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Coordinated Regional and City Planning Using a Genetic Algorithm

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COORDINATED REGIONAL AND CITY PLANNING USING A GENETIC ALGORITHM

by

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ABSTRACT

COORDINATED REGIONAL AND CITY PLANNING

USING A GENETIC ALGORITHM

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Improved methods of planning are needed to deal with today's issues of traffic congestion, sprawl, and loss of greenspace. Past research and recent legislation call for new methods that will consider a regional perspective. Regional planning is challenged with two difficult questions:

1. Is it possible to achieve regional goals without infringing upon the local autonomy of city planners?
2. Is it possible to objectively analyze the thousands, even millions, of land use and transportation plans to find the best design?

Metropolitan regions across the country have made great efforts to answer the first question. Unfortunately, effective methods for harmonizing the goals of regional and city planners have not been developed. Likewise, efforts have been made to introduce objectivity

into the planning process. However, current methods continue to be subjective because there is no way to efficiently analyze the millions of alternative plans for objective decision-making.

This thesis presents a new approach to regional planning that provides an affirmative answer to the two questions posed above. The first question is answered through a unique problem formulation and a corresponding 3 stage process that compels coordination between the regional and city planners. Regional goals are achieved because they are cast as objectives and constraints in stage one. Local autonomy is achieved because some of the decisions are left for the city planners to decide in the second stage. The third stage allows for negotiation between the regional and city planners. The second question is answered through the use of a genetic algorithm. The genetic algorithm provides the means to objectively consider millions of plans to find the best ones.

The new approach is demonstrated on the main metropolitan region of Utah and a local city center within the region. The results from the case study provided the opportunity to learn valuable lessons concerning land use and transportation planning that can be applied to other regions experiencing rapid growth.

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CHAPTER 1. Introduction

As urban populations in the United States continue to increase, citizens are turning to their political leaders to remedy the consequences of rapid growth. It is evident that improved methods of planning are needed to deal with today's issues of traffic congestion, sprawl, and loss of green space. Past research and recent legislation call for new methods that will consider a regional perspective and integrate land use with transportation (Calthorpe and Fulton 2001, Mackett 1994). This thesis presents a new approach to land use and transportation planning for regions facing rapid growth.

1.1 The Wasatch Front Metropolitan Region

The Wasatch Front Metropolitan Region (WFMR) in the state of Utah shares the challenges confronting metropolitan regions across the country. The WFMR consists of Weber, Davis, Salt Lake and Utah counties. The major urban centers in the WFMR are Salt Lake City, Ogden, Provo and Orem as illustrated in Figure 1.1. The region experienced a phenomenal 27 percent increase in population from 1990 to 2000 to a population of 1,702,450 residents. The Governor's Office of Planning and Budget (GOPB) projects that by 2020 the population will be 2,401,000 – a 41 percent increase over a twenty year period.

The concern of rapid growth in the WFMR is heightened by geographic constraints. The region is tightly confined between the Wasatch mountain range to the east, and the Great Salt Lake and Utah Lake to the west. The result is a narrow strip of developable land approximately 100 miles long from north to south and 20 miles wide from east to west. Notwithstanding these limitations the region is home to an astonishing 76 percent of the state's residents (Governor 2003).

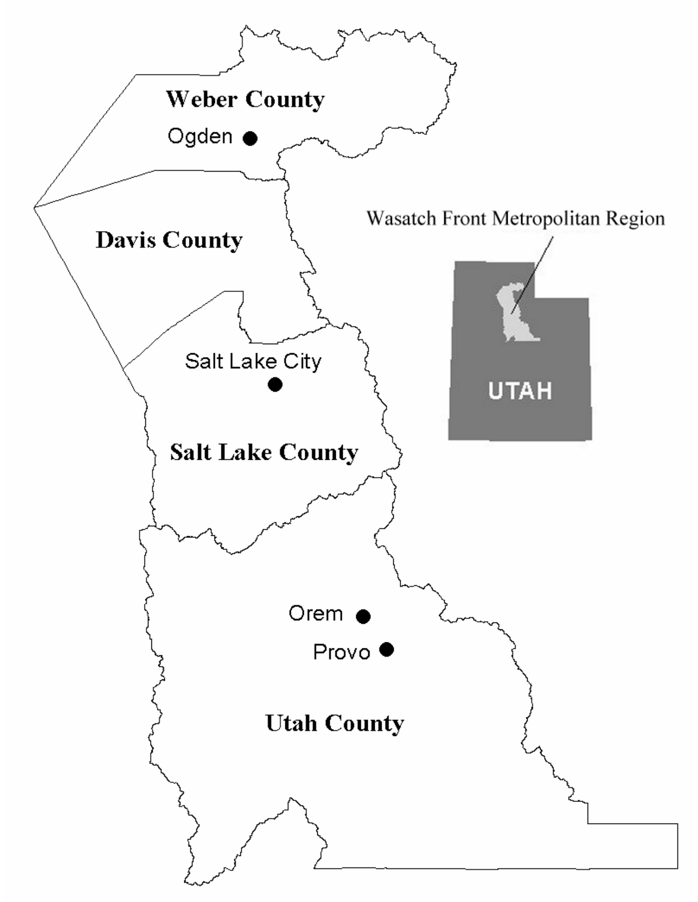


FIGURE 1.1 The Four Counties of the Wasatch Front Metropolitan Region

One obvious adverse effect associated with population growth is increased traffic congestion. The Texas Transportation Institute (TTI) reported that congestion in the Salt Lake area increased 440 percent between 1982 and 1996 (Davidson 1998). In the years leading up to the 2002 Salt Lake City Winter Olympics, traffic congestion was the state's top priority. Dozens of communities united to manage the 50,000 excess visitors per day to the Wasatch Front. This collaborated effort employed millions of dollars to enhance the transportation network from Ogden to Provo (Salt Lake Chamber of Commerce 2003).

Making preparations to host the world at the Olympics wasn't the first time that Utah communities saw the need to work together. In 1969 the local governments of Davis, Weber and Salt Lake Counties established the Wasatch Front Regional Council (WFRC) in response to the shared needs of the area (Wasatch Front Regional Council

2003). Two years later in 1971, seeing the benefits of such an organization, the local communities of Utah County and two neighboring counties not considered part of the WFMR organized the Mountainland Association of Governments (MAG) (Mountainlands Association of Governments 2003). These organizations were a step ahead of federal legislation that passed just a few years later. In 1975 the Federal Highway Administration and the Urban Mass Transit Administration Joint Regulations on Urban Transportation Planning (FHWA-UMTA) enumerated conditions under which federal assistance would be granted to urban areas. The new legislation required the establishment of a Metropolitan Planning Organization (MPO) (Meyer and Miller 2001). WFRC and MAG were soon deemed MPOs with jurisdiction over 45 cities and 25 cities, respectively, along the Wasatch Front. Although politically weak themselves, these alliances have aggressively sought ways to amalgamate the individual goals of the cities to achieve regional needs.

More recently, also in response to rapid regional growth, Governor Michael Leavitt held a "Growth Summit" in December of 1995. At the summit federal, state, local, and private groups presented and discussed ways to manage the region's population explosion. The three-day event attracted thousands of citizens and received unprecedented media coverage including a joint effort by all the major television stations to fully cover the workshops and lectures (Fouhy 1996). A Dan Jones poll prior to the Summit suggested a feeling of indifference toward transportation issues, while another poll taken shortly after the Summit revealed that Utahns viewed transportation problems as more important than crime, education, gang violence, and other social concerns (Growth Summit Survey Results 1995, KBYU College Exit Poll 1996).

In addition to increasing public awareness of growth issues, the Growth Summit resulted in the creation of two organizations that have continued to search out ways to manage growth along the Wasatch Front. The first, a state funded technical committee, known as Quality Growth Efficiency Tools (QGET), is coordinated by the GOPB. The other group, Envision Utah, is sponsored by a private non-profit organization called The Coalition for Utah's Future. Over the past decade these two organizations have worked independently and jointly to produce a variety of land use and transportation plans intended to curb the adverse effects of growth in the WFMR (Envision 1999).

1.2 Regional Planning

The federal, state, and private organizations that have risen in the WFMR over the past few decades must confront the same two difficult questions that are faced by other metropolitan regions throughout the United States:

1. Is it possible to achieve regional goals without infringing upon the local autonomy of city planners?

2. Is it possible to objectively analyze the thousands, even millions, of land use and transportation plans to find the best design?

The first question is a problem of regional and city coordination. An extreme solution is to circumvent coordination entirely by granting all authority to the regional planners. Obviously this would facilitate regional progress, but it would be politically impossible in most states and especially in Utah, which is arguably the most conservative state of the Union. Communities throughout Utah have enjoyed political autonomy for decades and are slow to concede power to higher levels of government such as regional agencies. The other extreme is to let the cities do what they want, completely neglecting the concerns of the region. This is what is currently happening in the WFMR, and regrettably, the communities often strive for different goals. The result has been undesired sprawl, increased traffic congestion, loss of valued green space, and stalemated improvements. It is evident that some form of coordination is necessary. Fortunately, recent citizen input suggests that Utah residents are willing to find the proper balance (Calthorpe and Fulton 2001, Jones 2003).

The second question solicits an approach to planning that incorporates objectivity. Traditional planning methods are inherently subjective because planners simply cannot examine the infinite number of plan possibilities. Instead planners typically design and analyze just a few plans. The plans are selected for analysis based on the preferences of the stakeholders and the experience of the planners (Solnit 1988). Unfortunately, this meager and inevitably biased selection does not represent the full range of possibilities. For example, shortly after the Growth Summit, Envision Utah presented to the public four future plans for the WFMR (Envision 1999). Many Utahns felt that three of the plans were deliberately inferior and that Envision Utah was railroading their ideologies in the clearly-better, fourth choice (Simmons 1999). This experience demonstrates that citizens want to know that a variety of alternatives are being objectively considered before a final decision is made.

The innovative approach of this thesis successfully answers the two questions posed above. The approach encourages coordination between regional and local planners through its formulation of the problem and a corresponding three-stage planning process. As will be explained, this formulation and process create a division of the decision-making, effectively allowing regional planners to achieve their goals while giving city planners adequate autonomy. Furthermore, this approach produces unbiased plans by objectively examining millions of alternatives with the aid of a genetic algorithm. It will be demonstrated that by harnessing the power of the computer, a genetic algorithm is an effective method to simultaneously evaluate land use and transportation plans.

The approach was developed as part of a research project at Brigham Young University (BYU) sponsored by the National Science Foundation (NSF). A previous NSF sponsored project at BYU sought to employ optimization techniques in the city planning process. Accordingly, a genetic algorithm was applied to city planning with a variety of formulations (Balling, et al. 1999). This thesis represents the first time that the genetic algorithm has been formulated and executed for a region. Furthermore, this is the first time that the three-stage process intended to achieve regional and city coordination has been implemented.

This thesis is divided into six chapters. Chapter 1 provides an introduction to the research including a definition of the problem and a brief explanation of the approach used to address the problem. Chapter 2 will present previous research and current planning practices dealing with the two questions introduced above. Chapter 3 will describe the new approach. Chapter 4 will present the first stage of the three-stage process; the formulation and execution for a region (the WFMR). Chapter 5 will demonstrate how the results from the first stage are passed on to a city for the second stage; the formulation and execution at the city level (Provo and Orem cities). Chapter 6 will provide conclusions and make suggestions for further work.

CHAPTER 2. Previous Research and Current Practices

This chapter will present previous research and current planning practices that seek to answer the two questions introduced in Chapter 1. It will be shown that efforts have been made to improve coordination between regional and city planners, yet specific methods for coordinating goals have not been fully developed. Likewise, advances have been made to incorporate objectivity into the planning process, but subjective planning is still the norm.

2.1 Region and City Coordination

In the past, land use and transportation planning only occurred at the city level. Most cities in America were founded prior to the invention of the automobile and airplane, at a time when long distance travel was lengthy, difficult, and often dangerous. Consequently, transportation was an intra-city concern and land use decisions did not consider more than the immediate area. Recently, however, a change of perspective has occurred (Burchell 1997). Travel is no longer viewed as something confined to a single city. Advances in communication and transportation have widened the boundaries of economic activity well beyond city borders. Metropolitan centers have expanded and diffused with neighboring communities, creating large, conglomerate urban areas. As a result, political leaders and planners across the country have been compelled to assume a regional perspective (Calthorpe and Fulton 2001).

Unfortunately, the new perspective has not been easy to swallow. Conflict is commonplace in today's planning arena (Steiner 1978). Cities continue to focus only on the land within their boundaries and they are often oblivious of the plans of their neighbors. Regional planners, seeking to maximize the benefit of the whole, often disregard the interests of individual cities when making plans. Planners have been challenged with an inability to align regional and local goals (Swenson and Dock 2003).

Numerous attempts have been made to overcome this challenge. As was mentioned in Chapter 1, the federal government established an act in 1975 that introduced the MPO to the planning process. This political body, made up of officials from around the region, must prepare regional plans to obtain federal funds for transportation projects. In 1998, the Transportation Equity Act for the 21st Century (TEA-21) gave additional power and funding opportunities to MPOs. Notwithstanding the help from the federal government, MPOs still have difficulty competing with local governments (Meyer and Miller 2001). Many MPOs, elected leaders, and other non-government organizations have made efforts to take the situation into their own hands.

