (Management, Regional Council Executive, Transportation Policy, Bicycle and Pedestrian, Elderly & Persons with Disabilities, Enhanced Peer Review, Intelligent Transportation Systems, Standard Specifications & Details, Street, Transit, Transportation Review, and Transportation Safety). Two of these committees are discussed above (Transportation Policy Committee and Transportation Review Committee). Official staff from MAG member agencies are acting members of these committees, and public meetings are held regularly (typically monthly) to review issues within the region and to make recommendations for regional policies and plans. The committees regularly seek assistance from Management and Engineering Consultants contracted by ADOT and MAG do perform transportation studies and environmental assessments and construction plans (MAG, 2005).

3.3.7 MAG Framework Studies. MAG periodically commissions broad framework studies to assess regional transportation demand due to increased development and economic growth (MAG, 2013a). The studies are employed as strategies for advancing the long-term planning efforts, but can also be considered scope rules because when they are

accepted they establish a range of possible outcomes for future planning⁴⁷. The framework studies are conducted by contracting professional consulting agencies, holding public workshops, and seeking input and coordination from DOT, ADOT, and MAG member agencies and committees. There have been seven framework studies conducted by MAG:

- Interstate 10/Hassayampa Valley Roadway Framework Study
- Interstates 8 and 10/Hidden Valley Transportation Framework Study
- Regional Transit Framework Study
- Central Phoenix Transportation Framework Study
- Hassayampa Framework Study for the Wickenburg Area
- Freight Transportation Framework Study
- Sustainable Transportation and Land Use Integration Study

Each of these assessments took multiple years to complete. The results of the studies are not requirements, but instead are meant to inform the planning process and ultimately the MAG RTP.

3.3.8 Regional Public Transportation Authority (RPTA)/Valley Metro. The regional transit system in Maricopa County is named Valley Metro, and the RPTA/Valley Metro organization, a formal institution, is a political arm of Arizona State government. The board of RPTA/Valley Metro is comprised of elected officials who are nominated by the agencies (municipalities and county government) who choose to be members (MAG, 2013a). The funds managed by the RPTA are from revenue generated by Proposition 400 (see Section 3.4.3), known as the Public Transportation Fund (PTF). The projects that the RPTA funds must be identified in the RTP, and the reporting must separately account for light rail transit, capital costs for other transit, and operations and maintenance for other

⁴⁷ These studies, in scoping a range of outcomes can simultaneously rule out implausible future conditions and also determine the criteria by which future planning will be assessed or judged. Once MAG accepts the framework study, it is not established as guidance or prescriptive plans but it holds normative weight for future planning efforts as a type of working rule (specifically a scope rule).

transit (MAG, 2013a). Valley Metro Rail, Incorporated is a non-profit public company that manages the light rail system currently operating in Phoenix, Tempe, and Mesa. In 2012 the leadership and staffs of Valley Metro Rail and RPTA/Valley Metro were combined, and both organizations share a single Chief Executive Officer.

3.3.9 Regional Transportation Plan (RTP). The RTP is a multi-modal plan covering 20-25 years of transportation activities in the MPO. The formal document is a strategy for long-term transportation planning. MAG's Transportation Policy Committee (TPC) directs the development of the RTP, and updates to the plan are staffed through MAG member agencies, MAG technical and policy committees, the CTOC, and ADOT (MAG, 2013a). A conformity analysis evaluates the plan against air quality criteria and reports the results to the Environmental Protection Agency. The MAG TPC make a recommendation of the final RTP and the Regional Council holds the authority to adopt the final plan. Because the plan is developed in a MAG committee, cities, towns, the county, and all MAG member agencies are able to consult and coordinate on the plan with each update. This coordination increases efficiency in regional transportation systems, decreases duplicated actions, and avoids unnecessary competition for finite resources. Previous versions of this regional long-range planning document were titled the Long Range Transportation Plan (LRTP), and the statewide plan that details long-range planning is still termed the LRTP.

3.3.10 Transportation Improvement Plan (TIP). The TIP is a five-year capital improvement plan that is coupled with the RTP and details the funded public transportation projects, to include transit and alternative modes of transportation (MAG, 2013d). The document serves as a scope rule, an authority rule, and a payoff rule. Projects are programmed in the TIP and each project is listed with its projected funding sources, revenue

expectations, operations and maintenance needs, and current status (as applicable for updates to ongoing TIP projects). The MAG technical and policy committees make recommendations for infrastructure improvements that might be funded in the TIP. Special studies conducted by MAG member agencies or technical consultants assist in formulating the recommendations for improvements, and the MAG Transportation Policy Committee is responsible for reconciling and/or accepting the recommendations to add projects to the TIP. The MAG Regional Council has final approval authority for the TIP, which is normally updated every two years. After the TIP is approved, MAG committees face difficult decisions when cost overruns occur on existing projects, or funding levels are changed from initial projections. The Congestion Management Program (CMP) is an important tool for quantitative evaluation of TIP projects, and is used to establish the costs and benefits of new projects or to advise committees on the comparative benefits from different projects when funding is constrained.

3.3.11 Freeway Life Cycle Program. The MAG Regional Freeway/Highway Program is managed by ADOT as part of the State Highway System. ADOT plans and manages the Freeway Life Cycle Program, which projects revenues and funding structures for Freeway projects. As managers of the State Highway System, ADOT is also responsible for activities related to freeway/highway design, engineering, right-of-way, construction, and maintenance (MAG, 2005). The program serves as a scope rule, an authority rule, an information rule, and a payoff rule.

3.3.12 Arterial Life Cycle Program (ALCP). The ALCP is the implementation of the RTP for arterial street projects. The program details the funding for specific projects that widen arterial streets, improve intersections, or build new segments of arterial roads (MAG, 2012a). ADOT controls arterial street funding and can issue bonds to MAG for

arterial street projects. Projects programmed in the ALCP are executed by cities, towns, or the county (MAG, 2013a). Projects programmed in the ALCP are planned over a 20-year life cycle (MAG, 2012a), and according to state law they must be fiscally constrained (meaning funding over the 20-year life cycle of each project must be reconciled with revenue projections from each funding source). In addition to regional budgets (the MAG Surface Transportation Program Funds), funding sources for arterial projects can come from the Regional Area Road Fund (RARF, see section 3.4.3) and the Congestion Mitigation and Air Quality funds (CMAQ, see section 3.4.4). The program serves as a scope rule, an authority rule, an information rule, and a payoff rule.

3.3.13 Transit Life Cycle Program (TLCP). The TLCP is a 20-year document (updated annually) that programs infrastructure projects for the regional transit system. The regional transit authority (RPTA-Valley Metro) is designated to manage the TLCP and reports the program to MAG. The program covers fleet replacement, corridor construction, expansion projects, transit centers, operations and maintenance facilities, and other basic transit infrastructure systems (MAG, 2013i). The TLCP excludes operations for the transit system, and does not include bicycle and pedestrian travel systems. The RPTA is not authorized to approve projects that are in conflict with or do not meet the goals of the RTP. Funding for the TLCP comes from the Public Transportation Funds (PTF, see Section 3.4.3). The program serves as a scope rule, an authority rule, an information rule, and a payoff rule.

3.3.14 MAG Member Agency Governments (Cities, Towns, Municipalities, Tribal Governments). Each of the MAG member agencies maintain their independence, and MAG does not have direct authority over the actions of the members. Representatives serving on MAG boards are authorized to speak and vote on behalf of their agency or

government, but are still accountable to the citizens and public demands. Within the transportation planning action arena, MAG member agencies are considered both a formal institution and a norm⁴⁸. Much of the data that are used in MAG regional planning must be generated by the member governments, such as General Plans, socio-economic forecasting, and land use plans (MAG, 2013a). Regular coordination between local staffs and within MAG committees is critical to maintaining consistent planning at the regional level.

3.3.15 Clean Air Act. The Clean Air Act, an information rule and a boundary rule⁴⁹, requires MAG to develop air quality plans for criteria air pollutants whenever a portion of the region fails to attain minimum air quality standards (termed “nonattainment”). MAG specifically conducts air quality planning separate from transportation planning, but both the RTP and the TIP must be evaluated for conformity with air quality standards if the projects or plans are in nonattainment areas (MAG, 2013c). The conformity analysis uses prescribed methodologies to perform a regional emissions analysis for the pollutants in nonattainment (currently carbon monoxide, eight-hour ozone, particulate emissions, and nitrous oxides) (ADOT, 2013; MAG, 2013c).

3.3.16 Management/Engineering Consultants. ADOT, MAG, and sometimes MAG member agencies (municipalities or transit agencies) contract with engineering consultant firms, which are formal institutions and individual people, to conduct studies and perform assessments of transportation projects. Such work includes construction plans, environmental assessments, and project scheduling and monitoring (MAG, 2005). The

⁴⁸ The MAG member agencies themselves are formal institutions (established governments taking actions and legislating decisions). However, for the purposes of the interactions and the transportation planning at the regional level, they are representing public opinions and needs.

⁴⁹ The Clean Air Act serves as a boundary rule by determining the participants (those who do not attain minimum air quality) and an information rule by establishing required reporting and disclosure standards.

results from contracted studies and reports are presented to the technical and policy committees, and are incorporated into plans, policies, and framework studies as the committees recommend or deem appropriate.

3.3.17 State Transportation Board. By statute, the State Transportation Board has authority for the State Highway System. It is a formal institution. Board members appointed by the Governor develop five-year construction plans for highways, and also holds authority to approve the MAG Freeway/Highway Life Cycle Program. The State Transportation Board coordinates with MAG to ensure that projects are not approved that conflict with the MAG RTP and TIP. This coordination aids the MPOs as they assess and report air quality conformity for projects within their region (MAG, 2005).

3.4 Transportation Finance Structure.

Regional transportation finance is heavily dependent on federal and state funding. Arizona transportation budgets are derived from federal and state funds and are supplemented by gas taxes, vehicle license taxes, and transportation-specific regional and local sales taxes (Arizona Town Hall, 2009). Local transportation budgets vary by municipality, but also can be sourced by taxes and fees. Maricopa County was the first county to publish a long-range transportation plan in 1960, before the Arizona Department of Transportation was formally established in 1974 (Chapman & Shultz, 2009). When MAG was established, the long-range transportation plan was integrated with the Arizona State Transportation Improvement Plan (STIP), and a regional TIP detailed funding structures for life cycle transportation programs. Under current transportation regulations, the federal government allocates funds to the state, the state releases both federal and state funds to the MPO, and the MPO manages the distribution of the funds based on the RTP and the TIP.

As of Fiscal Year 2014, 44% of the MAG budget is spent on transportation (see Figure 3.4 from MAG (2013e)). The basic institutions that interact to finance regional transportation in Phoenix are detailed in this section, in no specific order or rank.

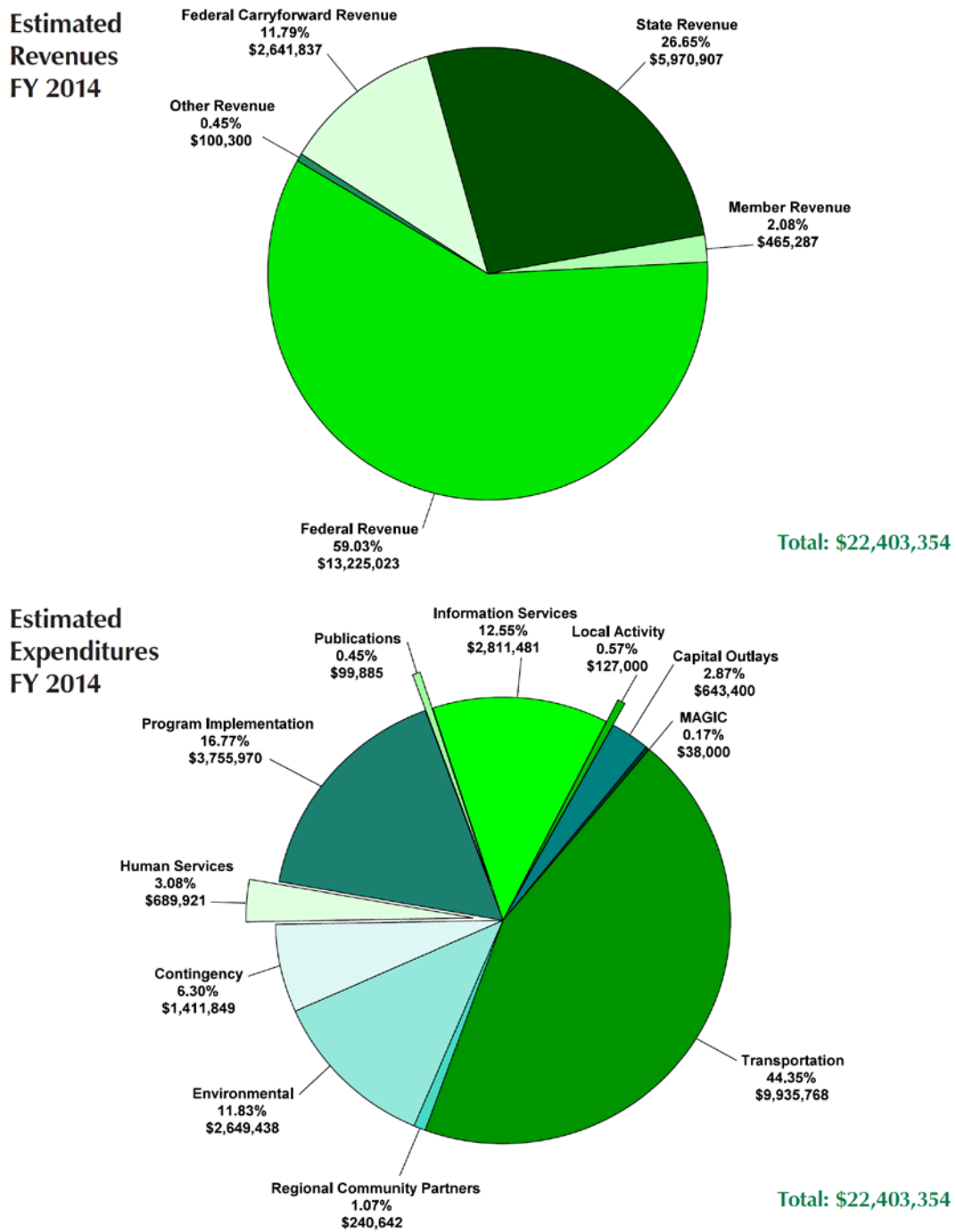


Figure 3.4. MAG Revenues and Expenditures. Fiscal Year (FY) 2014 (MAG, 2013e).