One region that stands out for its work to coordinate regional and city goals is Atlanta, Georgia. Atlanta is notorious for having more sprawl than any metropolitan region in the nation (Calthorpe 2001). In 1996 the summer Olympics were held in Atlanta and, just as it did for the WFMR, this event brought the transportation problems of the region into focus. An extensive effort was made by the local MPO to establish a "vision" for the region. A vision statement was created based on feedback from public hearings, surveys, newspaper stories, newsletters, and community focus groups. The statement outlined goals of the region concerning land use and transportation (Atlanta Reference 2000). By 1998, few improvements had taken shape and the state was facing the loss of $1 billion in federal transportation funds for non-compliance with the Clean Air Act. The newly elected governor made a radical move to ensure that the improvements necessary to keep the funds were accomplished. He significantly altered Atlanta's structure of planning through the establishment of the Georgia Regional Transportation Authority (GRTA). The GRTA usurped power from the Department of Transportation (DOT) and MPO for certain planning decisions. Many improvements were made and the funds were secured, but it is still too early to say how the GRTA will benefit the metropolitan region of Atlanta (Meyer and Miller 2001).

Another region that has made great efforts to mitigate regional and city disagreement is Seattle, Washington. Like the WFMR, the Seattle region is confined to a narrow strip of land. Mountains and lakes lie on the west and the Puget Sound lies on the east. Since the era of environmentalism in the 1960s there has been a strong desire to protect the mountains and coastline from sprawl. Hopes for a completely pristine region were shattered in the 1980s when Seattle emerged as a major international port and became the home of various booming companies such as Microsoft, Boeing, and Starbucks. In 1991, in response to the rapid growth, a new MPO was created. This revised MPO is unique because it gives weighted voting power to each city within the region, to the DOT, and to three port authorities. Also in 1991, the state passed the Growth Management Act. This act empowered the MPO to challenge the NIMBY (not in my backyard) mentality of cities by forming a court of appeals to hear land use and transportation complaints made by the cities. The act encouraged communities to have a stronger voice through incorporation or annexation to existing cities. By 2001 thirteen new cities were incorporated. Recently, the MPO selected 5 plans, including a "do nothing plan", to be evaluated by the public. Feedback from the evaluation was used to create a report called Vision 2020. The report establishes a framework for the cities to use when making planning decisions (Calthorpe and Fulton 2001). Notwithstanding these advances, it is felt that the voice of the public is not being appropriately considered (Nyerges et al. 2004).

The region most famous for its struggle to rectify regional and city conflict is Portland, Oregon. Portland's efforts have been driven by a powerful MPO and an aggressive non-profit organization called 1000 Friends of Oregon (an organization much like Envision Utah of the WFMR). The members of 1000 Friends first made waves in regional issues with an intense opposition to a proposed highway that would endanger large tracts of greenspace. The organization knew that to effectively block the construction of the highway they had to suggest alternatives, so they embarked in a now nationally celebrated research project called Making the Land Use, Transportation, Air Quality Connection, or LUTRAQ (Cambridge Sytematics 1991). LUTRAQ helped formulate regional goals with an emphasis on transit and non-motorized modes of transportation. Meanwhile, Portland's MPO selected four regional plans, including a "do nothing plan", to be examined and critiqued by the city planners and citizens of the region. After some discord, 1000 Friends and the MPO came together to produce a vision for land use and transportation for the year 2040. The vision statement describes the impact of regional policies on cities. The coalition between 1000 Friends and the MPO has been successful because the former is able to make bold and radical suggestions for change without fearing the backlash of city governments, while the latter is able to implement policies with a heavy hand (Calthorpe 2001). The two organizations have successfully managed to make much of the 2040 vision a reality; however there is ongoing debate over many of the particulars of the vision.

The efforts to coordinate regional and city goals in the WFMR are comparable to those of the three cities described above. As was mentioned in Chapter 1, there are a variety of organizations striving to define a common vision for Utah's future. Although the region is relatively small and typically considered homogenous, it has been difficult to establish such a vision. Case in point is the ongoing debate over the Legacy Highway. Plans for the Legacy Highway began in the 1960s. The plan is to create a highway parallel to the existing north-south interstate but on the other side of the corridor. In 1998 the Utah Department of Transportation (UDOT), supported by the governor of Utah, released a Draft Environmental Impact Statement (DEIS). Shortly after the release of the DEIS, community groups throughout the region united to stop the construction of what they claimed would destroy precious wetlands, consume productive farmland, and increase air pollution. Two years later the UDOT secured the wetlands permit necessary to continue the work on the project. Outraged citizens, this time backed by the Sierra Club and the Mayor of Salt Lake City, filed a lawsuit over the validity of the permit. In 2001, the U.S. 10th Circuit Court of Appeals put a halt to the Legacy Highway until further environmental impact studies are completed. This example illustrates the conflict that can arise because of differing goals. Unfortunately, there has been little research to develop methods for managing the conflict or harmonizing goals (Barnes and Langworthy 2003).

2.2 Automation and Objectivity

The advent of the computer in the 1950s introduced the opportunity for automation and objectivity to the planning field. The task of planning has always been to choose a land use and transportation plan that meets the needs of the people, and since there are an infinite number of possibilities, planners eagerly welcomed the opportunity to expedite the work through computer models. Over the years various land use/transportation models have been developed. The majority of the models have focused on plan analysis rather than plan selection. Despite this weakness, the two waves of development that have occurred since 1950 have produced a number of commercially available models.

The first wave of models arose in the 1960s and early 1970s at a time of widespread confidence in science and technology. These complex, large-scale models were based on the long-range planning theories of the time (Lee 1974). They included: EMPIRIC developed by Hill, Brand, and Hansen (Hill 1965), the Lowry model developed by Ira Lowry of the Rand Corporation (Lowry 1964), NBER developed by the National Bureau of Economic Research (Ingram et al. 1972), and CAM developed by the MIT-Harvard Center for Urban Studies (Birch et al. 1974).

These early models were greatly influenced by the 1962 Federal–Aid Highway Act which required a "comprehensive" consideration of the forecasts of "activity and travel" (Meyer and Miller 2001). This Act marked the first time that attempts were made to integrate land use planning with transportation planning. Figure 2.1 shows the basic structure of a typical model that integrates these two aspects of planning.

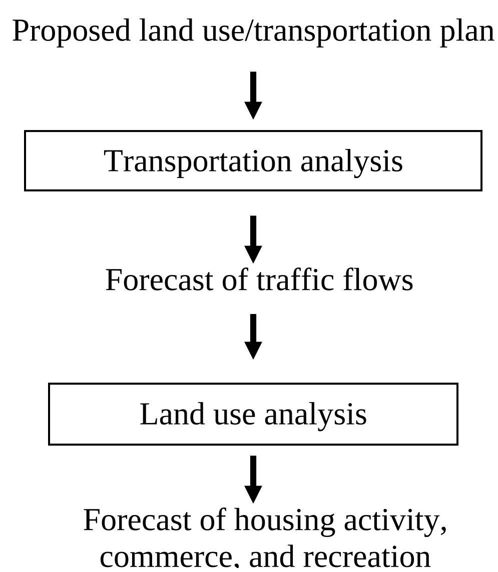


FIGURE 2.1 The Structure of a Typical Land Use-Transportation Model

As is illustrated in Figure 2.1, the input for the typical model is a single land use/transportation plan. The proposed plan, or policy, might entail a change in zoning, an improvement in a transportation corridor, or it might even be a “do nothing” plan. The computer model quickly analyzes the plan to produce a forecast of the traffic flows, which in turn are used to predict the impact the proposed plan will have on the various land uses.

In most models, the analysis for traffic flows is accomplished through the Urban Transportation Modeling System (UTMS). The UTMS is a well-accepted four-step process with various methods for achieving each step. Since nearly all models, as well as the new approach of this thesis, employ the UTMS, a general understanding of this ubiquitous process will prove to be valuable to the reader.

The first step, called Trip Generation, is the prediction of the number of trips produced by and attracted to each land use. The most common method used to make these predictions uses field observations and simple linear regression. The regression produces trip rates that can be used for the production/attraction predictions. The Institute of Transportation Engineers (ITE) Trip Generation Manual summarizes trip rates according to land use type. Tables 2.1 and 2.2 presents representation trip rates for the commute period of the day, called the Peak Hour, and for the non-commute period of the day, called the Off-Peak Period, respectively (ITE 1997). The trip rates in Tables 2.1 and 2.2 are in vehicles per hour (vph).

TABLE 2.1 Peak Hour Trip Rates

Land Use	Attraction (vph per acre)	Production (vph per acre)
Single family residential	1.32	3.08
Retail commercial	3.74	3.74
Agricultural	0.25	0.75

TABLE 2.2 Off-Peak Period Trip Rates

Land Use	Attraction (vph per acre)	Production (vph per acre)
Single family residential	1.09	1.09
Retail commercial	3.57	3.57
Agricultural	0.5	0.5

The second step of the UTMS, Trip Distribution, is the prediction of the origin and destination for the trips predicted from Trip Generation. In other words, in this step the trip productions are matched with the trip attractions. There are various methods for making these predictions, but the most common is the gravity model. This model is so named because the formula resembles the gravitational interaction experienced by physical bodies in space. The result is that trips produced near a particular attraction are more likely to go to that attraction than to a different attraction farther away.

The third step of the UTMS is Modal Split. In this step the trips are split between the available modes, such as auto, transit, bicycle, or walking. There are a number of methods for making these predictions. The usual variables for these methods include socioeconomic characteristics, such as income, household size, and auto ownership; characteristics of the urban landscape, such as distance from the CBD and population density; and characteristics of service for each mode, such as travel times and costs.

In the fourth step, Trip Assignment, the specific route through the link-node network is predicted for each trip. The simplest technique for predicting the route is called Minimum Path Assignment. Through this method, trips are assigned to the route with the shortest travel time regardless of the number of trips already assigned to that particular route. Obviously this technique would produce unrealistic results due to changes in route choice because of congestion (Meyer and Miller 2001). A more realistic stochastic method was proposed by Dial in 1971. This method, referred to as Dial's Multipath Assignment model, routes trips through one of the many potential paths based on probabilities (Dial 1971).

The traffic flows predicted through the UTMS are combined with the initial input for the analysis of land use impacts. The result is a forecast of housing activity, commerce, and recreation based on economic theory. For example the models typically incorporate economic base theory, bid-rent theory, input-output modeling theory, random utility theory, and discrete choice theory (Clay 2003).

The UTMS and the economic theories implemented in the first wave of models faced many challenges in practical application. Despite the excitement put forth by developers, practitioners rejected these early models for a variety of reasons. Foremost, the models required huge amounts of input that was not typically available or not reasonably attainable. Furthermore, the models were extremely complex, not user friendly and executed on weak computers (Lee 1973). These problems coupled with a paradigm shift in planning theory, from long range planning of the 1960s to short term planning of the mid 1970s, resulted in a disappearance of computer-aided planning (Mackett 1994).

In the 1980s, however, a second wave of models arose and has continued to advance through the past two decades. Improved software capabilities, remarkably faster processing speeds, and better data storage capabilities have compelled a renewed interest and confidence in computers. One noteworthy advance was the development of GIS software with its ability to provide visual understanding to large data sets. In conjunction with these technological advances, various agencies have been gathering large amounts of potential input through censuses, surveys, and field studies (Miller and Salvini 2000).

The current models, which are part of the second wave of model development, seek to integrate land use and transportation planning like their predecessors. However, a few of the models are actually land use models that can be interfaced with any external transportation model (Clay 2003). Three of the most popular models of this type are Urbansim (Waddell 1998), DRAM/EPAL (Putman, 1983), and PECAS (Hunt and Abraham 2003). The most common fully integrated models are TRANUS (Barra 1982, 1989) and MEPLAN (Echenique et al. 1990).

Notwithstanding the advances made in the second wave of models, most metropolitan areas do not currently employ land use/transportation models (Mackett, 1994). In Utah, there has been academic investigation of Urbansim interfaced with the state’s transportation model, previously called MINUTP but recently renamed to TP+ (Waddell 2003). Yet in practice Utah planners, like those of other regions, feel that the current models are still too data intensive, too complex, too expensive, and produce unreliable results. There simply is not enough skill in most DOTs and MPOs to execute the land use/transportation models of the day. To be useful on a practical level models need to have simple input that is GIS based and is executed through a simple program (Southworth 1995). Furthermore, the commercially available models only attempt to perform the analysis of plans, leaving the decision of which plans should be selected for analysis to the planners.

There has been one attempt to automate the selection of plans for analysis. In 1980 an Australian research team presented a model, called TOPAZ, which selected plans according to user defined constraints (Brotchie et al. 1980). The model was applied to various locations, including a suburban area in northern Virginia facing rapid growth. The Australian/American team that worked on the Virginia project concluded that the model did not select realistic plans, and therefore there is not a clear understanding of the role that TOPAZ should have in the planning process (Dickey and Leiner 1983). The TOPAZ model continues to be in an early state of research and development (Cambridge Systematics 1991).

The models that have been developed over the years successfully automate the analysis of plans, however objectivity is inhibited by their focus on prediction. Metropolitan regions that do use models, use them to select plans in a three-step process. First, they subjectively create a number of plans. Second, the plans are analyzed. Third, the results of the analyses are evaluated and a plan is selected for implementation. The employment of computer models greatly facilitates this process, but many alternative plans are never considered for analysis, and thus the process continues to be subjective. The problem is that there are millions of alternatives and a method has not been developed for examining more than one plan at a time.

CHAPTER 3. A New Approach To Regional Planning

This chapter introduces a new approach to regional planning that successfully answers the two questions posed in Chapter 1. It formulates the planning problem and describes the computer algorithm used for execution. This methodology will hereafter be referred to as the *Urban Genetic* approach and will be illustrated on a case study in the succeeding two chapters.