3.4.1 Safe Accountable Flexible Efficient Transportation Equity Act: A

Legacy for Users of 2005 (SAFETEA-LU). SAFETEA-LU superseded the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and the Transportation Equity Act for the 21st Century (TEA-21) and legislated over \$200 billion in federal funding for highway and public transportation projects in the United States (FHWA, 2005). ADOT and MAG are still operating under the legal authority of SAFETEA-LU at the time this research was completed, but are awaiting specific guidance and definitions from a newer federal regulation which was signed into law in 2012, the Moving Ahead for Progress in the 21st Century Act (MAP-21) (MAG, 2013a). SAFETEA-LU authorizes specific spending levels for federal transportation funds, and establishes fund-matching levels, tax and road pricing rates, and other fiscal policies for federal road and transit projects. Federal funds are distributed to state transportation agencies, and for MPOs the states have a contract with each MPO to deposit federal funds in MPO accounts for management. ADOT and MAG each perform annual audits to report that expenditures comply with federal regulations. SAFETEA-LU encompasses all seven types of working rules for the purposes of the institutional analysis.

3.4.2 Highway User Revenue Fund (HURF). The HURF fund is established by Arizona statute and is sourced by vehicle taxes and fuel taxes and fees, including enforcement of traffic laws and the sale of *Arizona Highways* magazine (Rall, Wheet, Farber, & Reed, 2011). The state can, and does, divert some HURF funds to the general fund. HURF is primarily used for state highway projects, to match federal funds for bridges, and cities and towns receive HURF money for street projects and special needs transit projects (Rall et al., 2011). The HURF fund is both an information rule and a payoff rule.

3.4.3 Regional Area Road Fund (RARF) and Proposition 400. The RARF is specific to Maricopa County, first approved by voters in 1985, and is a sales tax termed a

Transportation Excise Tax. The tax is commonly called the “half-cent sales tax” and applies to retail, contracts, utilities, real estate, restaurants and bars, and other business activities (ADOT, 2009). ADOT administers the RARF, which is the main source for freeway funding in MAG. In 2004, one year before the Transportation Excise Tax was set to expire, Maricopa County voters approved Proposition 400 to extend the “half-cent sales tax” through 2025. As of 2006, the Proposition 400 funds are deposited in the RARF for freeways and maintenance (56.2%) and arterial street improvements (10.5%), and in the Public Transportation Fund (PTF) for transit (rail and bus) service (33.3%) (ADOT, 2009). The RARF is a payoff rule, and Proposition 400 can be considered both an authority rule and a payoff rule.

3.4.4 Congestion Mitigation & Air Quality Program (CMAQ). The CMAQ is a federal fund that is obligated to the state for transportation projects that improve air quality in nonattainment areas. The CMAQ is a payoff rule directly associated with the Clean Air Act (see Section 3.3.15). The state of Arizona dedicates all of its CMAQ funds to the MAG region (MAG, 2005), and MAG obligates 100% of the available CMAQ funding (MAG, 2013c). Because the MAG region has several nonattainment designations for particulate pollution, and the dust in open desert areas contributes to particulate pollution naturally, the CMAQ funds can be used for paving and road construction projects to successfully improve air quality. In other geographic locations, paving projects and new road construction might contribute to poor air quality instead of improving it. Projects funded through CMAQ can be used for “credits” to substantiate air quality improvement efforts and eventually get the EPA to redact nonattainment designations in the region. CMAQ is not the sole funding for transportation projects that improve air quality. The funds are often used in conjunction with other state, federal, and local funding as part of the RTP (MAG, 2013c). For example,

CMAQ funds are used for rideshare and trip reduction programs, but those projects are supplemented with state, local, and sometimes private funding.

3.4.5 Federal Transit Fund. MAG receives two types of federal transit funding, Transit (5307) Funds that support bus purchases and transit capital projects and Transit (5309) Funds in the form of discretionary grants from the Federal Transit Administration (MAG, 2005). Transit (5309) grants can be used for “new starts” projects like new Light Rail Transit (LRT) systems. The Valley Metro LRT system (the 20-mile starter segment) has already been obligated with \$587 million in Transit (5309) grants. Bus transit grants must be matched by 20% with local funds, but “new starts” projects must have a 50% local funding match. The Federal Transit Fund is a payoff rule.

3.4.6 City Transportation-Specific Sales Taxes. In addition to the county sales tax approved through 2025 by Proposition 400, several cities in the MAG region have approved citywide sales taxes to fund transportation projects. These taxes can be considered both payoff rules and norms⁵⁰. The Cities of Scottsdale, Tempe, Mesa, Phoenix, Glendale, and Peoria have had these taxes, each in the range of 0.2% to 0.5% (MAG, 2013j). Some of the approved taxes are restricted to specific types of transportation and also have “sunset” dates when they will expire, for example the 0.4% tax in the City of Phoenix is only used for transit services and has a “sunset” date of 2020 (MAG, 2013j). Other cities do not restrict the special tax to just transportation, such as the City of Mesa with a 0.5% tax that expired in 2008 and was used for parks & recreation, police & fire, and transit (MAG, 2013j). This research is meant to provide insights at a regional level, and does not focus on local

⁵⁰ Taxes are payoff rules because they establish the benefits and costs of different programs (and in some cases establish incentives or disincentives). They can also be considered norms because their existence indicates the priorities and types of services that the public prioritizes in each city. The lack of a transportation-specific tax in one city is an indicator of a norm for that city as well.

transportation planning, but it is important to recognize that the local agencies participating in regional planning are not homogeneous entities and manage individual transportation systems that are part of the larger regional system.

3.5 Transportation Political Structure.

The institutions discussed in Sections 3.3 and 3.4 are subject to political pressure that influences transportation planning actions. According to Wachs (1995), nearly all transportation decisions are influenced by politics. The following subsections discuss how the institutions are subject to politics as well as the tensions and disconnects⁵¹ between different institutions.

3.5.1 DOT Officials. The US DOT is a government agency, and its employees are federal workers who are not elected into their position. DOT officials are formal institutions (people) and their collective actions can be considered norms for transportation planning systems. The leadership of the DOT is headed by the Secretary of Transportation, who is nominated by the US President and confirmed by Congress. In 2009, the White House issued guidance on an Open Government Directive requiring all government agencies to develop plans to improve transparency, participation, and collaboration. The DOT's most recent plan to comply with the directive was published in 2012, titled "DOT Open Government Plan v2.0" (DOT, 2012). The program initiatives encourage public participation in rulemaking, increase data releases and public access to data inventories, allow public comment and discussion on the DOT Strategic Plan, build a platform for employees to share best practices and learn from other departments, and fostering culture change to

⁵¹ A disconnect is a phenomenon that prevents the system from operating more efficiently as a whole. Examples of disconnects in a system of social institutions might be lack of interaction, misalignment of priorities, mismatched timelines, competing responsibilities, or incompatible budget processes.

ensure the DOT continues to meet Open Government objectives. Because the Open Government Directive is rather new, and the general public may not be fully aware of their ability to and the importance of interaction with the DOT, there is not any solid evidence that transportation policies or programs have changed for better or worse. The Transportation Secretary does still answer to the Executive Branch, and politics potentially influence federal transportation planning as well as federal support to state and local transportation agencies.

3.5.2 ADOT Officials. The director of ADOT is appointed by and reports directly to the Governor of the State of Arizona. The State Transportation Board (see Section 3.3.17) is also appointed by the Governor, and the board advises the ADOT director. ADOT officials are state government employees, and are not elected into their positions. They are considered formal institutions (people within a formal organization), and their collective actions can also be considered norms for transportation planning. The ADOT Government Relations division manages a process to communicate with the state legislature and by which state citizens can communicate with ADOT. Statutes, codes, and policies that govern ADOT activities are monitored and available to the public through the Government Relations division. In the same way that DOT officials are indirectly influenced by politics, ADOT officials work directly for the state government and only indirectly represent the voting public.

3.5.3 MAG Officials. MAG officials, like both DOT and ADOT officials, are both formal institutions (people in an organization) and norms for transportation planning systems. The current Chair of MAG is Mayor Scott Smith from the City of Mesa. Membership in the MAG Council of Governments is voluntary by a resolution, and members pay dues to the MAG general fund. There are currently 34 member agencies. The

representatives who serve as key officials on MAG committees are decided by the member agencies (except the Transportation Policy Committee, see Section 3.3.1, where membership is prescribed), but are usually high level staff members. Key officials from MAG regularly interact with higher levels of government, such as the state legislature, usually to provide technical information, updates, or testimony. MAG registers each of its key officials as lobbyists because some interactions with state and federal agencies might be considered lobbying activity (MAG, 2012c). The MAG representatives who are elected officials not only respond to the pressures and expectations of peer member agencies but also are accountable to constituents of their own city or town for their actions within MAG.

Other officials within MAG that are subject to political pressure in their actions are the advisory committees (see Section 3.3.6), the Regional Council (see Section 3.3.2), and the TRC (see Section 3.3.3). Because the citizens of each city or town voted the representatives into their political position, it is likely that the collective planning decisions made by divisions of MAG are aligned with voter opinions. In 2004, MAG was recognized for leadership in planning for the RTP and Arizona voters approved an extension of the half-cent sales tax (Proposition 400, see Section 3.4.3) by a margin of 57% to 43% (MAG, 2012c). During this research the author attended eighteen months of regularly scheduled transportation committee meetings and public outreach events and has witnessed less than ten citizens taking advantage of public comment during these sessions⁵².

⁵² The comments were all of a pleading nature, asking MAG to please consider a particular issue when future plans are finalized. There were only three issues voiced by the public: a desire to place a particular section of new freeway in a different location than where the TIP dictated, a plea not to enact fees for high-occupancy lanes (termed High Occupancy/Toll, or HOT lanes) because it would be a tax and it would break the middle class, and several variations of requests to ensure that public transit services are accessible to and safe for disabled citizens across the region.

3.5.4 CTOC members. The CTOC (see Section 3.3.5) is legally independent from ADOT, but is advised by ADOT officials on technical matters where necessary. The Governor of Arizona appoints two members of the CTOC, the Chairperson and one Member at Large. The other five members, one for each County supervisory district, are appointed by the Maricopa County Board of Supervisors, and must have transportation experience (MAG, 2012c). The CTOC members are not paid for their services, and are not considered employees of the State of Arizona or any county, city, or town. The members of CTOC each serve three-year terms. The main purpose of the CTOC is to provide independent oversight of regional planning in Maricopa County. This committee is integrated into MAG procedures and has direct interaction with MAG officials as they develop and execute transportation planning and policy. Because the Chairperson is appointed by the Arizona Governor there may be some political pressure on issues trending in state government, but after initial appointment to the CTOC the members do not answer to government officials and their term on the committee is not changed by elections.

3.5.5 RTP Partners. While the RTP Partners are an ad hoc group without any direct responsibility to one agency, the work that they accomplish to coordinate the implementation of Proposition 400 is in the best interest of all the agency partners. The information provided to the public on projects funded by Proposition 400 is a means of increasing public awareness on transportation issues and educating voters on the results of the legislation. In developing performance measures for the projects, the RTP Partners can influence the way that transportation systems are perceived by the public and in the long term whether or not the half-cent sales tax is renewed in 2025. ADOT officials have reported to MAG on new revenue sources in the future, some of which involve new or

increased taxes (MAG, 2012b), and the actions of the RTP Partners will likely influence any future proposals to change transportation revenue structures.

3.5.6 MAG Framework Studies. Framework studies are analysis and feasibility investigations conducted to look beyond the RTP in anticipation of future growth and future travel demand (see Section 3.3.7). The studies are commissioned by MAG, but are a combined effort between MAG agencies, contracted consultants, and public outreach. The studies have no legal authority and are not directive. The conclusions and recommendations from the studies, however, do provide information for future planning and decision-making in MAG and therefore represent some political influence. Citizens who participate in public outreach during the studies (by completing surveys, attending workshops, and providing feedback or comments) have a large stake in determining the alternatives explored in framework studies and may even define the assessment criteria for the project. The most recent framework study, the Sustainable Transportation and Land Use Integration Study (ST-LUIS) used public workshops to define sustainable transportation for the region, and also to gauge support for alternative transportation options in different urban settings (MAG, 2011). The resulting product of the ST-LUIS framework study is an interactive toolkit that MAG cities and towns can use to improve both transportation and land use planning for more sustainable practices. When the study was presented for approval in the MAG Transit Committee, voting members were cautious about the vote and asked for more time to fully understand the implications and recommendations of the study before approval (MAG, 2013f). The approval of the study is not a vote to accept, or even to follow, the recommendations in the framework study but instead is simply acknowledging that the work was completed and allowing it to be published by MAG. Committee members who were

cautious about voting to accept the study, and this event was not unique to just the transit committee, demonstrated the political and policy influence that framework studies represent.

3.5.7 RPTA/Valley Metro Officials. Because RPTA/Valley Metro is a political arm of the Arizona State Government (see Section 3.3.8), its board members are directly influenced by the member agencies who nominate them. There are other political pressures that come from within the corporation, and the CEO is responsible to the board for the economic success or failure of transit operations. The contracted service providers also hold political power, and periodic strikes influence operations and employment policies. Public demand places some pressure on the organization, as people “vote with their feet” and ridership and ticket sales demonstrate where transit is successful and which modes are desirable. Exploratory studies conducted by RPTA staffs can also have a reverse effect and influence public opinion for transportation policies⁵³.

3.5.8 Environmental Protection Agency. The Environmental Protection Agency (EPA), a formal institution, regulates the provisions of the Clean Air Act (CAA) (see Section 3.3.15) and the Clean Water Act (CWA). State governments, state departments of transportation, and other businesses and organizations have filed suit against the EPA to challenge the authority and sometimes the way the EPA defines its own authority under the acts. The current requirements for transportation planning under the CAA dictate conformity analysis for transportation plans when regions are in nonattainment status for specific air pollutants. Recent litigation (*Massachusetts v. EPA*, 549 U.S. 497) alleged that

⁵³ In conducting a transit study for outlying cities, citizen inquiries regularly ask why Valley Metro is not providing enough service in their town, and why things like light rail cannot extend to their city. An anecdotal story from the authors of the Northwest Valley Local Transit System Study recounted that in Town Hall meetings and during community outreach events, Valley Metro staff often remind citizens that the cities who have taxes to fund transit tend to get better service because they are helping to fund it. This information could influence newly-informed citizens to advocate for transit taxes in the future.

the EPA should also be regulating carbon dioxide as a greenhouse gas pollutant. The suit was originally filed by twelve states and many cities, and the case went to the Supreme Court where it was determined that carbon dioxide is a pollutant that is dangerous to human health and can be regulated by the EPA under the CAA. Other variations of the same issue are still in review by circuit courts and the Supreme Court at the time of this research. The interpretation of the CAA is a divisive political issue, and the outcomes from those debates (and litigation) may determine more rigorous environmental compliance for transportation systems in the future. If carbon dioxide is finally regulated by the EPA, urban regions may be designated as carbon dioxide nonattainment areas and subsequently be required to complete conformity analysis of transportation systems that will significantly target emissions from modes of travel favoring the internal combustion engine.

3.5.9 Planning and Engineering Consultants. Consultants who provide assistance on transportation planning projects (see Section 3.3.16) only answer to their own employers and the agencies contracting the work. The funding structure and regulatory requirements for transportation projects to be approved become motivators to shape the results of consulting work. Wachs (1995) describes interviewing transportation engineers who revised travel forecasts for transit projects at the request of their superiors. Obviously a new project will not be funded if it is not economically viable (whether it be revenue predictions or ridership estimates) or does not successfully meet travel demand (such as models for congestion mitigation projects). There are natural tensions between professional consultants and the firms that employ them as well as between the firms/consultants and the agency using the results for transportation plans. Cost overruns and inaccurate travel forecasts are rarely analyzed for the political pressures that influenced modeling assumptions or methodological choices of the consulting agencies (Cantarelli, Flyvbjerg, Molin, & van

Wee, 2010; Wachs, 1995). But, “good” work and favorable results are rewarded with more consulting contracts and recognition from transportation planning agencies.

3.5.10 State Transportation Board. The State Transportation Board is appointed by the Governor of Arizona (see Section 3.3.17), and is responsible for construction plans for highway projects. New highways are not constructed very often, but Arizona has some of the youngest sections of interstate highway in the country. Highway expansion projects such as adding lanes or altering traffic flows are still necessary as travel demand increases. The State Transportation Board works with MAG to ensure that projects align with the RTP and conform with air quality standards, but the ultimate decisions on highway construction do impact arterial road projects, local traffic flows, and even land values. Because members of the board serve on the MAG Regional Council (see Section 3.3.2), the interaction with MAG officials from cities and towns raises the awareness of any local and regional issues related to highway construction and maintenance projects. For example, a city mayor may advocate for more lanes on an interstate where a junction with an arterial road is causing congestion on local streets and in residential neighborhoods.

3.5.11 Transportation Funding. The laws directing transportation funding also dictate how the funds must be managed and controlled. By law (see Section 3.4.1) metropolitan areas larger than 50,000 people must conduct regional transportation planning in an MPO, but the organization and management of the MPO is not directed. States, regional, and local governments make policy decisions or establish statutes that determine the structure and specific responsibilities of the MPO. MAG officials (see Section 3.5.3) manage transportation planning according to the policies mandated in transportation regulations, and the funding structures can sometimes affect political interactions between member agencies and communities. For example, MAP-21 consolidated several bicycle and

pedestrian funding structures into one program that gives more flexibility to states in deciding how to appropriate money for projects. Under SAFETEA-LU the programs were Transportation Enhancements, Recreational Trails, and Safe Routes to School. These are now combined into a Transportation Alternatives program that gives half of the funding directly to MPOs and the other half to states to spend in areas within the state. The consolidation of funding structure under MAP-21 will save the federal government a significant amount of money, but there is no guarantee that bicycle and pedestrian programs at the local level will maintain the same level of funding as under SAFETEA-LU. Additionally, different levels of authority are involved in decisionmaking because of the new funding structure.

Fund-matching schemes also influence transportation planning. Different modes of travel receive different levels and types of fund-matching, and this can incentivize specific modes of transportation over others. Bus projects are matched higher than “new start” transit projects like rail transit (see Section 3.4.5) which likely makes it easier for the region to afford bus expansion than a new rail transit system that has higher capital costs to begin with. Revenue sources also influence transportation planning, for example cities or counties might have a tax that establishes a fund for one specific mode of transportation and as a result it is easier to program projects for that travel mode.

Land use policies also have political ramifications in local transportation planning. When developers build new housing or retail centers they are required to fund construction of all infrastructure systems (designed and built according to city codes and standards), and then relinquish the operation and maintenance of that infrastructure to the city or town. The land use planners approve the development plans in the first place, but the legacy of indefinite operation and maintenance costs fall completely on the local and regional

government. Land use planners do not operate independently of transportation planners, but the two professions are typically disconnected (Bartholomew, 2007; Cervero, Ferrell, & Murphy, 2002; TRB, 2009) and public demand for new and sprawling housing developments is rarely cognitively linked with an understanding of the budgetary impacts to city transportation systems.

3.5.12 Individual City and Town Opinions on Travel modes. Several of the aforementioned political institutions influence the opinions, desires, and needs of local communities. If a city has efficient transportation systems already, then they are not likely to have strong political or community involvement in new or alternative transportation projects. Such cities might have a secondary influence on the opinions of other cities. For example, the success of the LRT system in the Cities of Phoenix, Tempe, and Mesa have motivated other cities to lobby for the expansion of the system into their area. This phenomenon is not universally true, though, as transit corridor studies highlight strong potential for success of LRT expansion into the City of Scottsdale but Scottsdale voters and leadership do not want high-capacity transit. A recently-completed park-n-ride facility along this same corridor was funded with economic stimulus money, but so far has not been paired with plans for expansion of transit services in the City of Scottsdale. The opposite situation is true of political will and modes of transportation modes. If a city has a particularly serious problem with either environmental quality, congestion, or safety from automobile travel, then projects like trip reduction programs or bicycle and pedestrian programs are more likely to have political support and receive attention from elected officials as they conduct transportation planning and policymaking.

3.6 Goals, Regulations, and Targets for Sustainable Transportation.

Sustainable transportation as a general concept has many connotations (see Chapter 1) and institutional objectives or priorities for “more sustainable” transportation systems vary greatly at all organizational levels (Banister, 2008; Black, 2005). A review of the institutions in Phoenix passenger transportation systems identifies the institutions that have established goals, regulations, or targets related to sustainable transportation. Federal regulations for (and definition of) sustainable transportation have yet to be established, and the ST-LUIS framework study (see Section 3.5.6) is the only document that directly defines sustainable transportation for the region.

3.6.1 DOT. The DOT and the FHWA have not published specific goals and regulations that are required by states or MPOs, but there is a Sustainable Highways Initiative that convenes working groups to aid state and local officials as they incorporate sustainability in transportation planning (FHWA, 2013). The goals and definitions of sustainable transportation are open to interpretation. The FHWA does not specifically define a sustainable highway, but rather a sustainable approach to highways that helps “decision makers make balanced choices among environmental, economic, and social values” (FHWA, 2013). The initiative specifies that “A sustainable approach looks at access (not just mobility), movement of people and goods (not just vehicles), and provisions of transportation choices, such as safe and comfortable routes for walking, bicycling, and transit” (FHWA, 2013). The only reference document that is directive is an Executive Order, signed in November 2013, requiring government agencies to report their progress on plans to adapt to climate change through an annual Strategic Sustainability Performance Plan process, established under Executive Order 13514 in 2009. Other research reports and

performance assessments provide recommendations and best practices, but state, MPO, and local planners are given wide flexibility to define sustainable transportation for themselves.

3.6.2 SAFETEA-LU and MAP-21. Regulations require an environmental review process (not a sustainability assessment) for transportation planning, and provide guidance that transportation plans must incorporate environmental stewardship. SAFETEA-LU (and now MAP-21) does not specifically expand environmental requirements to sustainability requirements, although MAP-21 identified “environmental sustainability” as a “thematic area” which will eventually be assigned performance measures decided by the Secretary of Transportation (MAG, 2013a). The FHWA, in addition to its Sustainable Highways Initiative (see Section 3.6.1) published a guidebook for transportation planning and sustainability (FHWA, 2011). The guidebook defines sustainable transportation as “transportation that promotes sustainable development” and sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (FHWA, 2011).

3.6.3 RTP. The MAG RTP contains the word sustainable or sustainability 21 times, in nine sections. MAG chose to expand the definition of federally-required environmental planning factors (MPO responsibilities) to include “making transportation decisions that are compatible with... sustainable preservation of key regional ecosystems, and desired lifestyles” (MAG, 2013a). “Sustaining the Environment” is one of four goals outlined by the RTP, with supporting objectives to “reduce noise, visual, and traffic impacts,” “advance efficient trip-making patterns in the region,” and transportation decisions “compatible with air quality conformity and water quality standards, the sustainable preservation of key regional ecosystems and desired lifestyles” (MAG, 2013a). The level of integration of sustainability is new to the RTP, and significant planning efforts were conducted throughout

2012 to focus the RTP update on sustainable transportation and land use integration, complete streets, and bicycle/pedestrian planning (MAG, 2013b). The RTP pulls content on sustainability concepts from the ST-LUIS framework study (see Section 3.3.7 and 3.6.4), and acknowledges the potential benefits from increased transit/bike/walk travel in the region. The RTP defines sustainable communities as a component of successful land use planning for natural and historic resource conservation.

Recent legislation proposed setting targets for greenhouse gas emissions reductions for public utilities and outlined new requirements for MPOs to reduce emissions from the transportation sector. The Clean Energy Jobs and American Power Act (S. 1733) and the American Clean Energy and Security Act of 2009 (H.R. 2454) suggested reducing greenhouse gas emissions from major sources by 80% by 2050 (MAG, 2013a). Within these two pieces of legislation, MPOs would be required to develop targets and strategies in order to meet the emissions goals, and demonstrate progress towards meeting national goals (MAG, 2013a). The legislation did not become law⁵⁴, but still provides indicators to MPOs of what may be required in the future.

3.6.4 ST-LUIS Framework Study. From 2010 through 2013, the ST-LUIS framework study (see Section 3.3.7) coordinated stakeholder engagement, consulting engineer studies, and planning synthesis to assess the potential for combined transportation and land use planning in the MPO. The study spent significant time with stakeholders in workshops to define sustainable transportation for the region. The resulting definition,

⁵⁴ H.R. 2454, known as the Waxman-Markey bill, passed the House but not the Senate. S. 1733, known as the Kerry-Boxer bill, was introduced in the Senate, but did not pass. Both pieces of legislation are still referenced in the MAG RTP drafted in 2013.

acknowledged as a “working definition” because it is subject to community values and can change over time, is

A transportation system that provides a variety of options, offers attractive facilities for people who walk or bike, and locates high capacity transit in places that will be chosen by households and businesses seeking excellent access to local and regional destinations as well as to walkable communities.