3.1 Formulation and Process: Region and City Coordination

The first question presented in Chapter 1 asks for a planning method that provides regional planners the opportunity to achieve regional goals without infringing upon the local autonomy of the city planners. Regional planning should not attempt to micromanage city planning by taking over zoning and street design for each city. Cities ought to have the power to make these decisions, however if they ignore regional planning altogether, then regional goals will not be achieved resulting in a chaotic and inefficient situation. The Urban Genetic approach finds the proper balance by dividing the planning decisions between the regional and city planners.

Land use decisions are divided into *district* planning and *zone* planning, to be done by the region and the city respectively. The developable land of the region is delineated into districts which are subdivided into zones. Each zone is defined by a single land use, so that a district is a conglomerate of many land uses and is described by land use percentages as shown in Figure 3.1. The regional planners accomplish district planning by deciding future land use percentages for each district of the region. The percentages they choose are passed on to the cities as *targets* for zone planning. City planners are responsible for determining the particular land uses for each zone, but must strive to match the target percentages. This two stage process provides a means for meeting regional land use goals while granting city planners the authority to decide the details. A third stage is the period of negotiation and compromise between the regional and city planners.

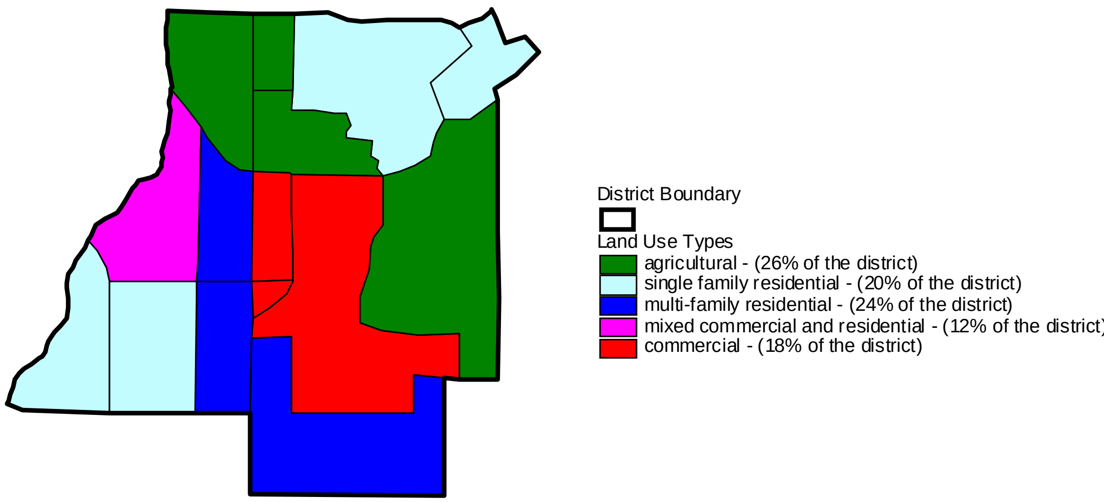


FIGURE 3.1 A Regional District Comprised of City Land Use Zones

Most cities have well established zoning maps to delineate zones, however, district boundaries must be determined through a coordinated effort between the city and regional planners. The districts need to be small enough to provide regional planners sufficient flexibility to meet land use goals. Yet, if a district is too small, it will only encompass a few zones. This limits the cities' ability to match the target land use percentages and effectively diminishes local autonomy. Furthermore, the cities have to be able to examine the zones within a district collectively and with sole jurisdiction. In other words, a single city must have the ability to change the zones within a district without the possibility of censure from an opposing political body. Consequently, districts need to be drawn according to political boundaries, such as county, city, neighborhood, and voting boundaries, with appropriate consideration of the number of zones per district. In this way, large cities might have responsibility for a number of districts while small towns may be considered just one district.

The land use decisions for zone planning are formulated as a discrete design problem. Table 3.1 presents a sample list of possible land use types. Note in the table that each land use type is given an integer value. The city planners must choose an integer value (land use type) for each design variable (zone). Thus a city's land use plan can be represented by a string of integers, where each point along the string corresponds to a specific zone. The planners may decide to reduce the list of possible land use types for some zones. For example, they may wish to preserve a residential area or agricultural area, so for those zones they would only consider a subset of the complete list of possibilities. In this example, such zones could only take on the integer values 1, 2, and 6 from Table 3.1.

TABLE 3.1 List of Land Use Types that Could be Used for Zone Planning

Integer Value	Land Use Types	
1	R1	Single Family Residential
2	R2	Duplex and Four-Plex Residential
3	C1	Retail Commercial
4	C2	Industrial Commercial
5	PL	Public Lands: Airports, Universities, Churches
6	AG	Agricultural

In district planning, the regional planners specify target land use percentages for each district. This design decision is made discrete by creating a list of land use percentage *scenarios* to choose from. A sample list of possible scenarios, with integer representation, is shown in Table 3.2. Like the city planners, the regional planners must decide on an integer value (scenario) for each design variable (district). Once again, it may be decided that the complete list is not suitable for every design variable. For instance, it is probable that some small towns would refuse an urban scenario assignment. District by district, the planners can choose a subset of allowable scenarios.

TABLE 3.2 List of Scenarios that Could be Used for District Planning

Integer Value	Land Uses (%)					
	R1	R2	C1	C2	PL	AG
1	15	10	40	20	15	0
2	35	5	30	15	15	0
3	40	10	0	0	0	50
4	50	10	0	0	20	20
5	85	5	0	0	10	0

The list of possible scenarios must meet the needs of the regional planners. Two things should be kept in mind when creating this list. First, it must be diverse enough to provide the planners adequate flexibility when creating plans. Second, it must have scenarios capable of representing the status quo of every district to provide the possibility of unchanged districts.

The status quo land use percentages of the districts are used to create the scenarios. Most regions have hundreds of districts, each with a unique status quo land use percentage. These percentages could be used, but a list that large would be overwhelming for the planners and many of the percentages would be essentially the same. Therefore, the similar status quo percentages are grouped together and the mean percentage for each group is calculated to define a single scenario. This creates a list of scenarios that represents the region, while reducing the number of choices to a manageable list. In addition to these scenarios, the planners might decide to include fabricated scenarios, or scenarios taken from other regions to introduce new land use compositions to the region.

The decision making for the transportation network is divided between regional and city planners in a similar way. First the regional planners design the *inter-district streets*, the major streets that run through multiple districts. This allows them to produce a transportation plan that addresses regional concerns. The plan is passed on to the cities to be used as a framework for designing the *intra-district streets*. The intra-district streets carry mostly local traffic and run through just a few districts.

Developing a street plan is a discrete design problem. The streets, either inter- or intra-district, are the design variables. Each street must be assigned a street class. The different classes represent varying volume capacities. For collectors and arterials, volume capacity is a function of the number of lanes and the design speed, while freeways are given a fixed capacity. Table 3.3 gives integer values to some typical street classes. The planners must specify an integer value for each street for which they have responsibility.

TABLE 3.3 List of Street Classes that Could be Used for Street Planning

Integer Value	Class	Number of Lanes	Design Speed (mph)	Volume Capacity (vph)
1	C2	2	30	1600
2	C4	4	35	3240
3	A4	4	40	3380
4	A6	6	45	5340
5	F	freeway	65	13000

The purpose of land use and transportation decision making is to develop a *plan.* As was explained earlier, a plan is created by giving integer values to every design variable. Planners must determine which plan is the "best" for the region or city.

The criteria for defining "best" consists of constraints and objectives which are functions of the design variables. Constraints are maximum or minimum requirements that must be met for the plan to be *feasible*, or acceptable. Some plans might surpass the constraint requirements, to which the planners are unconcerned, as long as the plan is feasible. Objectives, however, are goals without maximum or minimum limits. In other words, plans are more favorable if they excel in the objectives. In summary, the "best" plans are feasible and meet the objectives relatively better than the other alternatives.

Feasible plans must satisfy three minimum constraints: required housing capacity, required employment capacity, and required greenspace percentage. A plan's housing capacity is the number of people that can be supported by the plan's residential land, while employment capacity is the number of jobs that can be supported by the plan's commercial land. Population growth forecasts are used to set the minimum requirements. In this way, no matter which plan is selected, the future needs of the region are guaranteed to be met if the plan is deemed feasible. A plan's greenspace percentage is simply the amount of greenspace included in the plan, considering that nearly every land use type has some portion of greenspace. The required percentage is determined by the region or city. This constraint guarantees that development does not completely consume desirable greenspace.

One objective is to *minimize total travel time*, that is, to minimize the sum travel time of all trips within a region or city in a 24-hour period. A plan's land use pattern determines trip volumes throughout the day, while the ability to accommodate the volumes is dependent on the street classes. Regions and cities can use total travel time to measure traffic congestion and average commute times.

Another objective is to *minimize change from the status quo*. Experience suggests that most residents are adverse to change and wish to preserve the status quo as much as possible. On the other hand, land use and transportation plans that resemble the existing conditions are usually well received by the public.

The design variables, constraints and objectives for the region are formulated for Stage One of the Urban Genetic approach. The problem is written formally as:

Stage One: Regional Problem

Find:
- a scenario for each district
- a street class for each inter-district street

Minimize:
- total travel time
- change from the status quo

Satisfy:
- required housing capacity
- required employment capacity
- required greenspace percentage

In Stage Two, the results from the region are passed on to the city and used to solve the city design problem in much the same way. In this stage, however, there is an additional objective, *minimize deviation from the target scenario.* Recall that the city planners must strive to match the target percentages defined by the regional planners. The additional objective aims to minimize the mismatch between the district planning of the region and the zone planning of the city. The problem is written formally as:

Stage Two: City Problem

Find:	• a land use type for each zone • a street class for each intra-district street
Minimize:	• total travel time • change from the status quo • deviation from the target scenario
Satisfy:	• required housing capacity • required employment capacity • required greenspace percentage

The additional objective in Stage Two, deviation from the target scenario, is intentionally formulated as an objective rather than a constraint. If it were a constraint, the cities would have to match the targets with absolute compliance. This would be impossible because the zones have fixed areas, and therefore there is a restraint on what land use percentages can be attained for a district. No matter how the zones are assigned, they will most likely not be able to match the exact percentage specified by the target. More importantly, since the importance of each objective can be viewed differently, the cities are given the freedom to decide the significance of the target objective relative to the other two objectives. In fact the city planners can choose to completely disregard the targets. Unfortunately, if one city refuses to comply, the entire region may suffer. Complete acquiescence is not necessary, but a certain degree of compliance must be required by the region.

The required level of compliance is determined in Stage Three. In this stage, the MPOs, which are conglomerate counsels made up of various cities, provide a forum for accountability and negotiation. The counsel may ask the regional planners to assess the damage incurred from a particular city's noncompliance. The regional planners could use traffic models and sensitivity tests to demonstrate the extent of the impact on the region. Based on the assessment, the counsel would then decide if the city should be pressured to conform.

The three stages of the Urban Genetic approach facilitate coordination between the region and the cities within it. The land use and transportation decisions are divided in a way that allows both regional and city planners to pursue their specific goals. Table

3.4 summarizes the three stages of the Urban Genetic approach. Chapters 4 and 5 will illustrate Stages One and Two, respectively, on a case study. Stage Three will not be illustrated in this thesis because it must be studied in a real life setting where the pressures of politics are free to work naturally.

TABLE 3.4 The Three Stages of the Urban Genetic Approach

Stage One: Regional Planners	**Stage Two:** City Planners	**Stage Three:** Regional and City Planners
-Decide which scenario is best for each district -Decide which street class is best for each inter-district street	-Decide which land use type is best for each zone while tying to match the regional target scenario plan -Decide which street class is best for each intra-district street within the framework of the regional inter-district street plan	-Negotiate and compromise

3.2 Genetic Algorithm: Automation and Objectivity

The second question presented in Chapter 1 asks for a planning method that creates and analyzes alternatives with objectivity. The citizens of a region or city want to know that a variety of plans have been equally considered before a final decision is made. Unfortunately, there are an infinite number of possibilities and traditional methods of analysis are very time consuming. Planners typically only analyze a handful of plans that have been created based on their experience and the preferences of the most vocal stakeholders. The Urban Genetic approach uses a computer algorithm to quickly analyze millions of alternatives to develop plans without preferential bias.

An algorithm is a step-by-step procedure for finding solutions to a problem. The complete set of all possible solutions is called the *design space.* Computers are used to automate the execution of an algorithm to *search* the design space for the best solutions.

The most basic algorithm is exhaustive search. Through exhaustive search the planners would analyze every plan in the design space until the best plan is found. Unfortunately, the design space of the planning problem is too immense for this type of algorithm. Consider the finite number of solutions from the discrete formulation of the Urban Genetic approach. The number of possible plans is calculated as outlined in equation 3.1:

$$N = X^a * Y^b \tag{3.1}$$

where:
- a = number of districts (or zones)
- b = number of streets
- X = number of possible scenarios (or land use types)
- Y = number of possible street classes
- N = number of possible plans

For example a region with 200 districts, 20 possible scenarios, 50 streets, and 10 possible street classes would have:

$$N = 20^{200} * 10^{50} = 1.6*10^{310} \text{ possible plans.}$$

Even with the fastest computers available, exhaustive search would require too much time to be practical. If a single plan could be analyzed in just one second, it would take $2*10^{220}$ years to analyze $1.6*10^{310}$ plans. Consequently, an optimization algorithm must be used. Optimization algorithms do not attempt to analyze every possible plan; instead they find trends in the design space that lead to the best plans, significantly reducing the execution time.

There are various optimization algorithms. One group uses calculus to differentiate the constraint and objective functions. Such methods cannot be applied to this problem because the design variables are integer valued rather than real valued and therefore the constraint and objective functions are non-differentiable.