In planning, funding and operating this system, priority will be placed on initiatives that promote:

- Land use and community design measures to increase walkability and bicycle use throughout the region and transit productivity in high capacity transit corridors,
- Equitable access to services and to destinations,
- Safety for all users,
- Energy Efficiency (MAG, 2011)

The product of the ST-LUIS framework study is an interactive toolkit that can be used by local planners to guide future transportation and land use planning. The study emphasizes that there is no “one size fits all” approach to planning, and therefore does not direct specific quantitative performance measures for sustainable transportation.

CHAPTER 4

ADVANCING LCA RESULTS BY INCORPORATING THE IAD FRAMEWORK

LCA results are rarely joined with analyses of the social systems that control or influence decisionmaking and policies, and this disconnect means that LCA conclusions often lack information about who or what controls different parts of the system, where and when the processes' environmental decisionmaking happens, and what aspects of the system (i.e. a policy or regulatory requirement) should change to enable lower environmental impact futures. The methods are described for the LCA in Chapter 2 and the institutional analysis in Chapter 3. The combination of the two frameworks (institutional analysis and LCA) into an IA-LCA advances sustainability research by identifying and assessing the barriers to sustainability transitions and bridging the gaps between environmental practitioners, transportation planning stakeholders, and institutional decisionmakers.

4.1 Why LCA and Institutional Analysis are not Exclusively Adequate for Complex Social Systems.

Formal LCA research is conducted according to International Organization for Standardization (ISO) standards (ISO, 2006a, 2006b), but the results may not be useful to decisionmakers who are left with insights that are too broad-reaching and are not tailored to the levels of control held by those decisionmakers (Baumann & Tillman, 2004; Haes, Heijungs, Suh, & Huppes, 2004; Jeswani, Azapagic, Schepelmann, & Ritthoff, 2010). Complex social systems, such as those experiencing sustainability problems, are overcome by competing priorities and demands, at different levels and timeframes, with solution sets that are disconnected from the stakeholders and decisionmakers capable of affecting change (Lang et al., 2012). Social sciences research, such as institutional analysis, provides critical insights of the action arena where the problems are experienced (and ultimately where they

will be solved). However, institutional analysis alone does not provide answers to problems (E. Ostrom, 2005). Environmental assessment, such as LCA modeling, provides critical knowledge of the comprehensive outcomes from actions that are taken within the action arena. The aim of sustainability science is to forge the links between the knowledge and the actions through interdisciplinary research (Kates et al., 2001; Wiek, Farioli, Fukushi, & Yarime, 2012).

The IA-LCA overlay gives context to the LCA results, reveals the scope of authority at a specific level in a complex system, identifies causal links for benefits and costs, and reveals systems or processes (“externalities”) that cannot be addressed by or are outside the control of the social system even though they are included in the LCA system boundary. The quantitative outcomes of the LCA are not predictors of the institutional changes, but rather the combined IA-LCA helps identify *which* institutions must take *what* actions (or make changes) and *when* if the trajectory outcomes are possible in the future.

4.2 Linking the IAD Framework and the LCA Model.

Using a sustainability lens to view the research problem requires an interdisciplinary approach that combines social systems thinking (the institutional analysis framework) and LCA thinking (the empirical LCA model) to form strategies that are place-based and solutions-oriented (Wiek, Ness, Schweizer-Ries, Brand, & Farioli, 2012). The intervention points for sustainability transition strategies are revealed by combining the insights from both frameworks and determining where and when the institutions have any control to affect change in the drivers of the LCA processes. Just as the institutional analysis must include some institutions at levels above and below the action arena (e.g. state, federal, and local institutions) to be comprehensive, the LCA model includes processes that are

“upstream” from but compulsory to the transportation activities (e.g. automobile manufacturing, mining aggregate for road construction). Not every LCA process is an opportunity for a sustainability transition that is available to the regional transportation system as an action arena, and not every action taken within transportation planning will definitely cause a change in the results of the LCA model. However, the intersection of the two frameworks is the contribution that advances existing LCA research and complements the social analysis to allow conclusions to be made regarding future sustainability solutions.

Achieving organizational change that will enable Phoenix transportation systems to transition to a more sustainable state will require sustainability transition strategies at key intervention points. The quantitative assessment detailed in Chapter 2 modeled the life cycle energy and environmental effects for four different trajectories through the year 2050. Each one of these trajectories is detailed below with the institutional factors (analyzed in Chapter 3) that would need to be changed, the intervention point where the change would be made, and the timeframe necessary for the benefits modeled in that trajectory. Table 4.1 synthesizes the discussion and associates the transition strategies with the life cycle processes (analyzed in the LCA in Chapter 2) that would directly and indirectly yield quantitative benefits. Appendix A is an expanded version of this synthesis table.

4.2.1 Business as Usual (BAU) Trajectory. The BAU trajectory assumes that transportation planning in the MAG region will continue as described in Section 3.2. The new initiatives for sustainable transportation (such as new performance measures that might be required when MAP-21 is fully implemented) are not modeled in this trajectory. Because this is the “base case” for comparison to other trajectories, there are no specific transition strategies or intervention points associated with BAU. In each of the trajectories, it is assumed that population growth occurs uniformly, as forecasted by MAG planners.

Additionally, it assumes that MAG members do not integrate the planning considerations or the tools provided in the ST-LUIS framework study (see Section 3.6.4).

The BAU trajectory may not be a realistic outcome when considered in context with societal changes and growth trends experienced by other (older, more developed) metropolitan areas. “Peak travel” or “peak cars” has been theorized in statistical studies of metropolitan areas within the last decade (Dutzik & Baxandall, 2013; Goodwin & Van Dender, 2013; Millard-Ball & Schipper, 2011; Newman & Kenworthy, 2011), but each geographic location has different infrastructure, cultures, economic systems, and demographics. Will Phoenix inevitably be “another L.A.” as discussed in Gober (2005) and Ross (2011)? If Phoenix does grow in the same way as other cities with aging infrastructure and constricted land resources, then the BAU trajectory modeled here may not be valid in 2050. If fuel prices continue to rise then the impacts on cost of living expenses may discourage growth in Phoenix⁵⁵. Automobile traffic congestion has been steadily increasing (TTI, 2012), and the amount of vehicle travel modeled in the BAU trajectory might exacerbate congestion at some point to impair further unconstrained travel growth. Furthermore, emerging travel behavior research suggests that next-generation adults (so-called millennials) do not want to be tied down by grooming front lawns and driving long commutes, and increasingly shun the idea of even obtaining a license to drive (Dutzik & Baxandall, 2013). Despite the reputation as a city full of retired senior citizens, the projected

⁵⁵ Arizona prices for gasoline have risen at a sharper rate than retail electricity prices since 1970, according to the Energy Information Administration’s State Energy Data (EIA, 2013b). The same statistics for nationwide energy prices show that the rate of change in gasoline prices is much closer to the rate of change in electricity prices. With increased vehicle travel in a BAU trajectory, higher gasoline prices would have a significant impact on household budgets in Phoenix.

demographic growth of Phoenix will largely comprised of working-age adults and their families (MAG, 2003).

4.2.2 Plateau Trajectory. This trajectory assumes that the BAU growth and travel trends, as modeled by MAG, will occur through the year 2031, and then new growth after 2031 will be accommodated by infilling urban core areas with transit-oriented development (TOD). This implies that significant changes in transportation and land use will emerge, likely facilitated by evolving political and ideological norms at all levels (federal, state, local, corporate, citizens, etc.). The “TOD growth” that occurs after 2031 will only be possible if a conjunction of intervention strategies are successful over the next decade or more.

The federal legislation that governs compliance of transportation systems and planning under the Clean Air Act (see Section 3.3.15) would need to require more comprehensive reporting of emissions, to include mobile sources of carbon dioxide. CMAQ funds (see Section 3.4.4) could be evaluated for obligation using LCA performance measures. If the EPA begins to regulate carbon dioxide (and mobile sources are included in compliance requirements), then areas within MAG would likely be identified as “carbon nonattainment” areas and would require conformity analysis of long-range transportation plans. Projects funded through CMAQ that reduce low-density fringe growth could be used for “credits” to demonstrate air quality improvements in the region (in the same way that “credits” are possible for similar infrastructure projects that can demonstrate an air quality improvement). Each of these regulatory requirements would have to change before the next update of the RTP (nearly immediately) so that long-range planning could be evaluated for its comprehensive emissions impacts. These changes will likely require significant education campaigns (workshops, information packets, training materials) to inform MAG members, city planners, and others who manage CAA or CMAQ requirements.

New expertise is necessary for transportation planning to be evaluated by the quantitative sustainability performance measures proposed here. LCA practitioners must be included with management and engineering consultants (see Section 3.3.16) and be fully integrated into MAG studies and planning efforts. Consulting firms would need to seek out such expertise, and MAG would likely have to craft contracts to specify that LCA expertise is necessary for specific studies or grants. The RTP partners (see Section 3.3.4) might be the right group to assume new responsibilities to oversee the implementation of environmental performance measures under MAP-21. The RTP partners might also be an appropriate agency to partner with higher levels of government to help define the new MAP-21 sustainability performance measures (see Section 3.6.2) and the targets to meet new “clean energy” legislation (see Section 3.6.3). The CTOC (see Section 3.5.4) would need to be educated on the concepts of new performance measures, and perhaps LCA as a methodology, in order to provide useful oversight in new planning efforts. For consulting professionals, the RTP partners, and the CTOC, transitions must take place immediately to ensure that the next update of the long-range plans will include sustainable transportation.

Transportation finance structures would need to transition to enable new investment in sustainable systems by 2031 (and also to discourage investment in unsustainable systems). Under the new MAP-21 (see Section 3.4.1), fund-matching levels could incentivize densification and the innovative use of existing infrastructure. This implies a fundamental shift in thinking on how federal budgets are decided. MPOs who meet travel demand using existing infrastructure could be funded for improvement projects at higher levels than MPOs who plan to build more of the same (unsustainable) infrastructure. The Plateau trajectory requires that densification (TOD) projects be incentivized and ready to accommodate all new development by 2031. The federal government could also require MPOs to integrate

LCA into planning procedures as a performance measure for sustainable transportation. In order to maintain the system as-is in Phoenix, the HURF, RARF, Proposition 400, and Federal Transit funds (see Sections 3.4.3, 3.4.3, and 3.4.5) would need to remain at current levels (i.e. not be reduced or removed) through 2050.

Revenue sources would need to be created or expanded to subsidize sustainable transportation projects⁵⁶. City or town transportation-specific taxes (see Section 3.4.6) must be supported by voters to make it affordable to bring adequate and connected public transit access to all MAG municipalities. A creative approach might be successful in quelling low-density growth, such as a “TOD tax” to fund development initiative programs in urban areas. This would have to be passed by voters at the state or county level, similar to Proposition 400 (see Section 3.4.3). The benefits would be attracting economic growth to the city center, making more efficient use of existing infrastructure, and reducing the overhead, capital and maintenance costs that would result from new low-density “fringe” growth. These revenue changes would ideally begin immediately in order for the Plateau trajectory to alter the BAU path after 2031.

Political and ideological norms must begin to change immediately to alter long-range transportation planning by the year 2031. DOT officials (see Section 3.5.1) could recognize TOD projects as good and valid transportation planning. This will not happen magically, and will involve voters and citizens who are vocal about their desires for TOD (or similar transit-connected, walkable neighborhoods). MPOs will need to advocate for the benefits of

⁵⁶ The general assumption is that sustainable transportation projects are more expensive, but this is not necessarily true. There are many sustainable transportation projects that are less expensive than status-quo automobile-oriented projects. However, the existing revenue structure is tuned for status-quo infrastructure. Therefore, even if a new sustainable transportation project is equal or lower in cost, a new revenue structure would have to be established to fund any alternatives to status quo transportation infrastructure.

TOD, and state and federal institutions must be partners in recognizing land use alternatives. The cultural changes are necessary within DOT leadership, amongst DOT employees, and for the local communities whose citizens should engage DOT to express how the organization can best serve local interests. The same attitude shifts are necessary at ADOT (see Section 3.5.2), MAG (see Section 3.5.3), and amongst the RTP partners (see Section 3.5.5). Within MAG, citizens must engage officials and take advantage of public comment periods to demonstrate to the decisionmakers that the current long-range transportation plans could be improved for sustainable transportation. There is some evidence that attitudes towards sustainable transportation are changing, but not at all scales of transportation planning for the region⁵⁷. Future MAG framework studies, and city urban planning projects should embrace the public involvement model being implemented in the Reinvent Phoenix project (City of Phoenix, 2013) as a means of building public support for sustainable transportation projects.

Changes to formal institutions within MAG must be transitioned to facilitate the integration of sustainable transportation concepts. The MAG TPC could include an additional business representative who specializes in TOD development or smart growth. Currently the TPC (see Section 3.3.1) only includes business representatives from transit, freight, and construction. This representation potentially skews the discussions and inputs towards new transportation infrastructure and expanded land development in the long-term. Including a business representative who specializes in mixed-use development or smart

⁵⁷ The ST-LUIS study describes general public support (see Section 3.6.4), the recent draft of the RTP now includes broad discussion of long-term sustainable transportation goals (see Section 3.6.3), and MAG representatives (specifically from the Cities of Phoenix, Mesa, and Tempe) regularly extoll the virtues of light rail transit and TOD growth in their cities while participating in MAG committee meetings. The author attended eighteen months of regularly-scheduled transportation committee meetings and public outreach events during the course of this research, and MAG member agency comments on public transit and TOD are documented in the minutes from those meetings.

growth would balance the influence of the freight and construction industry and integrate sustainability concepts into TPC discussions. The State Congress would have to decide on the new representatives, and MAG organizational structures would need to be agreed on by the member agencies. Alternatively, the “construction” representative might be required to have prior experience from smart growth projects and/or sustainable land use planning⁵⁸.

The MAG Regional Council (see Section 3.3.2) and the Transportation Review Committee (see Section 3.3.3), together with the State Transportation Board (see Section 3.3.17), would need to approve new funding structures that disincentivize low-density fringe growth. A potential version of such a disincentive policy might be a penalty/reward system to make transit projects easier for existing low-density cities if they accommodate new growth through densification and avoid constructing new infrastructure systems. MAG members (cities, towns, and municipalities) would need to agree on any funding structure changes, unless they were dictated at the federal level (for example if MAP-21 established incentive-based funding systems for smart growth in MPOs). The state legislature and voters would likely need to pass a statute to establish any sort of separate “sustainable growth fund” in the same way that Proposition 400 was established (see Section 3.4.3). The public involvement described in the MAG ST-LUIS framework study (see Section 3.6.4) indicates that there may be strong public support for smart growth legislation (MAG, 2011), but there may be mixed sentiments in statewide voter populations.

⁵⁸ Anecdotal information from developers in the region suggests that infill and densification projects can be successful despite zoning restrictions and unfavorable land use policies, particularly when the developers understand that the “rules” are not always rules. For example, maximum residential densities and restrictions on mixed use development can be waived if communities express a desire for the development and the city approves exceptions.

Planning and guidance documents produced by MAG should also be updated to facilitate planning for sustainable transportation. MAG framework studies (see Section 3.3.7) could explore the methodology tested in this research to expand on the ST-LUIS framework study and support the conclusions with quantitative benefits and costs. The ST-LUIS study should be considered a sustainability transition that is already partially successful, as the results from the study are already mentioned heavily in the draft 2035 RTP (MAG, 2013a). If the Plateau trajectory is possible, the RTP (see Section 3.3.9) must be updated to project the “no fringe growth” concept after 2031. The TPC would have to develop the RTP using this growth concept (i.e. the next update of the RTP), and the MAG Regional Council would have to approve the plans (and keep the growth concept in the plan through the TIP that is executed in 2050).

The TIP (see Section 3.3.10) could be updated to integrate the LCA framework with the performance measures already used to compare projects. This would increase the likelihood that more sustainable projects are competitive for funding. The current TIP programs projects that will execute the RTP through 2018. The Plateau trajectory would require the TIP to enable more sustainable transportation projects by 2027 (i.e. the 2028-2031 TIP). Likewise, the freeway, arterial, and transit life cycle programs (see Sections 3.3.11 through 3.3.13), in order to ensure that they do not conflict with the RTP, would need to implement the updated LCA performance measure procedures from the RTP and TIP. The State Transportation Board (see Section 3.3.17) would need to evaluate its 5-year construction plan in the same way to coordinate with the RTP. With these new performance measures fully integrated into the RTP, the TIP, and the modal life cycle programs, there is a uniform means for comparison of transportation projects that may break the automobile-dependent planning paradigms of the past. Of course, all of these

changes are predicated on MAG member agencies (see Section 3.3.14) coming to a consensus on the definition of sustainable transportation in MAG as well as the conclusions about the benefits and costs of different planning strategies. MAG is already anticipating a requirement for quantitative assessment of sustainable transportation planning that will be dictated by federal legislation (see the “clean energy” legislation discussed in Section 3.6.3). If legislation requires MPOs to establish quantitative targets and report emissions reductions, then MAG member agencies would not be deciding on *whether* to conduct such assessments but *how*. LCA methods that already align with existing planning procedures (see Chapter 2) could be a seamless fit. However, federal or state law would have to mandate these procedures before MPOs would expand the scope of their planning and reporting procedures.

4.2.3 Integrated Transportation and Land Use (ITLU) Trajectory. The ITLU trajectory is an aggressive approach to modeling growth in Phoenix, and assumes that the currently-approved transportation budget is the extent of BAU growth. After 2017, new development projects outside the urban core are not constructed and TOD infill begins immediately. This trajectory implies that many actions be taken by dozens of individual cities to deploy and connect transit infrastructure across Phoenix. Using the conservative estimate of market demand for TOD from the ST-LUIS framework study (Gehrke & Srivastava, 2011), the demand for TOD growth is exhausted by the year 2033. From 2033-2050 the growth is modeled using travel behavior for new residences within the urban core area but not in locations that have ready access to public transit (Chester, Nahlik, Fraser, Kimball, & Garikapati, 2013).

All of the transition strategies discussed in Section 3.7.2 (for the Plateau trajectory) must be accomplished immediately in order to alter the BAU trajectory and change the path

after 2017. As with the Plateau trajectory, the political and ideological norms that must evolve rapidly and at all levels are significant. The benefits to be had from these changes are compounded over time compared to the same changes in Plateau not occurring until 2031.

4.2.4 Sustainable Phoenix Trajectory. Sustainable Phoenix is an attempt at modeling a utopian transportation planning trajectory. It expands on the ILLU trajectory by adding phased-in taxes (state gasoline tax and a price on carbon that applies to gasoline sales), and also assumes that the capacity for TOD infill is adequate for all new growth through 2050. Each of the transition strategies discussed in the Plateau and ILLU trajectory must be achieved in the next few years along with new taxes, increased adoption of alternative fuel vehicles, and land use planning to generate new market demand for TOD.

The gasoline taxes would have to be implemented immediately, voted into law by state government and phased in over more than a decade. ADOT officials have already presented alternative funding scenarios to MAG committees, and presented the funding gaps projected if the current funding system goes unchanged (MAG, 2013b). MAG member agencies are cautious to readily agree to new taxes due to political pressures against taxes, but also recognize that something must be changed to fund known infrastructure needs and planned transportation systems (MAG, 2013c). There is some support for a gasoline tax in the state legislature (MAG, 2013c), but the tax would have to be approved in the next few years if the Sustainable Phoenix trajectory is possible as modeled in Chapter 2. MAG members recognize that significant education and outreach campaigns are necessary before an increase in the gasoline tax would be politically viable (MAG, 2014).

The price of carbon would need to be mandated by federal regulation, and would likely correspond to major decisions in the Supreme Court cases considering the EPA's authority under the Clean Air Act and Clean Water Act. The Sustainable Phoenix trajectory

models a phased-in price on carbon dioxide emissions as originally proposed in the American Clean Energy and Security Act (H.R. 2454, see Section 3.6.3), starting at \$20 per ton in 2020 and ramping up to \$75 per ton in 2050⁵⁹. The State of Arizona could choose to enact legislation mandating a price on carbon before any federal legislation is successful, but this is unlikely until Arizona citizens are fully aware of how sensitive the region is to the impacts of climate change. Political and social concern for climate change amongst the voting public might only be changed if major disruptions to the status quo are introduced, for example if regional temperatures increased dramatically, if fresh water supplies run dry, or if a western carbon market is established (and Arizona could profit by participating). Pricing carbon as a transition strategy is a major barrier that is outside of the control of the institutions studied in this research. However, MAG and ADOT officials, in their roles of informing the public and conducting long-term transportation planning, can advocate for legislation on carbon pricing and anticipate the benefits and costs in planning efforts⁶⁰. Coordination with health services organizations could generate further support for carbon pricing and broaden the perceived benefits from changes in transportation costs (prices). Through coordination with federal, state, and local transportation planners, MAG can lend political support for carbon pricing, and can build the anticipated benefits into existing planning efforts as a way of alleviating existing budget gaps⁶¹.

⁵⁹ The price on carbon is modeled as an additional fuel cost to drivers, using the elasticity of gasoline price to compute the corresponding reduction in vehicle travel (see Chapter 2 for specific methodologies). This corresponds to 18 cents per gallon carbon tax in 2020 and 67 cents per gallon in 2050.

⁶⁰ As described in Section 3.5.3, MAG officials are actually registered as lobbyists because they regularly interact with elected officials in their capacity as transportation planners. While it may be naïve to suggest that politicians would campaign for a price on carbon, MAG and ADOT planners already recognize that a cultural shift in transportation revenue and funding structures must occur (MAG, 2013b) and are actively exploring ways to both lobby for and educate the public about generating new transportation revenues (MAG, 2014).

⁶¹ This research does not intend to dictate specific financing schemes or innovative budget policies, but there may be opportunities for solving projected gaps in transportation budgets when a price on carbon will generate new revenues. Whether or not this opportunity is real depends on the specific legislation that is passed, and who passes it largely determines where the money will go and how it is collected (i.e. the polluters might pay

The Energy Information Administration (EIA, 2013a) lists electric vehicle sales at 0.22% in 2011, and predicts 6.3% sales by 2040. The Sustainable Phoenix trajectory inflates these predictions to generate a more optimistic estimate of plug-in vehicle adoption⁶², specifically 10% of vehicle sales by 2025, 20% by 2035, 25% by 2040, and 35% by 2050. There are several institutions that could aid in achieving this transition, namely public outreach by transportation agencies to encourage electric vehicle adoption. ADOT could extend the right-of-use privileges for high-occupancy vehicle lanes that are currently offered to electric vehicle drivers (these benefits are set to expire in the coming years). Cities can alter zoning regulations to require electric vehicle charging infrastructure and payment schemes for multi-family residences and mixed-use developments. Government agencies (federal, state, local) can establish policies for workplace charging of the vehicles, and incorporate these policies into the trip reduction programs (see Section 3.4.4). The federal government could continue to provide tax incentives for the purchase of electric vehicles, and the State of Arizona could follow the example of several other states by offering state tax incentives on top of federal refunds. Additionally, ADOT could establish a user fee directed at electric vehicles to recuperate the “avoided” gasoline taxes, and this would aid in equity issues that will likely be associated with increased gasoline taxes.

Finally, land use planners and transportation planners must work together with city governments and business leaders to develop a larger market for TOD. The ST-LUIS framework study (see Sections 3.3.7 and 3.6.4) was a conservative estimate of the market

for each process that generates pollution or the consumers might pay when they buy from the producers, with the producers passing on the costs of production pollution to the consumers).

⁶² There are a range of alternative fuel vehicles on the market, but this study simplifies the scope of the LCA modeling to just include pure-electric plug-in vehicles, and also assumes that the electricity used by the vehicles would be generated with renewable energy. The LCA model could be expanded in the future to specifically model a variety of alternative fuel sources, and the upstream emissions generated by producing those fuels.

demand for TOD in Phoenix (Gehrke & Srivastava, 2011). As land use planners and city governments attempt to attract new businesses and residents to their cities, travel corridors and employment centers may shift and new opportunities for TOD may be developed. The collective bargaining for which parts of Phoenix will grow is not an easy process, and there will be “winners and losers” amongst different locations⁶³. City zoning laws can be a first step to incentivizing TOD (which implies a multitude of actions at the city/town/municipality level in dozens of local governments), but county or state level incentives could also be developed to encourage developing new markets for TOD. Financial incentives for large corporations could generate new jobs in the region, but could be linked to requirements for the design and density of the land consumed by the new jobs. The “leapfrog” effect that has generated much of the sprawl in Phoenix (Heim, 2001) is partially linked to specific land holdings of state and federal government. There may be opportunities for land conservation at the fringe of the urban area if some of the government land in the urban core could be developed responsibly as new TOD. There are demonstrated economic incentives in real estate values before, during, and after transit deployment (Golub, Guhathakurta, & Sollapuram, 2012) that could also justify the growth in transit systems necessary to enable new markets for TOD.

⁶³ As an example, the Town of Buckeye has grand plans of becoming “the next Mesa” but is clearly in a location that would exacerbate sprawl in the region. How Buckeye views their role in regional growth and the decisions they make in land use planning will clearly impact a regional plan for sustainable transportation. MAG does not have any authority to direct Buckeye not to grow, but there may be incentives that avoid “picking winners and losers” in regional growth plans.

Table 4.1. Transition Strategies and Intervention Points. Institutions identified as intervention points for sustainable transportation in Phoenix are synthesized in the table below. Each strategy is linked directly or indirectly to LCA Processes in Figure 4.1.