Genetic algorithms are the most appropriate optimization algorithm for this problem. They are very efficient when searching problems with an extremely large design space and they can effectively search non-differentiable functions. The most important advantage is that they are multi-solution algorithms. Other optimization algorithms begin with one starting plan and iteratively change that plan to produce a single, final plan. A genetic algorithm is unique because it begins with a group of plans, called a *generation*, and iteratively changes the entire group to produce a *final generation* of "good" plans. The final generation is a spectrum of solutions with tradeoffs between the various objectives. Recall that the regional problem has two objectives and the city problem has three objectives. A plan from the final generation might be excellent in one objective, yet not as good in the other objectives. The final generation gives planners the opportunity to explore tradeoffs in the objectives before choosing a single plan.

Figure 3.2 shows the general procedure of the genetic algorithm used in the Urban Genetic approach. Let *nsize* be the number of plans in a generation and let *ngener* be the number of generations until the final generation. The algorithm loops through the generations to produce the final generation. The steps of the procedure will be explained below.

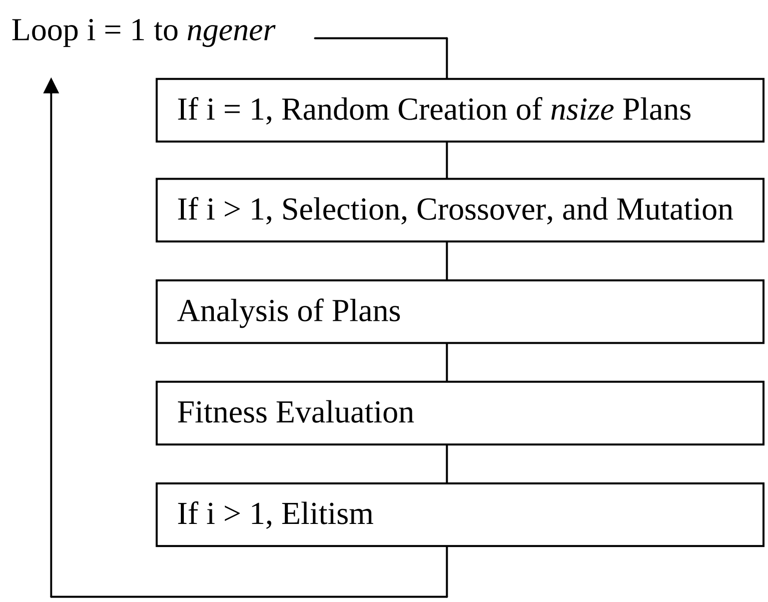


FIGURE 3.2 The Procedure for the Urban Genetic Approach

The first time through the loop a random generation of *nsize* plans is created. This is accomplished by randomly assigning integer values to the design variables (i.e., districts or zones and streets). Each design variable is called a *gene.* A plan is represented as a string of genes called a *chromosome*. Figure 3.3 shows three randomly created plans represented by chromosomes. Note that if the integer value of any of the genes were to be changed, a different plan would be represented.

integer values randomly
given to each *gene*
(district or zone and street)

Plan 1: 382387613744279965775344896371897697

Plan 2: 124692718327953564495922377929763527

Plan 3: 858461416591499332711564376727291624

FIGURE 3.3 Chromosome Representation of Three Randomly Created Plans

As was shown in Figure 3.2, the algorithm skips Selection, Crossover, and Mutation the first time through the loop. The next step is Analysis of Plans. In this step, the constraint and objective functions are calculated for each plan. Recall that the constraints are minimum requirements for housing capacity, employment capacity, and greenspace percentage. These values are calculated using housing densities, employment densities, and greenspace percentages that have been specified for each scenario and land use type. The objectives are minimize total travel time, minimize change from the status quo, and, for Stage Two, minimize deviation from the target scenario.

Total travel time is the sum travel time of all trips within a region or city in a 24-hour day. It is measured in hours. The algorithm analyzes each plan following the UTMS four-step model. The 24-hour day is divided into two periods: the peak commute period, and the off-peak period. For each period, trip production and attraction rates are specified for the scenario and land use types using the ITE Trip Generation Manual. Trip origins and destinations are predicted through the gravity model. The trips are assigned to links in the network according to Dial's multipath assignment model. The travel time across a link is the product of the link’s length and speed, which is determined by its street class assignment. During the peak commute period, the link time is increased as the number of trips assigned to that link reaches or exceeds the street class’s capacity. Such increases are not imposed during the off-peak period since trips occur throughout the day rather than simultaneously as they do in the peak commute period (Powell 2002). Equation 3.2 shows the calculation for the total travel time of a plan.

$$\text{total travel time} = \sum_{i=1}^{\#\,of\ periods} \sum_{j=1}^{\#\,of\ links} \left(link\ time_{ij} \times link\ trips_{ij} \right) \tag{3.2}$$

where:

link time$_{ij}$ = the travel time for the *i*th link during the *j*th period
link trips$_{ij}$ = the number of trips on the *i*th link during the *j*th period

Change is measured in terms of status quo population affected. A change factor is specified for every possible change (i.e., scenario *x* to scenario *y*, land use *x* to land use *y*, and street class *x* to street class *y*). Equation 3.3 outlines the calculation for the change value of a plan which is measured in the number of people affected. The change factors are based on the intensity of public resistance toward that particular change. This can be determined through public meetings, surveys, or other forms of public input. The status quo population affected is the number of people currently living and working in a district or zone, or along a street.

$$\text{change} = \sum_{i=1}^{design\ variables} \left(pop\ affected_i \times change\ factor\left(status\ quo_i,\ planned_i \right) \right) \tag{3.3}$$

where:

pop affected$_i$ = the number of people currently living and working in the *i*th district or *i*th zone, or on the *i*th street
change factor(status quo$_i$*, planned*$_i$) = the change factor for a particular change in scenario, land use type or street class from the status quo to the planned change

Deviation from the target scenario is a measure of the mismatch between the zoning plan of the city and the scenario plan specified by the region. Recall that for each district the regional planners give target land use percentages to the city planners. The deviation from the targets is the sum of the squared differences between target land use areas and the land use areas planned by the city. It follows that deviation is measured in acres.

In the Fitness Evaluation step presented in Figure 3.2, the quality of each plan is quantified with a *fitness* value. Fitness is evaluated differently for feasible and infeasible plans, so first a *feasibility* value is calculated. Recall that a feasible plan satisfies all three constraints. A constraint is satisfied if the relationship in Equation 3.4 holds true:

$$planned \geq required \tag{3.4}$$

where:
planned = the housing capacity, employment capacity, or greenspace percentage for a plan calculated using housing densities, employment densities, and greenspace percentages
required = the minimum required housing capacity, employment capacity, or greenspace percentage set by the region or city

Equation 3.4 is equivalent to:

$$1 - \frac{planned}{required} \leq 0$$

Feasibility is calculated for each plan according to Equation 3.5:

$$\text{feasibility} = \max\left(1 - \frac{planned\ h}{required\ h}, 1 - \frac{planned\ e}{required\ e}, 1 - \frac{planned\ g}{required\ g}, 0\right) \tag{3.5}$$

where:
planned h, e, g = the plan's housing capacity, employment capacity, and greenspace percentage, respectively
required h, e, g = the minimum required housing capacity, employment capacity, and greenspace percentage, respectively

Note that feasible plans have a feasibility value equal to zero, while plans that violate a constraint have positive feasibility and are deemed infeasible.

For feasible plans fitness is evaluated by comparing objective values and determining *dominance*. A plan dominates another if it is better in all the objectives. Such a plan is considered "more fit" and is given a better fitness value. Dominance is shown graphically in Figure 3.4. In the figure, a generation of regional plans is plotted using the two objective values for the coordinates of each plan (a generation of city plans would be plotted on a 3-dimensional plot because there are three objectives).

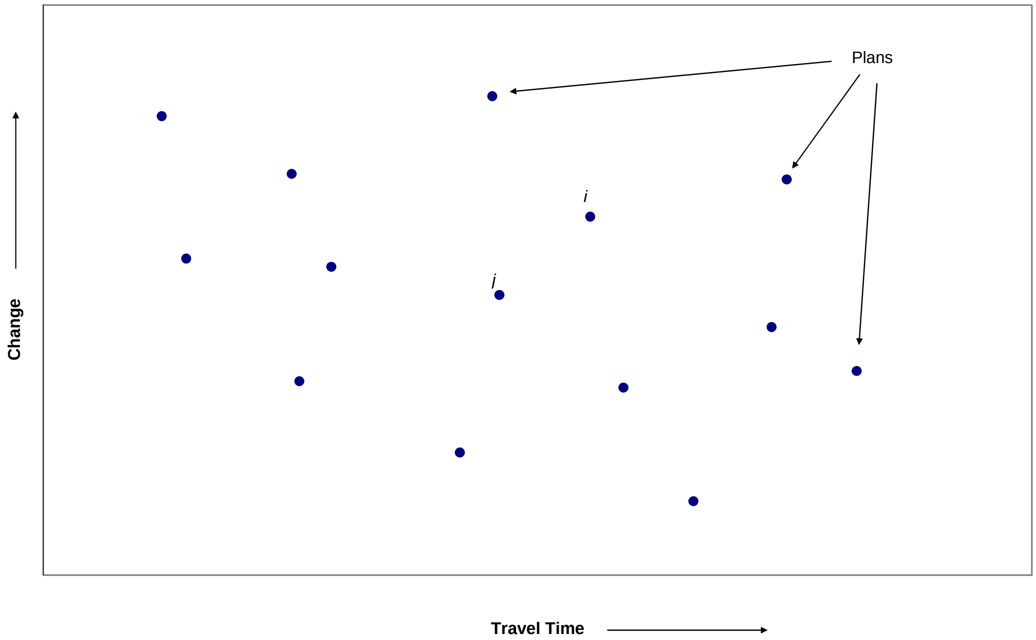


FIGURE 3.4 A Generation of Regional Plans Where Plan *j* Dominates Plan *i*

Note that plan *j* dominates plan *i* because it has a lower total travel time and a lower change value. This can be written formally for all plans:

Let

$travel_i$, $travel_j$ = the total travel time of the *i*th and *j*th plan

$change_i$, $change_j$ = the change from the status quo of the *i*th and *j*th plan

plan *j* dominates plan *i* if:

$$travel_j \leq travel_i \ AND \ change_j \leq change_i$$

This is equivalent to:

$$0 \leq \min(travel_i - travel_j, change_i - change_j)$$

And therefore, *i* is a dominated plan in the set of feasible plans F if:

$$0 \leq \max_{j \neq i, j \in F} (\min(travel_i - travel_j, change_i - change_j)) \tag{3.6}$$

The objective values (i.e., total travel time, change from the status quo, and deviation from the target) are scaled in order to calculate a fitness value for each plan that is relative to the other plans. Scaling is done as outlined in Equation 3.7:

$$scaled\ objective_i = \frac{objective_i - objective_{\min}}{objective_{\max} - objective_{\min}} \quad (3.7)$$

where:

$objective_i$ = the objective value for the ith plan
$objective_{\max}$ = the maximum value for the particular objective from the generation of plans
$objective_{\min}$ = the minimum value for the particular objective from the generation of plans

Using the scaled objective values and equation 3.6, the fitness for plan *i* from the regional plans of Stage One is calculated as outlined in Equation 3.8 (Balling 2003):

$$\text{fitness}_i = \max_{j \neq i,\, j \in F}\left(\min\left(travel_i - travel_j\,,\ change_i - change_j\right)\right) \quad (3.8)$$

For the city plans of Stage Two the fitness for plan *i* is calculated according to Equation 3.9:

$$\text{fitness}_i = \max_{j \neq i,\, j \in F}\left(\min\left(travel_i - travel_j\,, change_i - change_j\,, target_i - target_j\right)\right) \quad (3.9)$$

where:

fitness_i = fitness of *i*th plan in the generation
$travel_i$, $travel_j$ = scaled travel time objective of *i*th and *j*th plans in the generation
$change_i$, $change_j$ = scaled change objective of *i*th and th plans in the generation
$target_i$, $target_j$ = scaled target objective of *i*th and *j*th plans in the generation
F = set of feasible plans in the generation

The lower the fitness value, the better the plan. *Non-dominated* plans have a fitness that is always less than zero, while the fitness of dominated plans is greater than or equal to zero. The non-dominated plans are the “best” or “most fit” plans of the generation. They are called non-dominated because they cannot be dominated by any other plan in the generation. The dashed line in Figure 3.5 distinguishes the non-dominated plans of a generation of regional plans (for city plans the non-dominated set is a 3-dimensional surface). For each plan along the line, another plan may be better in one objective, but no other plan is better in both objectives.

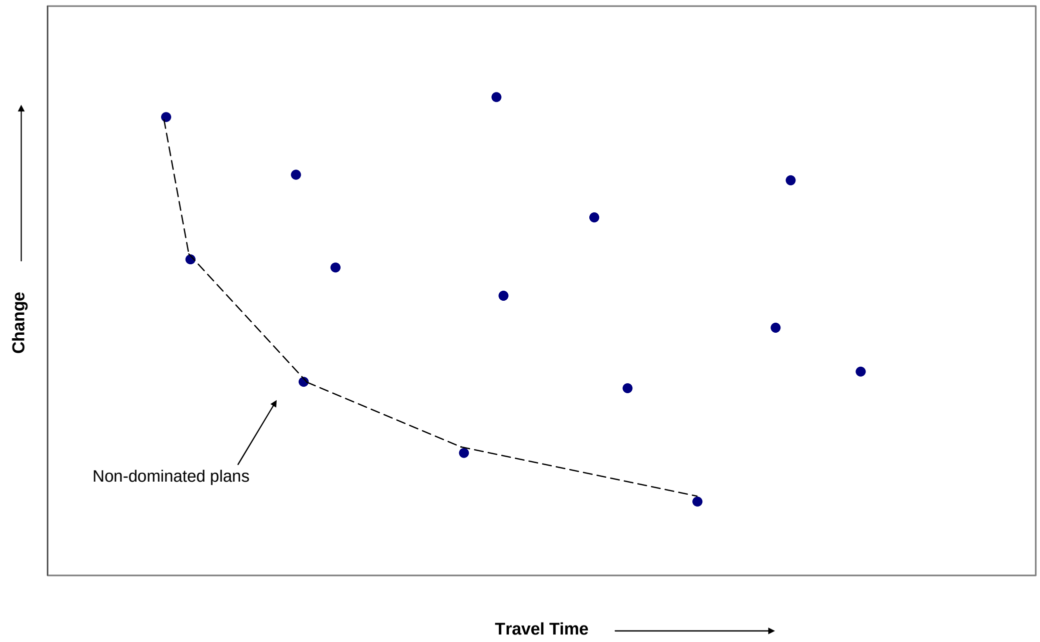


FIGURE 3.5 The Non-dominated Plans of a Generation

The fitness of the infeasible plans is evaluated after the fitness of all the feasible plans is evaluated. Let *maxfit* be the fitness of the least fit plan of the generation. The fitness of an infeasible plan is the sum of *maxfit* and the feasibility of the plan. Thus, the fitness of feasible plans is always worse (greater) than the fitness of feasible plans.

As outlined in Figure 3.2, the algorithm skips Elitism the first time through the loop. For the second loop and all subsequent loops, the algorithm skips Random Creation to allow for the creation of successive generations through the processes of Selection, Crossover, Mutation, and Elitism. These are the key components of genetic algorithms. Following the theory of survival of the fittest, these processes mimic the evolution of species to produce successive generations better than every previous generation.

Selection is done through a tournament procedure that utilizes the fitness values to select plans from the previous, or *parent*, generation to produce plans in the next, or *child,* generation. Tournament size is set to three. The tournament begins by randomly picking three plans from the parent generation. The plan with the best fitness is selected as the father. Three more plans are randomly chosen from the parent generation, and again, the one with the best fitness is selected as the mother. In this way, the likelihood of being selected as father and mother is greatest for the most fit plans. Remember the lowest fitness value is the best fitness.

The crossover process uses the father and mother plans to produce two children plans. Crossover probability is set to 70 percent, so that there is a 70 percent chance that crossover will occur for every set of parents, otherwise, the father and mother plans become the children plans. Crossover is accomplished by slicing the chromosome of each parent at a random gene location and swapping the tails. Figure 3.6 illustrates that the first child plan is identical to the father for the design variables up to the slicing point and identical to the mother for the remaining design variables. Likewise, the second child plan is identical to the mother for the design variables up to the slicing point and identical to the father for the remaining design variables. In this way, children plans inherit many of the qualities of their parents, yet are different plans.

Father: 3823876137 44279965775344896371897697

Mother: 8584614165 91499332711564376727291624

Child 1: 3823876137 91499332711564376727291624

Child 2: 8584614165 44279965775344896371897697

FIGURE 3.6 Crossover Occurrence for Two Parent Plans

The mutation process allows random changes to enter the population of plans with low probability. Mutation probability is set to one percent. The occurrence of mutation is considered independently for each design variable, so that for each gene of a chromosome there is a one percent chance that the integer value will be randomly changed. Mutation is necessary to maintain diversity in the population of plans.

Each execution of Selection, Crossover and Mutation creates two new child plans from two parent plans. These processes are repeated until a child generation of *nsize* plans is created. The newly created child generation is analyzed and then combined with the parent generation for fitness evaluation. At this point there are *nsize* plans from the parent generation and *nsize* plans from the newly created child generation. Fitness is evaluated over the combined group of 2 x *nsize* plans so that parent plans can compete with child plans for fitness.

The last step of the procedure, as shown in Figure 3.2, is Elitism. The purpose of this step is to ensure that the best plans survive from generation to generation. This is done by keeping the best half of the 2 x *nsize* plans for the next loop of the procedure and discarding the worst half. The *nsize* plans that are kept become the parent generation for the next loop.

CHAPTER 4. Stage One: The Wasatch Front Metropolitan Region

This chapter illustrates Stage One of the Urban Genetic approach on the WFMR in north central Utah. The WFMR consists of four counties (Weber, Davis, Salt Lake and Utah) and includes Salt Lake City, Ogden, and Provo. Land use and transportation planning for the region is the responsibility of the Utah DOT, WFRC, and MAG. These organizations provided the raw data that was used to create the input and they were the primary recipients of the results.

4.1 WFMR Input[1]

The WFMR was delineated into the 343 districts shown in Figure 4.1. The delineation excluded undevelopable land (i.e., areas covered by water or wetlands, exhibiting a slope gradient steeper than 25 percent, or owned by the Forest Service, the Division of Wildlife Resources, or the military). District boundaries were drawn in accordance with county, city, neighborhood, voting, and traffic analysis zone (TAZ) boundaries. Large areas were divided into approximately one district for every 5,000 persons (Smith 2000). For each district the status quo land use percentages were determined using the following land use types:

R1	single family residential
R2	duplex and four-plex residential
R3	multi-family apartments residential
R4	mobile home residential
R5	high density apartment residential
C1	retail commercial
C2	industrial commercial
C3	warehouse commercial

---

[1] Note that any input from Stage One and Stage Two that is especially long and does not significantly contribute to the understanding of the Urban Genetic approach is found in the Appendices rather than the text.

C4 office commercial
PL public lands: airports, universities, churches
AG agricultural
PA parks
VA vacant

Scenarios were created from the status quo land use percentages. The 343 districts were grouped into 17 clusters based on their status quo land use percentage. Clustering was accomplished using Minitab's cluster analysis. The land use percentages were averaged within each cluster to create the 17 scenarios presented in Table 4.1. Figure 4.2 illustrates the status quo scenario for each district. This data and the district areas in acres are found in Appendix A.

TABLE 4.1 Seventeen Scenarios Used for the WFMR

Integer Value	Land Uses (%)												
	R1	R2	R3	R4	R5	C1	C2	C3	C4	PL	AG	PA	VA
1	11	0	0	0	0	2	1	0	0	3	79	0	4
2	34	0	0	0	0	0	0	0	0	0	0	65	1
3	41	1	0	1	0	3	3	1	0	4	40	1	5
4	47	1	0	0	14	0	0	0	0	0	36	0	2
5	86	2	1	0	0	4	1	0	0	1	2	1	2
6	68	2	1	1	0	4	1	0	0	10	7	2	4
7	42	46	0	0	0	3	0	0	0	0	9	0	0
8	48	3	5	1	0	12	4	0	1	9	3	8	6
9	57	1	2	0	0	29	1	0	0	3	1	1	5
10	11	0	38	0	0	25	6	0	0	0	0	0	20
11	13	2	2	0	0	32	23	2	1	8	0	2	15
12	11	0	1	1	0	65	5	0	0	3	5	0	9
13	21	1	3	2	0	8	8	1	1	25	4	2	24
14	4	1	0	0	0	5	17	1	0	4	9	6	53
15	3	1	0	0	0	2	77	1	0	0	16	0	0
16	21	1	9	0	0	4	0	0	10	48	1	5	1
17	11	0	1	1	0	3	1	0	0	76	2	2	3

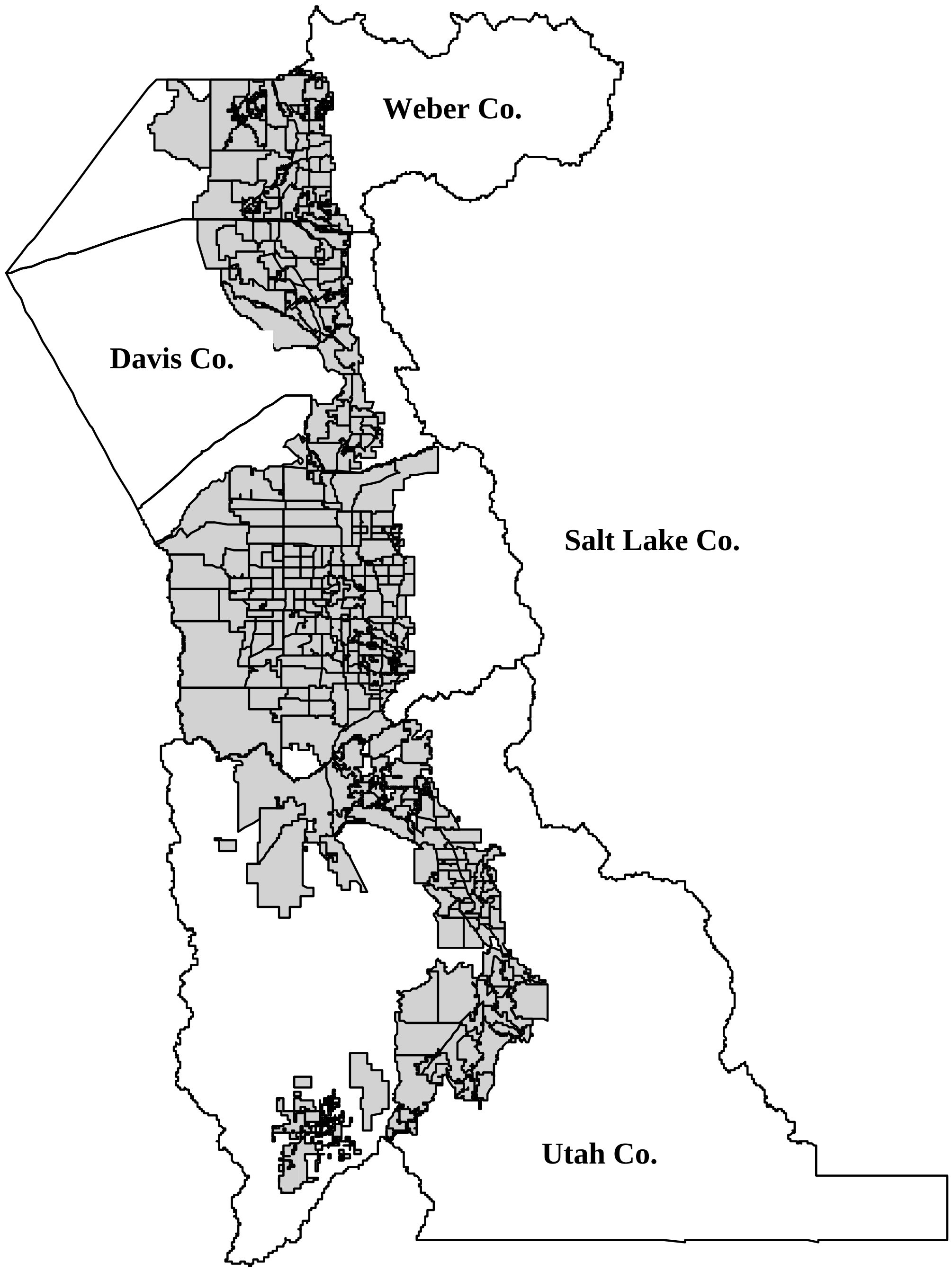


FIGURE 4.1 The 343 Districts of the WFMR

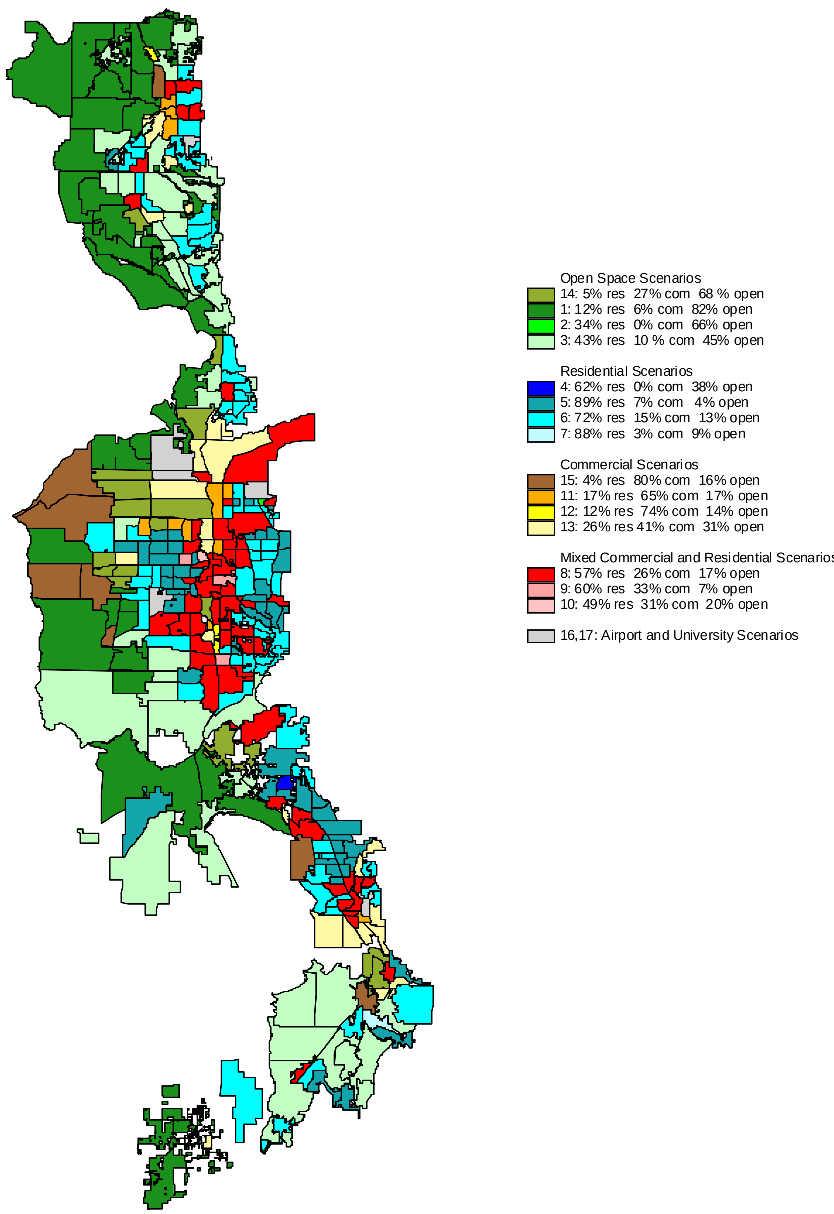


FIGURE 4.2 Scenarios for the WFMR: The Status Quo

The street network of the WFMR was divided into 260 inter-district streets. A set of 11 street classes were created based on the status quo street plan. Table 4.2 presents the 11 street classes (Powell 2000). Figure 4.3 shows the 260 inter-district streets. A single street maybe comprised of several links. There are 343 centroidal connector links (one for each district) and 665 links that form the 260 streets. The status quo street class for each link, each link's length, and the link-node connectivity data are found in Appendix A.