Institution (number used in Figure 3)	Action or Change	When for Plateau	When for ITLU	When for Sustainable Phoenix
1. MAG TPC	Add committee members	2031	2017	2017
2. MAG Regional Council	Funding disincentives for sprawl	2031	2017	2017
3. RTP Partners	Oversee new gasoline tax and carbon tax structures	N/A	N/A	2017
	Integrate sustainability performance measures into project assessments	<-----As soon as possible----->		
4. Framework studies	Assess life-cycle benefits and costs of long-range scenarios	2031	2017	2017
5. RTP	Update to discourage “fringe growth”	<-----Next update----->		
6. TIP	Include LCA measures in project evaluation	<-----Next update----->		
7. Transportation Life Cycle Programs	Implement updated “no fringe growth” RTP and TIP	<-----Next update----->		
8. MAG member agencies	Integrate sustainable transportation definitions and goals into future planning	2031	2017	2017
9. Clean Air Act	Require more comprehensive life-cycle emissions reporting	2031	2017	2017
10. Consultants	Expand and integrate LCA expertise	2031	2017	2017
11. State Transportation Board	Evaluate 5-year construction plan using updated RTP (see #5)	2031	2017	2017
12. Federal Regulations (SAFETEA-LU and MAP-21)	Adjust fund matching to incentivize sustainable growth	<-----As soon as possible----->		
	Require LCA measures in evaluating transportation systems	<-----As soon as possible----->		
13. Federal, state, regional transportation funds	Maintain at least the current funding (i.e. no decrease or stop)	<-----At least through 2050----->		
14. CMAQ	Funding contingent on evaluating LCA performance measures	<-----As soon as possible----->		
	Incentivize sprawl reduction with “credits” for regional air quality improvements	<-----As soon as possible----->		
15. Federal transit funding	Adjust fund-matching to incentivize transit projects	<-----As soon as possible----->		
16. City Taxes	Fund transit projects with dedicated tax	<-----As soon as possible----->		
	Fund land use incentives for TOD infill	<-----As soon as possible----->		
17. DOT, ADOT, MAG officials	Advocate for TOD and infill projects	<-----As soon as possible----->		
	Integrate sustainable transportation definitions and goals into planning	<-----As soon as possible----->		
18. CTOC	Incorporate LCA in project evaluation	<-----As soon as possible----->		
	Oversee implementation of sustainable transportation strategies in planning	<-----As soon as possible----->		
19. State government	Institute gasoline tax	N/A	N/A	Immediate
20. Federal or state government	Institute a price on carbon (CO ₂) in gasoline	N/A	N/A	Immediate

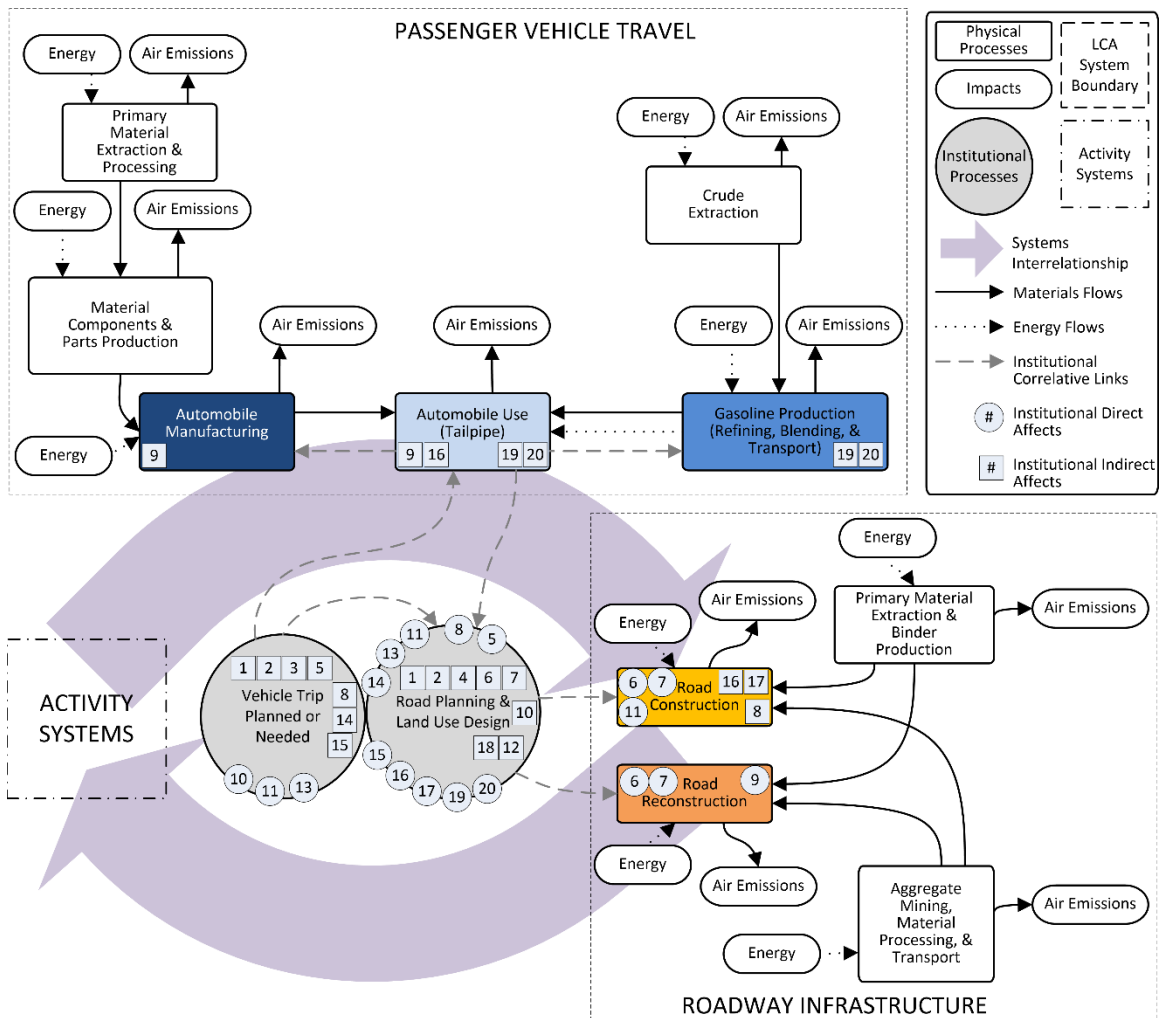


Figure 4.1. The Final IA-LCA System Diagram. Institutional demands (grey circles) and causal links (grey dashed arrows) are added to the original LCA system boundary diagram from Chapter 2. Table 4.1 (and the more detailed table at Appendix A) connects the transition strategies to LCA processes and causal links.

4.2.5 Institutions and Processes Outside the Action Arena. The institutions discussed in Chapter 3 and the processes modeled in the LCA in Chapter 2 are within the action arena of passenger transportation systems in Phoenix, but there are clear examples of institutions that should be noted outside the action arena. The institutional analysis framed in this research has a narrow scope and is not meant to capture complex interactions at

much larger scales (i.e. state, federal, or international transportation systems). However, the relationships between different institutions and the transition strategies that are associated with these interactions reveal broad-reaching institutions that are critical to the system but are outside of the direct control of actors in the action arena.

Developers who build residential and commercial infrastructure are independent actors who make plans and decisions outside of the transportation planning action arena. While the developers do get permits and sometimes financial incentives from local government organizations, the transportation institutions do not have any authority to control the actions of land developers. The business of Phoenix is growth, and land developers are successful when land use planning encourages urban growth (especially sprawl). If any of the transition strategies for increasing TOD growth are to be achieved, individual developers will need to build projects differently to execute TOD growth strategies. Banking institutions must also act differently than in the past because the builders can only finance new development projects if the banks deem them financially viable.

Transportation systems are a common-pool resource and individual travelers make mode choices each time they need to make a trip. The transportation planning institutions can only provide mode choices, and in general cannot dictate the actions and choices of individuals using the systems⁶⁴. Many of the transition strategies outlined in this research are predicated on the actions of individual vehicle drivers and passengers as they respond to changes in the transportation institutions (rules, norms, strategies). Behavioral change in

⁶⁴ There are obvious exceptions to this statement. For instance, certain classes of vehicles are not permitted on certain roads. Bicycles cannot use some highways and freeways, pedestrians are not allowed on train tracks, and motorcycles are not allowed on dedicated bicycle paths.

passengers using transportation systems is a critical component in achieving the transition strategies, but is outside the scope of this research.

The energy consumption and emissions results from the LCA of transportation systems reveals significant effects from vehicle manufacturing. Reductions in vehicle travel can reduce the number of vehicles manufactured to drive those miles, but the manufacturing process is not necessarily a static system. Vehicle manufacturing processes could be improved to generate energy and environmental benefits that could compound the benefits of future Phoenix transportation systems. However, there are no vehicle manufacturing facilities in Phoenix and the automobile industry is outside the purview of transportation planning systems. The state or county government might have some authority to require certain standards for vehicles sold in the region (similar to California initiatives mandating low-emissions vehicles), but in general the industry is acting in its own interests and only is responsible to the rules and regulations in the locations where they do operate manufacturing facilities. None of the transition strategies directly impact vehicle manufacturing processes.

Gasoline production (fuel processing, refining, and delivery) is a life cycle process not directly within the action arena of transportation planning. There are no fuel refineries in the geographic area, and the fuel industry controls the specific processes that they use to produce gasoline (within regulatory compliance). The vehicle travel occurring in Phoenix does result in gasoline production effects, but none of the transition strategies directly address fuel production processes. California and some other states have required specific quality of gasoline, and this has impacted fuel production processes in the refinery and production locations, but in general the fuel industry makes its own decisions about technology and processes (in compliance with regulatory requirements). Automobile

manufacturers can indirectly impact fuel production by the technology they produce for automobile engines/motors. As vehicle technology changes, the fuels produced to move cars will change and the fuel industry will have to respond to consumer demands (e.g. fuel quality and fuel type).

Road maintenance is not addressed by any of the transition strategies in this research. There are obvious design considerations and quality standards that could address the frequency or the methods for roadway maintenance⁶⁵ but once a road is constructed it requires maintenance indefinitely. There are no specific institutions that could change the physical nature of infrastructure systems. The more the infrastructure is used, the more it requires maintenance to stay functional. There is an indirect link to roadway maintenance in any of the transition strategies that reduce vehicle travel, but unless roads are removed or deconstructed there will always be a physical requirement for road maintenance.

4.2.6 Acknowledging the Limitations of the Trajectories as Modeled. It is important to note that by designing the trajectories using insights from the institutional analysis, a bias is introduced that favors future systems, policies, and technologies already influenced by the status quo. Population growth is modeled uniformly in all scenarios, but this neglects the idea that different growth patterns and infrastructure configurations may attract more or less people to Phoenix in the future. Several economic policies are incorporated into the Sustainable Phoenix trajectory, but in deliberate forms (gasoline tax increase and putting a “price on carbon”). Other economic policies could have been modeled (e.g. a VMT tax or congestion pricing), but were not chosen for the trajectories based on insights from the institutional analysis. In this case, there is a bias towards the

⁶⁵ MAG technical committees, the State Transportation Board, and individual cities and municipalities all develop standards for road construction, design, and maintenance.

current institutional culture, mindset, and knowledge base that may contribute in its own way to reinforcing the status quo path dependence. The institutions (and the institutional memory) should not be treated as static through 2050, and future work might address questions such as “what could change the conditions to allow different trajectories to be viable?” and “could there be a shock to the system that invalidates the trajectories as modeled?”

Innovations in technology and socio-economic systems have strong potential for disrupting the trajectories as modeled. Intelligent Transportation Systems (e.g. vehicle-to-vehicle safety systems, real-time data monitoring and navigation, autonomous vehicles, and multi-modal payment systems) could make automobile travel much more efficient and result in both increases in VMT and decreases in environmental impacts. New business models for work, school, and entertainment could decrease the need for travel, and this may dovetail with economic and land use policies that could be introduced in the region. For example, Phoenix could offer financial or regulatory incentives to large corporations who bring jobs to the region but attach those incentives to requirements for tele-work or home-based activity systems. Schools and universities in the region could change the cultural norm of attending class in-person and encourage students to attend via network connection even if they live within driving or commuting distance of the classroom.

There are endless possibilities for future trajectories, and those modeled here are meant to demonstrate a range of plausible outcomes. ADOT has explored several of these future technologies and potential cultural changes (Roubik, 2001a, 2001b, 2002), but explorations of the future are mired in and informed by the understanding of the present (Selin, 2006a, 2006b). Recognizing that socio-technical systems are complex and new challenges and problems will be created by attempting to “solve” existing ones (Allenby,

2009), the trajectories and transition strategies are deliberately chosen because they are already suited for (and compatible with) the existing transportation planning institutions. The transition strategies should not be considered exhaustive, and both the Phoenix transportation system and the assemblage of sustainable transportation strategies will evolve over time.

4.3 IA-LCA Conclusions.

Phoenix passenger transportation planning is a complex system with multiple scales and elaborate institutional interactions. No single institution holds the key to solving transportation problems in the region. The IAD framework paired with the LCA results reveals specific transition strategies and the mechanisms or actors that would need to change to achieve alternative trajectories in the future. The results of the prospective LCA can be incorporated with institutional insights as a strategy for identifying intervention points for sustainability transitions. Also, the integration of LCA and institutional analysis can quantitatively test future transitions and inform stakeholders. These results are not meant to prescribe how any institutions or decisionmakers should function. Instead, this work is derived from existing research on transportation and land use planning concepts and pairs these tenets with the results of a prospective LCA placed in the context of the Phoenix passenger transportation planning system over the next four decades.