TABLE 4.2 Eleven Street Classes

Integer Value	Class	Number of Lanes	Design Speed (mph)	Volume Capacity (vph)
1	C2	2	30	1600
2	C3	3	30	2000
3	C4	4	35	3240
4	C5	5	35	3640
5	A2	2	40	1700
6	A3	3	40	2125
7	A4	4	40	3380
8	A5	5	40	3805
9	A6	6	45	5340
10	A7	7	45	5785
11	F	freeway	65	13000

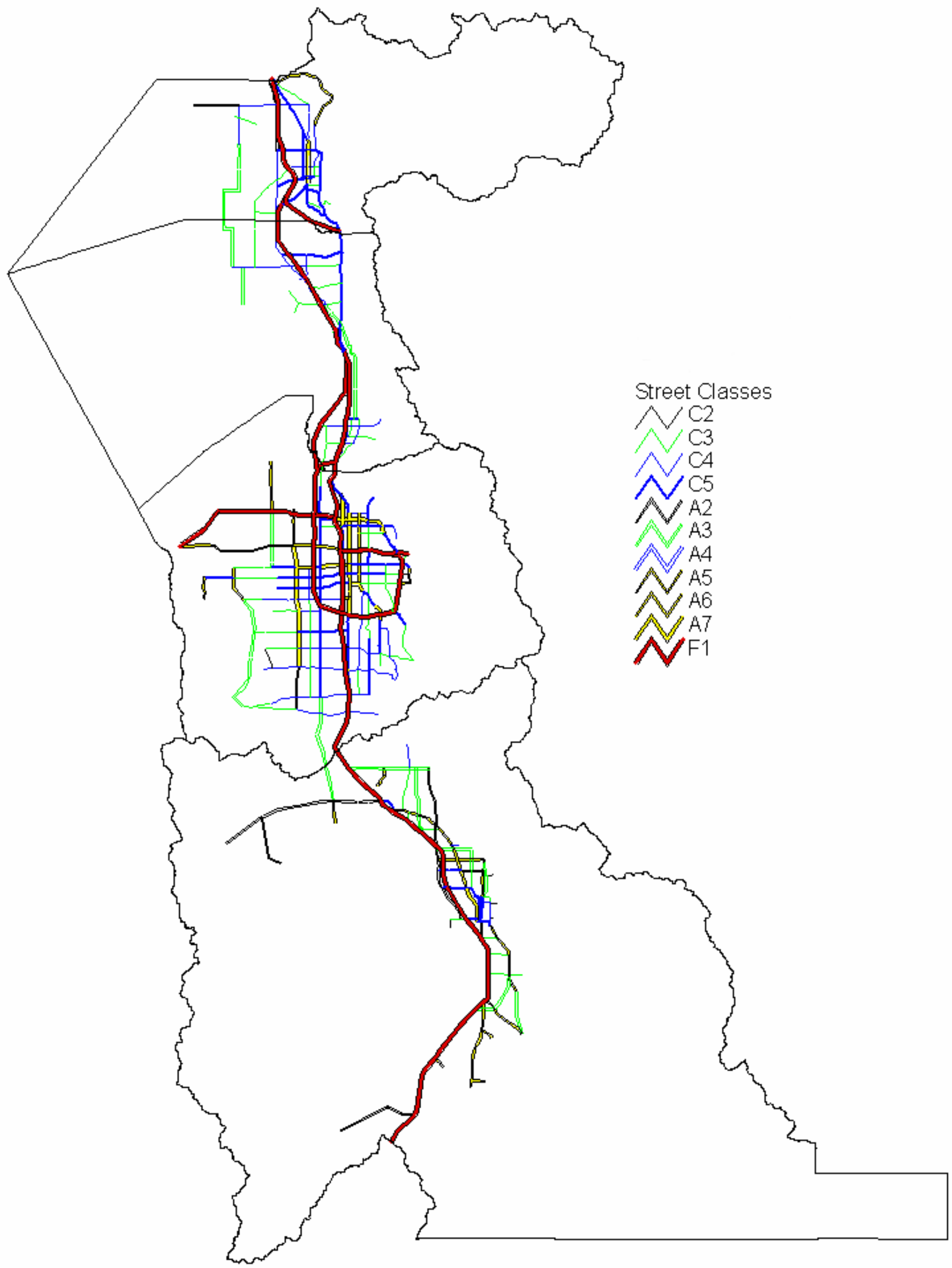


FIGURE 4.3 Street Classes for the WFMR: The Status Quo

Attributes were specified for each scenario as shown in Table 4.3 for the analysis of the constraint functions (Powell 2000). The housing capacity of future plans was constrained to be greater than the projected population of 2,401,000 for the year 2020. The employment capacity of future plans was constrained to be greater than the projected 1,210,000 jobs needed for the year 2020. These values were based on the growth forecasts of the 2000 census (Governor 2000). The greenspace percentage was constrained to be greater than 20 percent of the developable land (The status quo greenspace percentage is 43 percent. The constraint was simply set at 20 percent to ensure some greenspace but without inhibiting development. In practice the planners would determine an appropriate percentage of greenspace after much deliberation).

TABLE 4.3 Scenario Attributes for Calculating Constraint Values

Scenario	Housing Density (people/acre)	Employment Density (jobs/acre)	Greenspace Percentage (%)
1	0.65	0.40	81
2	1.79	0.01	65
3	2.28	0.64	45
4	7.03	0.02	37
5	4.80	0.44	3
6	3.94	0.93	17
7	5.79	0.26	9
8	3.76	1.66	19
9	3.51	2.29	5
10	8.04	2.10	5
11	1.25	3.98	11
12	0.83	5.13	9
13	1.75	2.52	31
14	0.29	1.47	31
15	0.25	3.91	16
16	2.89	4.91	41
17	0.82	4.83	62

Trip rates were created for each scenario to calculate a plan's total travel time. Daily trip rates were derived from the scenario's land use percentages and the ITE Trip Generation Manual (ITE 1997). These rates were split into attraction and production for three different trip types: home-based-work (HBW) trips representing trips from home to work; home-based non-work or home-based other (HBO) trips representing trips from home to something other than work, such as school, shopping, recreation, and other homes; and non-home-based trips (NHB) representing delivery trips from businesses to other businesses. These three unique trip types were used because the total travel time objective function uses different parameters for calculating the travel time for each (Brown 1998). The trip rates for the one hour commute period, called the Peak Hour, are shown in Table 4.4 and the trip rates for the non-commute period of the day, called the Off Peak period, are found in Table 4.5. Note in Table 4.4 that the only trip type considered during the peak period is HBW. In reality there would be other trip types, but they would be relatively insignificant. This allows a direct evaluation of commute trips.

TABLE 4.4 Peak Hour Trip Rates for the Scenarios

	Attraction (vph per acre)			Production (vph per acre)		
Scenario	HBW	HBO	NHB	HBW	HBO	NHB
1	0.25	0.00	0.00	0.19	0.00	0.00
2	0.01	0.00	0.00	0.62	0.00	0.00
3	0.41	0.00	0.00	0.71	0.00	0.00
4	0.00	0.00	0.00	2.46	0.00	0.00
5	0.09	0.00	0.00	1.67	0.00	0.00
6	0.67	0.00	0.00	1.11	0.00	0.00
7	0.02	0.00	0.00	3.03	0.00	0.00
8	0.60	0.00	0.00	0.94	0.00	0.00
9	0.19	0.00	0.00	1.08	0.00	0.00
10	0.13	0.00	0.00	2.46	0.00	0.00
11	1.56	0.00	0.00	0.32	0.00	0.00
12	0.38	0.00	0.00	0.20	0.00	0.00
13	2.42	0.00	0.00	0.37	0.00	0.00
14	1.06	0.00	0.00	0.07	0.00	0.00
15	3.03	0.00	0.00	0.08	0.00	0.00
16	4.53	0.00	0.00	0.58	0.00	0.00
17	7.16	0.00	0.00	0.20	0.00	0.00

TABLE 4.5 Off-Peak Period Trip Rates for the Scenarios

Scenario	Attraction (vph per acre)			Production (vph per acre)		
	HBW	HBO	NHB	HBW	HBO	NHB
1	0.04	0.17	0.02	0.02	0.03	0.02
2	0.00	0.05	0.01	0.07	0.15	0.00
3	0.07	0.30	0.05	0.07	0.14	0.03
4	0.00	0.05	0.05	0.29	0.68	0.00
5	0.07	0.36	0.06	0.17	0.36	0.02
6	0.07	0.37	0.06	0.12	0.21	0.03
7	0.04	0.26	0.07	0.33	0.74	0.00
8	0.16	0.76	0.08	0.04	0.00	0.05
9	0.32	1.62	0.13	0.00	0.00	0.10
10	0.29	1.43	0.13	0.09	0.00	0.07
11	0.70	3.00	0.18	0.04	0.09	0.17
12	1.22	6.00	0.30	0.02	0.05	0.29
13	0.23	1.10	0.10	0.04	0.10	0.09
14	0.19	0.55	0.04	0.01	0.02	0.04
15	0.42	0.18	0.06	0.01	0.02	0.06
16	0.22	1.07	0.16	0.06	0.15	0.14
17	0.27	1.59	0.22	0.02	0.05	0.22

Change factors were created for every possible scenario or street class change in order to calculate a plan’s change from the status quo. The scenario change factors are given in Table 4.6 and the street change factors are shown in Table 4.7. In these tables, rows correspond to the status quo scenario or street class, and columns correspond to the scenario or street classes of the future plan. Large change factors indicate that such a change would be met with greater disdain by the public.

Limitations were placed on the allowable changes. Changes that were not allowed are marked with an X in Tables 4.6 and 4.7. Districts were allowed to change to scenarios that were slightly more developed than their status quo scenario, but were not allowed to change to scenarios that were less developed. Note that the status quo scenario is always an allowed future scenario. Note, further, that scenarios 15, 16, and 17 were not allowed to change from the status quo. Scenario 15 is primarily heavy industrial, scenario 16 is primarily university, and scenario 17 is primarily airport. Streets were allowed to change to any street class with an equal or greater number of lanes except to a freeway and streets that are currently freeways were not allowed to change.

TABLE 4.6 Scenario Change Factors for the WFMR

		Future Plan Scenario																
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Status Quo Scenario	**1**	0.0	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.7	X	X	X	X	X	X	X	X
	2	0.3	0.0	0.1	0.2	0.3	0.4	0.4	0.5	0.7	X	X	X	X	X	X	X	X
	3	X	X	0.0	0.2	0.2	0.3	0.3	0.4	0.6	X	X	X	X	X	X	X	X
	4	X	X	0.2	0.0	0.2	0.3	0.3	0.4	0.5	X	X	X	X	X	X	X	X
	5	X	X	X	X	0.0	0.2	0.2	0.3	0.4	X	X	X	X	X	X	X	X
	6	X	X	X	X	0.2	0.0	0.3	0.3	0.4	0.5	X	X	X	X	X	X	X
	7	X	X	X	X	0.5	0.5	0.0	0.3	0.5	0.6	X	X	X	X	X	X	X
	8	X	X	X	X	X	0.7	0.5	0.0	0.2	0.5	0.5	0.6	X	X	X	X	X
	9	X	X	X	X	X	0.8	0.7	0.7	0.0	0.4	0.3	0.4	X	X	X	X	X
	10	X	X	X	X	X	X	0.5	0.8	0.3	0.0	0.3	0.3	1.0	X	X	X	X
	11	X	X	X	X	X	X	X	1.0	0.9	0.4	0.0	0.2	1.0	X	X	X	X
	12	X	X	X	X	X	X	X	X	X	0.6	0.2	0.0	1.0	X	X	X	X
	13	X	X	X	X	X	X	X	X	X	0.9	0.8	0.8	0.0	0.4	X	X	X
	14	X	X	X	X	X	X	X	X	X	0.4	0.4	0.6	0.3	0.0	0.7	X	X
	15	X	X	X	X	X	X	X	X	X	X	X	X	X	X	0.0	X	X
	16	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	0.0	X
	17	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	0.0

TABLE 4.7 Street Class Change Factors for the WFMR

		Future Plan Street Class										
		C2	**C3**	**C4**	**C5**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**F**
Status Quo Street Class	**C2**	0.0	1.0	3.7	4.7	3.3	4.3	5.3	6.3	9.0	10.0	X
	C3	X	0.0	2.7	3.7	0.0	3.3	4.3	5.3	8.0	9.0	X
	C4	X	X	0.0	1.0	0.0	0.0	1.7	2.7	5.3	6.3	X
	C5	X	X	X	0.0	0.0	0.0	0.0	1.7	4.3	5.3	X
	A2	X	X	X	X	0.0	1.0	2.0	3.0	5.7	6.7	X
	A3	X	X	X	X	X	0.0	1.0	2.0	4.7	5.7	X
	A4	X	X	X	X	X	X	0.0	1.0	3.7	4.7	X
	A5	X	X	X	X	X	X	X	0.0	2.7	3.7	X
	A6	X	X	X	X	X	X	X	X	0.0	1.0	X
	A7	X	X	X	X	X	X	X	X	X	0.0	X
	F	X	X	X	X	X	X	X	X	X	X	0.0

4.2 WFMR Execution and Results

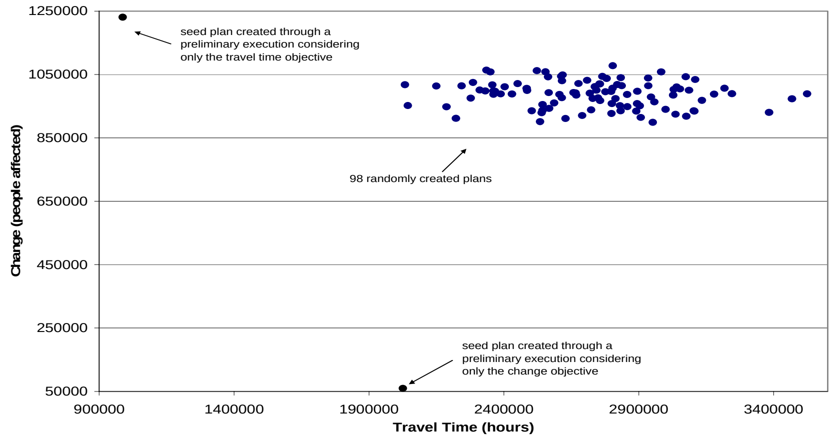
The genetic algorithm was executed with a generation size of 100 plans. The execution time was dominated by the analysis of the total travel time objective function. When both objectives were considered, execution time for a single generation required 1 hour on a Dell Precision computer with a 1.7 GHz dual processor and 1 gigabyte of RAM. Execution for 100 generations required 4 days.

Recall that the genetic algorithm begins with a randomly created starting generation, and changes the entire generation through an evolutionary-like process to produce a superior final generation. The process is accelerated by introducing a few superior plans into the starting generation. Such plans, called seeds, are created through preliminary executions of the algorithm that exclusively consider just one objective. The algorithm was executed for 100 generations considering the travel time objective only and then for 10,000 generations considering only the change objective. For the second seeding execution, it was possible to execute 10,000 generations because the computationally expensive travel time objective was ignored. The plans with the lowest objective values from the final generation of these two preliminary executions were labeled as seed plans. Finally, the algorithm was executed for 100 generations considering both objectives, however, the two seed plans were added to the other 98 random plans of the starting generation.

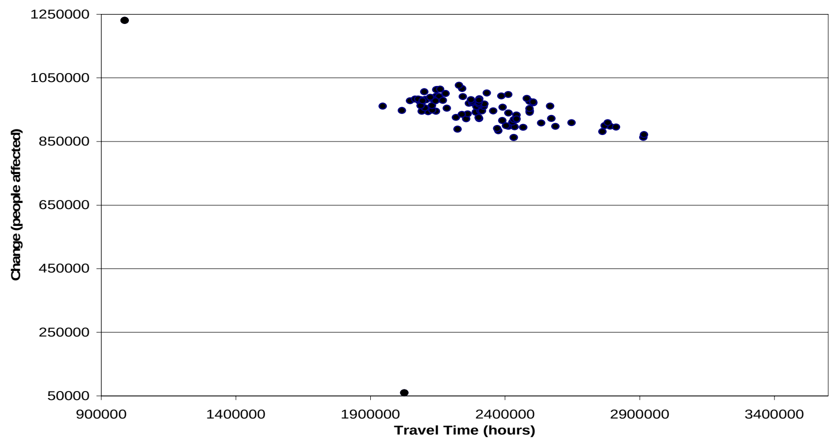
The parameters for the genetic algorithm were set as described in Chapter 3. The tournament size for selecting parent plans was set to three. The probability of cross over was set at 0.70 and the probability of mutation was set at 0.01

The progression that occurred between generations is illustrated in the plots of Figures 4.4 and 4.5. Each plot has 100 plans plotted using the plan's objective values for coordinates. Recall that change is measured in people affected and total travel time is measured in hours. Figure 4.4 (a) plots the plans of the starting generation, Figure 4.4 (b) plots the plans of the second generation, and Figure 4.4 (c) plots the plans of the fifth generation. Note in the starting generation the two seeded plans and the 98 randomly created plans. It is evident from the plots that the plans of successive generations have improved objective values. Figure 4.5 continues to illustrate the improvements with objective values. Figure 4.5 (a) plots the plans of the tenth generation, Figure 4.5 (b) plots the plans of the thirtieth generation, and Figure 4.5 (c) plots the plans of the final generation.

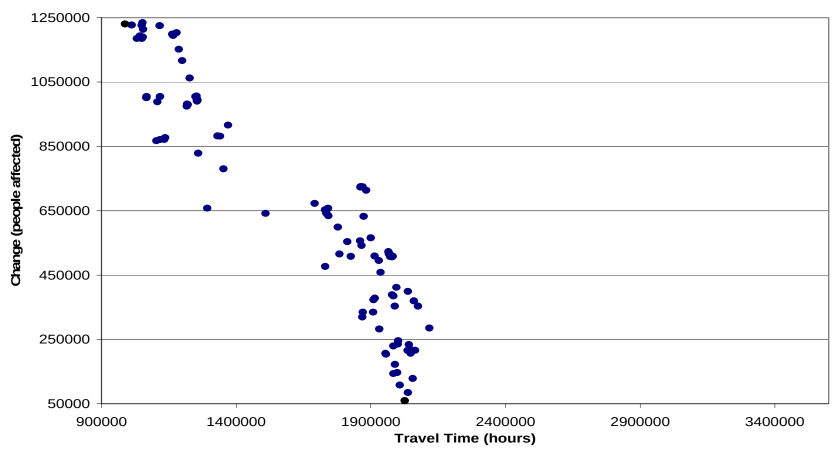
An inspection of Figure 4.5 (c) reveals that the genetic algorithm produced a final generation that appears to be a diverse non-dominated set. These plans represent a trade-off curve between the travel time and change objectives. Every plan along the curve is superior to its neighbor in one, but not both, of the objectives. The plans in the upper left have low travel times and high change values while the plans in the bottom right have high travel time and low change values.



(a) Starting Generation

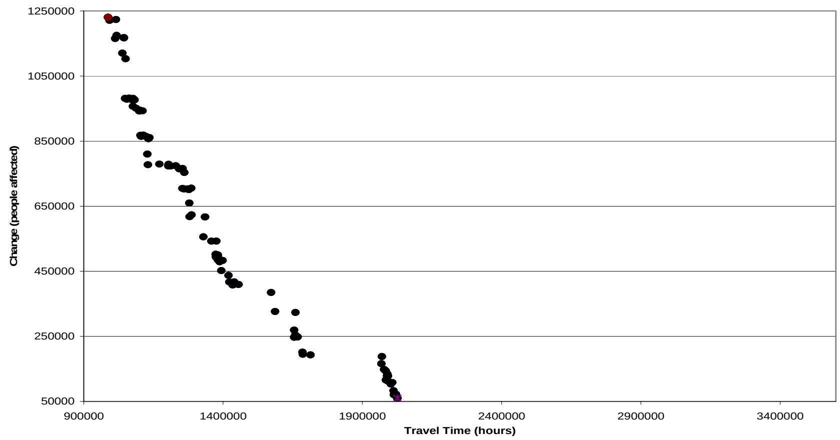


(b) Second Generation

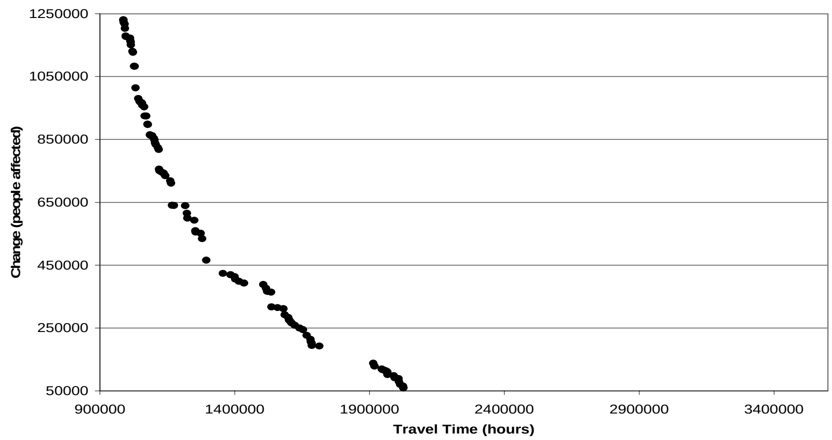


(c) Fifth Generation

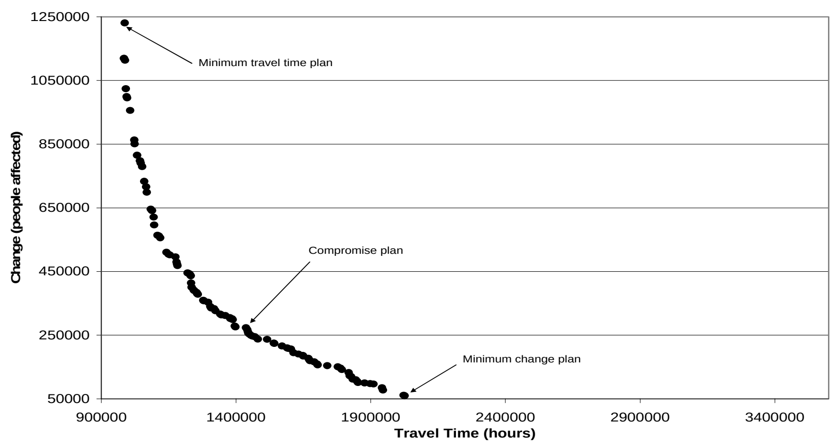
FIGURE 4.4 Three Generations from the WFMR Execution Including the Starting Generation



(a) Tenth Generation



(b) Thirtieth Generation



(c) Final Generation

FIGURE 4.5 Three Generations from the WFMR Execution Including the Final Generation

The final generation provides regional planners a set of superior plans from which a future plan can be selected. All plans in the final generation were feasible, while only 58 percent of the plans in the starting generation were feasible. The planners can examine a variety of plans from the final generation before selecting one plan. Table 4.8 presents the analysis of the status quo and three plans from the final generation: 1) the minimum change plan, 2) the minimum travel time plan, and 3) a compromise plan. These three plans are identified in Figure 4.5c. Understand that any plan along the trade-off curve could be chosen as a compromise plan because every plan in the final generation is a superior plan. This compromise plan was selected because it exhibits significant reduction in total travel time from the status quo but relatively little change.

TABLE 4.8 Analysis of the Status Quo and Three Plans from the Final Generation

	Status Quo	Final Generation Plans		
		Minimum Change	Minimum Travel Time	Compromise
Change (people affected)	0	59,934	1,119,385	273,753
Total Travel Time (hours)	1,349,617	2,025,681	984,436	1,493,006
Number of Trips	4,325,258	5,767,161	3,450,627	4,539,935
Housing Capacity (people) Required = 2,401,000	1,742,914	2,401,937	2,401,360	2,410,032
Employment Capacity (jobs) Required = 1,210,000	995,293	1,210,048	1,466,150	1,376,804
Greenspace (acres) Required = 165,000	349,583	248,541	247,840	228,256

Note in Table 4.8 that the housing and employment capacities of the status quo plan are below the required values of 2,401,000 and 1,210,000, respectively. This means that the status quo plan cannot support the forecasted population of 2020, and therefore, changes need to be made with respect to scenario assignments. The three final generation plans shown in Table 4.8, like the other 97 final generation plans, made changes in the scenarios to be able to provide more housing and employment.

For the minimum travel time plan, in addition to the scenario changes, significant changes were made to the street classes. Figure 4.6 shows that for the minimum travel time plan most of the streets were upgraded to classes with maximum speeds and capacities. Not surprisingly, the minimum travel time plan has the largest change value.

On the other hand, for the minimum change plan no changes were planned for the streets since travel time was considered unimportant. The compromise plan made 22 changes from the status quo in street classes. Figure 4.7 shows the street classes for the compromise plan.

A closer examination of the scenarios for each plan brings understanding to the analysis presented in Table 4.8. The following figures present the scenarios that changed from the status quo for each plan. Recall that the status quo scenarios were shown in Figure 4.2. The scenarios for the minimum change plan, the minimum travel time plan, and the compromise plan are shown in Figures 4.8, 4.9, and 4.10, respectively.