This methodology can and should be used by decisionmakers to anticipate planning and regulatory needs for transportation systems in the future. The results of the LCA demonstrate that broad-reaching emissions reductions goals, such as those proposed in H.R. 2454 (see Section 3.6.3), are not achievable for Phoenix transportation systems even in the most optimistic and utopian trajectory. Chapter 2 explains that per capita emissions and energy consumption for passenger transportation in Phoenix has been steadily declining

since the mid-1970s. This is a great success story and should not be ignored. But the energy and environmental effects from a region projected to double in population by 2050 must be addressed responsibly. Phoenix is on a crash course towards unsustainable energy consumption and environmental degradation unless MAG embraces the concept that BAU is not possible and facilitates a fundamental shift in the paradigm of planning (with top-down support from federal and state agencies also changing their own policies such as pricing carbon and sustainability performance measures in funding structures). Having comprehensive, prospective, and quantitative data on the effects of passenger transportation region-wide is necessary to develop realistic long-term planning goals and also to devise sensible criteria for measuring sustainable transportation in the future.

4.4 Benefits of a Combined Approach.

This research advances the state of practice of existing research on sustainability problems by combining analyses of social systems and technical systems, and the conclusions reached through this interdisciplinary approach are different than those that could be made by separate and independent approaches. The institutional analysis is a framework that helps researchers understand how the system works, but it does not answer questions about what is wrong with the system unless it is paired with analysis of a normative (past, present, or future) state. The LCA analysis is a framework that helps reveal the holistic system, including externalities, but completed alone it does not answer questions about how any of the processes could be changed or might be different. By intersecting the two frameworks, the LCA gains context, the scope and authorities in the social system can be associated with quantitative effects in physical systems, drivers (correlative links) for benefits and costs in future trajectories can be identified, and the systems or processes

(“externalities”) that cannot be addressed in the social system (action arena) are identified and quantified.

4.4.1 Adds Context to LCA Results. A majority of previous LCA research has been focused on singular products or processes, either for attributional analysis (e.g. which product is better than the other) or consequential analysis (e.g. what are the consequences of changing the way the product is made). In using LCA models to inform decisionmaking in complex systems, the data inputs and system boundaries often limit the applicability of the results (Finnveden, 2000; Jeswani et al., 2010). Jeswani et al. (2010) proposes options for expanding LCA approaches that suggest including the assessment of social systems to provide the context necessary in sustainability assessments. Hybrid LCA methods are employed to bridge the gaps between methods that reduce complexity and methods that are both comprehensive and standardized. However, this research ventures outside the LCA silos to incorporate a pure social science framework as a means of providing context to empirical modeling results.

4.4.2 Reveals the Scope of Authority in a Complex Social System. The range of potential costs and benefits available at each level of authority becomes more clearly defined by connecting the quantitative assessment (LCA) insights with the results of the institutional analysis. Specific to this research, a thorough analysis of published sustainability goals identified future normative conditions for the regional transportation system⁶⁶, but the trajectories that were initially modeled in the LCA (Plateau and ITLU) were not sufficient to improve current conditions. Likewise, the range of potential energy consumption and

⁶⁶ To be fair, the documents published by MAG did not contain quantitative goals for improving the environmental impact of transportation systems. The documents did make reference to the types of transportation and land use improvements that would be considered improvements to the current system, and also anticipated federal implementation of more strict environmental regulations in the future.

environmental emissions trajectories modeled in the LCA revealed barriers and gaps in the institutional framework that are contributing to path dependence in the immediate future. The institutional analysis informed the scope of the LCA, and the LCA informed the practicality of the sustainability strategies in the social institutions.

4.4.3 Identifies Drivers for Benefits and Costs. Borrowing the institutional analysis methodology (asking *who* does *what*, *when*, and *how*) to review the LCA system boundary uncovered institutional sources of the benefits and costs in the transportation planning system. Figure 4.1 is the synthesis of this exercise, and demonstrates that there is a synergistic effect of the institutional drivers (transportation demand and infrastructure planning) on life cycle processes in the regional transportation system. This is not an original insight, but it confirms the concept that transportation planning decisions influence life cycle effects in the Phoenix passenger transportation system (both retroactively and prospectively). Furthermore, having a transparent LCA model allows these insights to be targeted to specific sectors of the social system (e.g. road construction, vehicle technology, or land use policies).

4.4.4 Reveals Externalities. Social systems (such as regional transportation systems) with inherent “spillover effects” or “externalities” do not have control over the indirect effects caused by providing the public good or common pool resource (V. Ostrom, Tiebout, & Warren, 1961). Designing the LCA system boundary to match the action arena of the institutional analysis can uncover a range of benefits and costs that are secondary and tertiary effects resulting from the immediate actions of the institution. The transportation planning institutions can choose to continue disregarding the externalities (either by deliberate decision or by neglect), or make attempts to “internalize” the externalities and build the functions into the system. For example, putting a “price on carbon” is a way to

internalize the effects of carbon emissions in the system (the economic elasticity of the price would disincentivize gasoline-powered vehicle travel), or changing land use policies to bring more transit-oriented development into the urban core is a way to internalize the effects of urban sprawl in the system (as the urban core becomes more dense, the region can grow in population but have fewer commuters making vehicle trips from fringe suburbs). While there is not a direct cause-effect link between the externalities and the institutional drivers, the synergistic effect of the life cycle processes and the institutional decisionmaking can be revealed to inform future planning and decisionmaking and break status quo path dependence.

4.5 Limitations and Uncertainties of a Combined Approach.

LCA has inherent uncertainties based on the system boundary, assumptions, and modeling methodology (Huijbregts, 1998), and Institutional Analysis is limited to a specific portion of a larger system (E. Ostrom, 2005). Combining these two analyses introduces a synergistic effect that confines the utility of the research to a specific set of problems or social system. The advantages of such an approach have already been discussed and are necessary for the type of intervention strategies that are needed for sustainability solutions (see Lang et al. (2012)). However, this approach cannot be used to generate universal insights that would be useful at another scale or in a similar but separate social system. Lastly, there is a danger in applying a prospective LCA framework to suggest “solutions” in a complex social system. The links between institutional changes and LCA trajectories are only correlations and not causalities. The results of the prospective LCA cannot be taken for predictions of future states, the transition strategies must be qualified as changes that are necessary to set the right conditions that will make the LCA trajectories possible.

4.6 Opportunities for Future Research.

The methodology developed here can be applied to other metropolitan areas, expanded to include more processes in the system boundary and action arena, and even performed concurrently in multiple locations to network the results for broader conclusions.

4.6.1 Different Case Studies. The IA-LCA methodology is designed to be adapted to any metropolitan area, and multiple case studies will further refine and validate the process. Results and conclusions could be contrasted with the Phoenix case study if the methodology is also applied to cities with more complex histories and more varied infrastructure systems, such as Los Angeles, Chicago, or Atlanta. By comparing several case studies, common conclusions might be useful as universal insights for sustainable transportation systems while conflicting results could reveal new transition barriers and the nature of those unique barriers.

There may also be an opportunity to apply the methodology to smaller planning areas where long-term transportation and land use planning occurs, such as military installations, college campuses, or large industrial or corporate campuses. As an example, Arizona State University has made a commitment to mitigate all carbon emissions from transportation by the year 2035. While the campus is located in three different cities within the Phoenix metropolitan area, the university does own and operate transportation infrastructure and might use an IA-LCA approach to enable or inform the transition strategies that must be executed to reach the 2035 carbon neutrality goal. Another small-scale case study could be individual military installations, which are often urban areas operating much like metropolitan cities and will soon be required to mitigate transportation emissions as part of comprehensive sustainability planning. Executive Order 13514, Federal Leadership in Environmental, Energy and Economic Performance, sets priorities for

sustainability goals in federal agencies and mandates reductions in emissions and petroleum consumption. A phased-in requirement will eventually require federal agencies (including military installations under the Department of Defense) to address “Scope 3” vehicle emissions, which includes “greenhouse gas emissions from sources not owned or directly controlled by a Federal agency but related to agency activities such as vendor supply chains, delivery services, and employee travel and commuting” (Federal Register, 2009).

4.6.2 Expand the System Boundary. The IA-LCA could be expanded to include transit infrastructure and land use infrastructure, as well as analyzing the institutions in that expanded action arena. Kimball et al. (2013) conducted an integrated transportation and land use LCA that demonstrates an expanded system boundary for a prospective LCA in the Phoenix metropolitan area, but the assessment only considered the “next dwelling unit” coming to Phoenix and did not include existing residents. The institutional analysis to incorporate with such an expanded system boundary would significantly increase in complexity, crossing multiple planning disciplines, governmental structures, and public and private corporations. However, with this research as a starting point, a more comprehensive system boundary would further validate the utility of the IA-LCA methodology.

4.6.3 A Network of Metropolitan Areas. As new IA-LCA studies are conducted in different metropolitan areas, the results and conclusions can be contrasted and evaluated together to develop broad insights on sustainable planning practices, to assist in national decisionmaking, and as a means for metropolitan areas to attract jobs and residential growth from organizations and people prioritizing sustainable practices and lifestyles. By sharing results between multiple metropolitan areas, researchers can address questions such as “what are the tradeoffs if you add a household to Phoenix instead of Chicago?”

With each new IA-LCA conducted in a different location (and possibly over a different time-scale), common conclusions can emerge that will validate or invalidate entrenched planning and policy paradigms. Mutual transition strategies, intervention points, and barriers can be further analyzed to draw correlations with geographic or cultural characteristics. If a particular institutional barrier (e.g. a policy or a planning practice) is common across a majority of MPOs, then this insight could motivate changes in national policies that would benefit all MPOs and might not have been changed by just one MPO realizing the barrier. Likewise, statistical analyses of the quantitative results from a network of regional-level LCAs could provide further insights for transportation planning practices and feedback information to evaluate travel forecasts.

As national priorities and regulations related to pollutant emissions and energy consumption begin to take shape, comprehensive analysis of large-scale metropolitan systems will be valuable for decisionmakers. As discussed in Chapter 3 and in Greenblatt (2013), goals for emissions and consumption reductions can be too optimistic and sometimes unobtainable if the goals are set without a clear understanding of the system generating the activity. If IA-LCA analyses are performed on the largest metropolitan areas in the United States, then decisionmakers and policymakers at the national level can begin to comprehend both the severity of the problem and the nature of the transition strategies that must be executed to enable solutions. Networks of IA-LCA analyses could begin with simple evaluation factors that are already required by regulation (e.g. vehicle miles traveled for passenger transportation systems in each MPO), and then could be incrementally expanded to evaluate more specific sustainability factors (e.g. greenhouse gas emissions, or including public transit and bicycle/pedestrian travel systems).

The economic viability of metropolitan cities is tied to growth, and by using comparative results from a network of regional IA-LCAs cities may discover a new avenue for attracting jobs and residents. Imagine the long-term impact on the regional economy if Phoenix demonstrates that a corporation/university would enjoy a more sustainable supply chain and operational environment by building the next campus/factory in Phoenix instead of Boston or Seattle, and that the human health and lifestyle conditions are better for new residents. Alternately, if Boston or Seattle could demonstrate the opposite, then this would motivate Phoenix to improve its practices along with other “less sustainable” metropolitan cities. The utility of these networked IA-LCA studies does depend on the likelihood that corporations (or universities, hospitals, families) are considering sustainability in their decisionmaking process, but recent evidence suggests that this is an emerging paradigm (Azapagic, 2003; Banister, 2008; TRB, 2009).

4.7 The Road Ahead.

Two roads diverged in a wood, and I – I took the one less traveled by, and that has made all the difference.
–Robert Frost (1874-1963)

This research is motivated by the idea that passenger transportation systems are locked-in to automobile-oriented paths leading metropolitan areas towards unsustainable futures, and that the only way to break the path dependence is to create new paths that go where we choose (towards our definition of sustainability). The question will be whether or not we have the capacity to create these new paths and not choose existing roads.

*Camiente, no hay camino
Se hace camino al andar*

*Walker, there is no path
The path is made by walking*
-Antonio Machado (1875-1939)

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CHAPTER 1

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CHAPTER 4

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APPENDIX A

TRANSITION STRATEGIES SYNTHESIS TABLE

Institution [bold # notes the direct process link noted in Figure 4.1]	Type (Formal Institution, rule, norm, strategy)	Action or Change	Who or What Authority Makes the Change	When or How Long	Direct LCA Process Link	Indirect LCA Process Link
MAG TPC (Section 3.3.1) [1]	Formal Institution	Include an additional business representative who specializes in TOD or smart growth	State Congress decides on business representatives	NLT 2031 for Plateau, 2017 for ITLU and Sustainable Phoenix		Road Planning & Land Use Design, Vehicle Trips
MAG Regional Council (Section 3.3.2) and TRC (Section 3.3.3) [2]	Formal Institution	Approve new funding structures that disincentivize low-density fringe growth	Individual funding for projects within the TIP, but changing funding policy would likely be voter proposition or state-level decision	NLT 2031 for Plateau, 2017 for ITLU and Sustainable Phoenix		Road Planning & Land Use Design, Vehicle Trips
RTP Partners (Section 3.3.4 and 3.5.5) [3]	Strategy	Assume new roles and responsibilities to oversee the implementation of new state gasoline taxes and the price on carbon. Also be designated as the organization to establish performance measures for sustainable transportation (in accordance with MAP-21) and then evaluate Proposition 400 projects using those performance measures	MAG Regional Council, Arizona statute	NLT 2017 for Sustainable Phoenix, immediately for establishing performance measures in all trajectories		Vehicle Trips
Framework Studies (Section 3.3.7) [4]	Strategy and Scope Rule	New or updated framework study could evaluate the life cycle benefits and costs of long-range transportation scenarios as a means of matching quantitative results with qualitative conclusions	MAG	NLT 2031 for Plateau, 2017 for ITLU and Sustainable Phoenix		Road Planning & Land Use Design
RTP (Section 3.3.9) [5]	Strategy	The RTP must be updated to include “no fringe growth” plans	TPC develops the plan and Regional Council approves	Next update of the RTP is ideal for all trajectories	Road Planning & Land Use Design	Vehicle Trips

Institution [bold # notes the direct process link noted in Figure 4.1]	Type (Formal Institution, rule, norm, strategy)	Action or Change	Who or What Authority Makes the Change	When or How Long	Direct LCA Process Link	Indirect LCA Process Link
TIP (Section 3.3.10) [6]	Scope Rule, Authority Rule, and Payoff Rule	Include LCA measures in evaluating and approving projects	TPC builds the TIP and Regional Council approves. MAG Officials would approve a change in TIP procedures and ADOT and DOT would recertify the MPO procedures	Next update of the RTP is ideal for all trajectories	Road Construction, Road Re-construction	Road Planning & Land Use Design
Transportation Life Cycle Programs (Sections 3.3.11, 3.3.12, and 3.3.13) [7]	Scope Rule, Authority Rule, Information Rule, and Payoff Rule	Implement the RTP and TIP while programming road funding (as transitioned to plan for “no fringe growth”)	ADOT and RPTA-Valley Metro	Immediate implementation after RTP and TIP are updated to include the trajectory	Road Construction, Road Re-construction	Road Planning & Land Use Design
MAG Member Agencies (Section 3.3.14) [8]	Formal Institution and Norm	Must accept regional definition of sustainable transportation, and agree to integrate sustainability concepts into future planning	Cities, Towns, Organizations, and the communities they represent	Immediate change is ideal for all trajectories, but NLT 2031 for Plateau and NLT 2017 for ITLU and Sustainable Phoenix	Road Planning & Land Use Design	Road Construction, Vehicle Trips
Clean Air Act (Section 3.3.15) [9]	Information Rule	Require more comprehensive reporting of emissions, to include mobile source CO ₂ emissions, using LCA methods	Federal government, possibly as mandated by Executive Order or Supreme Court decisions	NLT 2031 for Plateau, 2017 for ITLU and Sustainable Phoenix	Road Planning & Land Use Design, Road Construction	Vehicle Manufacturing, Gasoline Production
Consultants (Section 3.3.16) [10]	Formal Institution	LCA practitioners work with consulting firms and become integrated into MAG studies and planning efforts	MAG leadership, MAG committee, transportation consulting firms	NLT 2031 for Plateau, 2017 for ITLU and Sustainable Phoenix		Road Planning & Land Use Design
State Transportation Board (Section 3.3.17) [11]	Formal Institution	Evaluate 5-year construction plan based on updated RTP (that integrates “no fringe growth” long-range plans)	State of Arizona, ADOT	NLT 2031 for Plateau, 2017 for ITLU and Sustainable Phoenix	Road Planning & Land Use Design, Road Construction	
SAFETEA-LU and MAP-21 (Section 3.4.1)	Working Rules (Boundary,	Adjust fund matching levels to incentivize	Federal government	Immediate guidance is		Road Planning &

Institution [bold # notes the direct process link noted in Figure 4.1]	Type (Formal Institution, rule, norm, strategy)	Action or Change	Who or What Authority Makes the Change	When or How Long	Direct LCA Process Link	Indirect LCA Process Link
[12]	Position, Scope, Authority, Aggregation, Information, and Payoff)	sustainable growth in MPOs and require MPOs to integrate LCA into planning procedures as a performance measure for sustainable transportation systems		ideal in all trajectories		Land Use Design
HURF, RARF, and Proposition 400 funds (Section 3.4.2 & 3.4.3) [13]	Payoff Rule, Information Rule, Authority Rule	Maintain funding through 2050, or if funding is altered then continue the level of funding for MAG systems	DOT, ADOT, Arizona State, and MAG	Indefinite	Road Planning & Land Use Design	
CMAQ funds (Section 3.4.4) [14]	Payoff Rule	CMAQ funding becomes contingent on evaluating LCA performance measures for sustainable transportation (to include land use effects on transportation). Projects funded through CMAQ that reduce sprawl (TOD incentives) could be used for “credits” to justify air quality improvements in the region.	Federal government, DOT, EPA	Immediate change is ideal for all trajectories	Road Planning & Land Use Design	Vehicle Trips
Federal Transit Fund (Section 3.4.5) [15]	Payoff Rule	Adjust fund-matching structures to incentivize high-capacity transit projects	Federal government, DOT, Federal Transit Authority	Immediate change is ideal for all trajectories	Road Planning & Land Use Design	Vehicle Trips
City Taxes (Section 3.4.6) [16]	Payoff Rule and Norm	All MAG member cities and towns approve new taxes to fund transit, and possibly create taxes to fund land use incentive programs for TOD infill	Individual cities and towns, citizens in regional communities	Immediate change is ideal for all trajectories	Road Planning & Land Use Design, Vehicle Trips	Road Construction, Vehicle Use
DOT, ADOT, and MAG Officials (Sections 3.5.1, 3.5.2, and 3.5.3)	Formal Institution (People) and Norm	Advocate for TOD projects in transportation planning and find innovative ways to	Organizational leadership and individual employees. Also, citizens apply	Immediate change is ideal for all trajectories	Road Planning & Land Use Design	Road Construction

Institution [bold # notes the direct process link noted in Figure 4.1]	Type (Formal Institution, rule, norm, strategy)	Action or Change	Who or What Authority Makes the Change	When or How Long	Direct LCA Process Link	Indirect LCA Process Link
[17]		meet travel demand using existing infrastructure. Also integrate sustainable transportation concepts into practices and planning	political pressure to garner support for this change			
CTOC (Section 3.5.4) [18]	Norm and Strategy	CTOC members learn and understand the concepts of LCA and how to evaluate benefits and costs to oversee implementation of sustainable transportation strategies in planning efforts	MAG officials and CTOC members	Immediate change is ideal for all trajectories		Road Planning & Land Use Design
State Government [19]	Formal Institution	Institute a gasoline tax to be phased in over time to both fill transportation funding gaps and disincentivize vehicle travel	State legislature would create a proposition, voters must approve the tax, institutions created (or expanded) to manage and oversee the funds	Not required for Plateau and ITLU trajectories, but immediate action is required for Sustainable Phoenix trajectory.	Road Planning & Land Use Design, Vehicle Trips	Vehicle Use, Gasoline Production
Federal or State Government [20]	Formal Institution	“Price on Carbon” (CO ₂)	Congressional (or State legislature) action to create the law and establish pricing system and oversight. If state-level carbon pricing is established, Arizona voters would need to approve a statute.	Not required for Plateau and ITLU trajectories, but immediate action is required for Sustainable Phoenix trajectory.	Road Planning & Land Use Design, Vehicle Trips	Vehicle Use, Gasoline Production

APPENDIX B

TRANSPORTATION METAPHORS IN SUSTAINABILITY

The following is a list of transportation metaphors identified in the literature during this research. The role of path dependence in transportation systems is discussed in Chapters 1 and 2, and even the term “path dependence” is a metaphor for travel.

Path dependence

Pave the way (as in set the right conditions)

Drive... (the results, the behavior, the politics, etc.)

The *road* to... (sustainability, a future state, a situation, etc.)

Intervention *point* (implies the point is a place and the situation has physical dimensions)

Trajectory (implies a destination and a course of events that gets to that destination)

Approach (as in a way of doing something, or a plan)

One-*way*, Two-*way* (as in “a two-way street”)

Bypass

Bridge (a connection)

Avenue (as in explore different avenues)

Shift gears (as in change the way of doing things)

Barriers or *obstructions*

Off-ramp (as in a way to exit the current path)

Detour

Green light (to approve)

On track (on schedule or following the plan)

APPENDIX C

ACRONYMS

AASHTO – American Association of State Highway and Transportation Officials

ADOT – Arizona Department of Transportation

ALCP – Arterial Life Cycle Program

ANL – Argonne National Laboratories

BAU – Business as Usual

BLS – Bureau of Labor and Statistics

BqAZ – Building a Quality Arizona

CAA – Clean Air Act

CCAG – Climate Change Advisory Group

CEO – Chief Executive Officer

CMAQ – Congestion Management and Air Quality [fund]

CMP – Congestion Management Process

CTOC – Citizens Transportation Oversight Committee

CWA – Clean Water Act

DOE – Department of Energy

DOT – Department of Transportation

EIA – Energy Information Administration

EPA – Environmental Protection Agency

FHWA – Federal Highway Administration

FTA – Federal Transit Administration

GAO – General Accounting Office

GHG – Greenhouse Gases

GIS – Geographic Information System

GREET – Greenhouse Gases, Regulated Emissions, and Energy use in Transportation

[model]

GWP – Global Warming Potential

HOT – High Occupancy Toll

H.R. 2454 – The American Clean Energy and Security Act of 2009 (U.S. Congress)

HUD – Housing and Urban Development [U.S. Department of]

HURF – Highway User Revenue Fund

IAD – Institutional Analysis and Development [framework]

IA-LCA – Institutional Analysis and Life Cycle Assessment

ISO – International Organization for Standardization

ISTEA – Intermodal Surface Transportation Efficiency Act of 1991

ITLU – Integrated Transportation and Land Use

LCA – Life Cycle Assessment

LCC – Life Cycle Costing

LCI – Life Cycle Inventory

LCIA – Life Cycle Impact Assessment

LRT – Light Rail Transit

LRTP – Long Range Transportation Plan

MAG – Maricopa Association of Governments

MAP-21 – Moving Ahead for Progress in the 21st century Act of 2012

MCDA – Multi-Criteria Decision Analysis

mmt – million metric tons

MOVES – Motor Vehicle Emissions Simulator

MPA – Metropolitan Planning Area [for transportation management]

MPO – Metropolitan Planning Organization

NHTS – National Household Travel Survey

NHTSA – National Highway Traffic Safety Administration

PaLATE – Pavement Life-cycle Assessment Tool for Environmental and Economic Effects

PM_{2.5} – Particulate Matter of size 2.5 microns or less

PM₁₀ – Particulate Matter of size less than 10 microns, larger than 2.5 microns

PTF – Public Transportation Fund

RARF – Regional Area Road Fund

RPTA – Regional Public Transportation Authority [Valley Metro RPTA]

RTIP – Regional Transportation Improvement Plan

RTP – Regional Transportation Plan

RTP Partners – Regional Transportation Plan Partners

SAFETEA-LU – Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users [Public Law 109-59 of 2005]

SEA – Strategic Environmental Assessment

SES – Social-Ecological System

SIP – State Implementation Plan

STIP – State Transportation Improvement Program

ST-LUIS – Sustainable Transportation and Land Use Integration Study

TAZ – Transportation Analysis Zone

TEA-21 – Transportation Equity Act for the 21st Century [Public Law 105-178 of 1998]

TIP – Transportation Improvement Program

TOD – Transit Oriented Development

TPC – Transportation Policy Committee

TRACI – Tool for the Reduction and Assessment of Chemical and other Environmental
Impacts

TRC – Transportation Review Committee

TTI – Texas Transportation Institute

WTS – Advancing Women in Transportation Systems

VMT – Vehicle Miles Traveled

BIOGRAPHICAL SKETCH

Mindy graduated from the U.S. Military Academy at West Point in 1996 with a B.S. in Environmental Science. She is an officer in the United States Army, and has served as a Human Resources manager (1996-2003) and a Space Operations officer (2008-present). In 2005 she earned an M.S. in Geology from California State University East Bay, and went on to teach environmental science, physical geography, and geology at West Point (2005-2008). Her Army career has taken her to New York, Bosnia, South Korea, Georgia, California, Texas, Iraq, and Washington, D.C. After Mindy completes her PhD program in Sustainability, she will return to West Point for a 3-year assignment teaching environmental science, geology, and ecology. In March of 2013, while pursuing her PhD at Arizona State University, she was promoted to the rank of Lieutenant Colonel in the Army. Mindy is married to Lieutenant Colonel Ray Kimball, an Army aviator and strategic planner who is currently pursuing his EdD in Learning Technology at Pepperdine University. Ray and Mindy have one child, Daniel, who is currently in the 6th grade. The family is rounded out by their dog, Ike, a Jack Russell Terrier who is still a puppy at the ripe age of 14 (98 in dog-years).