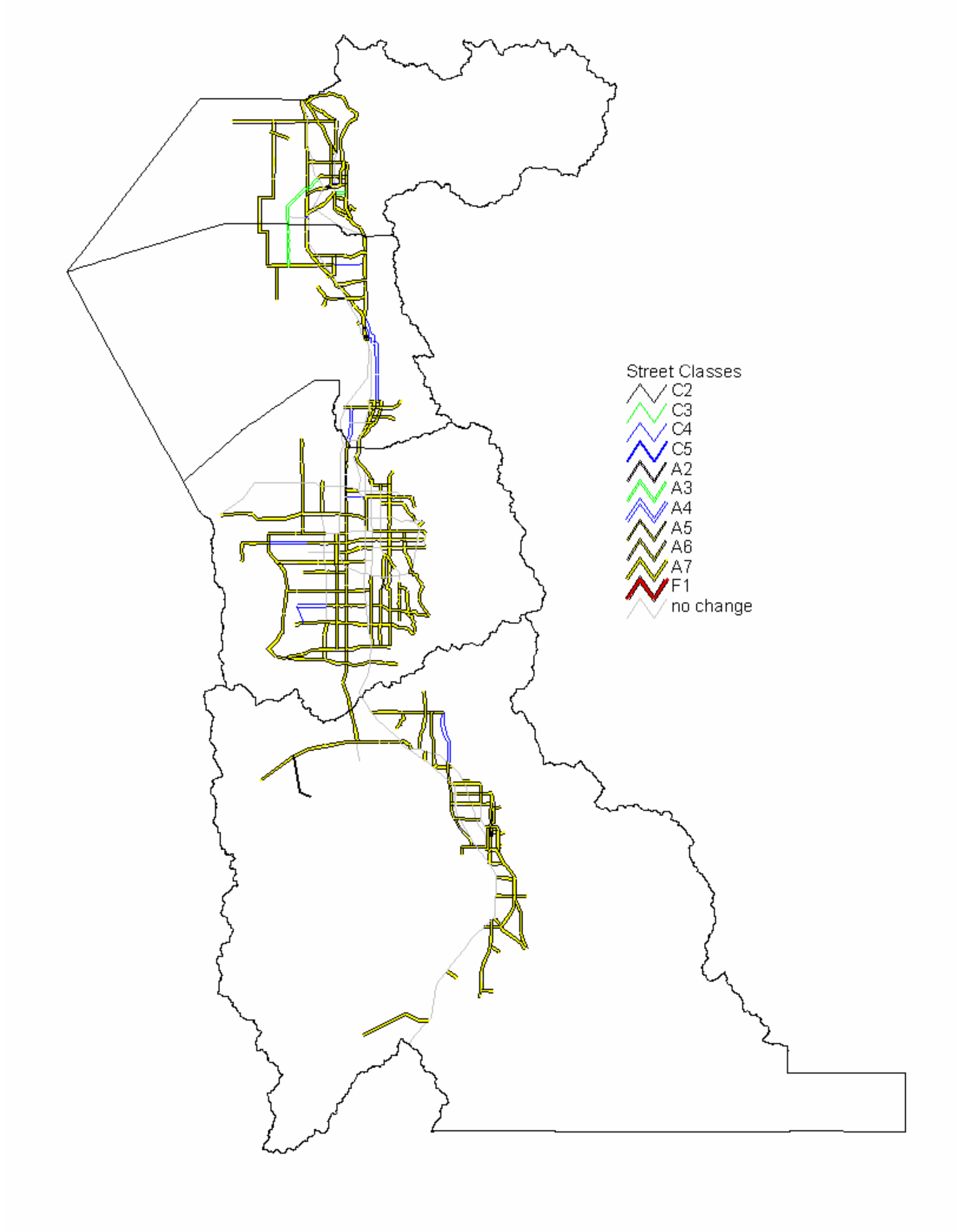


FIGURE 4.6 Street Classes for the WFMR: The Minimum Travel Time Plan

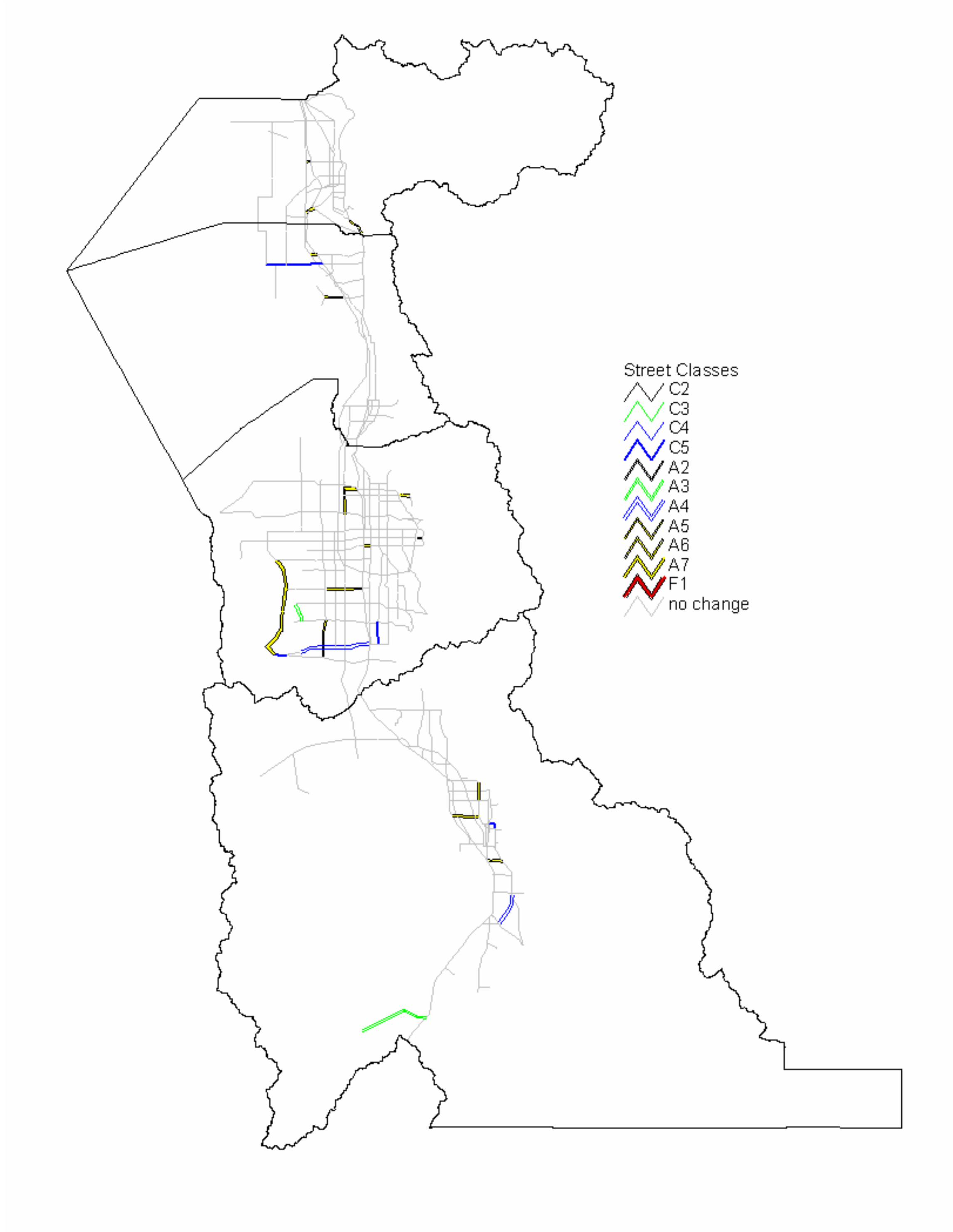


FIGURE 4.7 Street Classes for the WFMR: The Compromise Plan

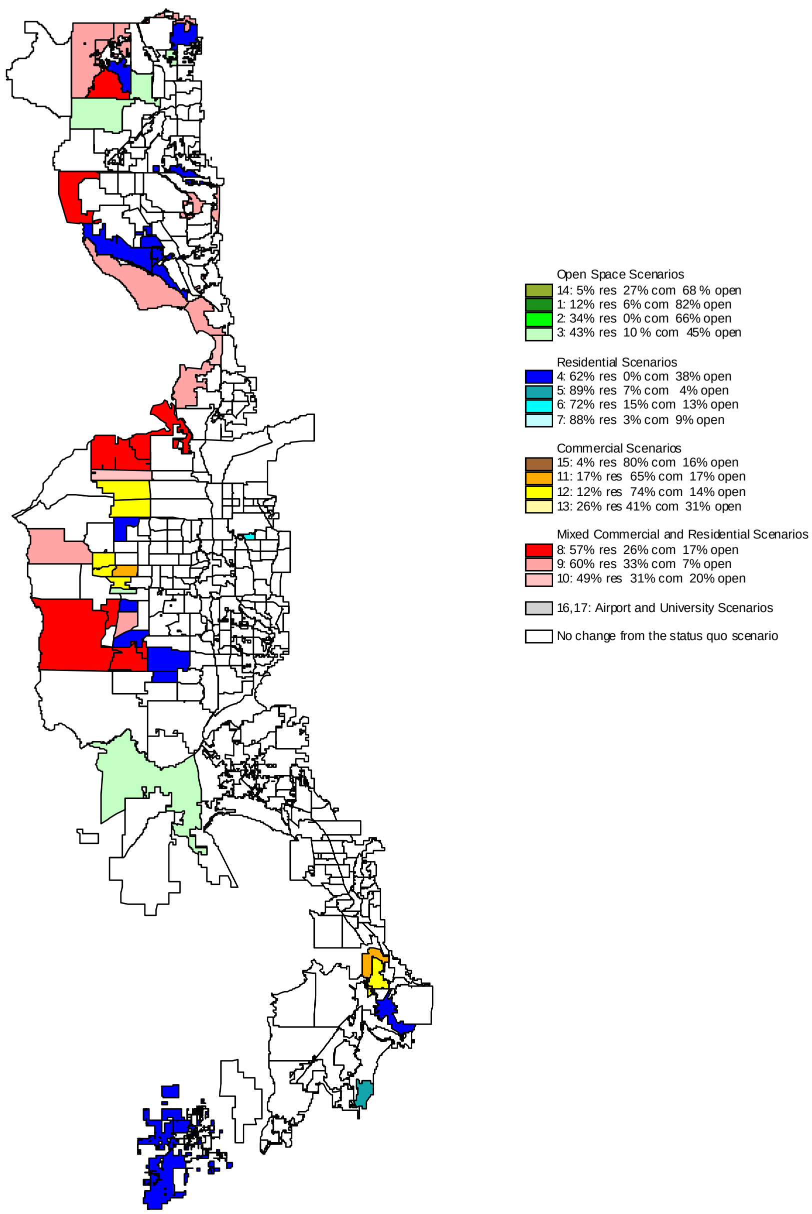


FIGURE 4.8 Scenarios for the WFMR: The Minimum Change Plan

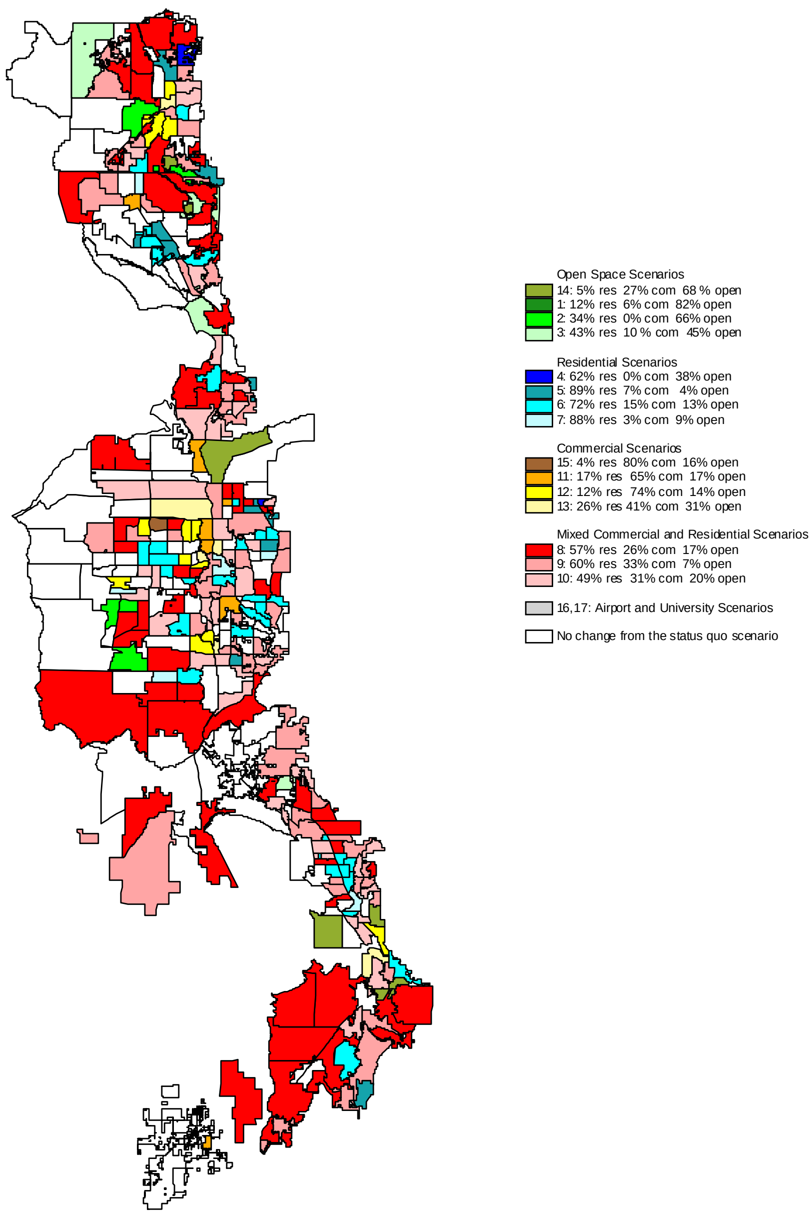


FIGURE 4.9 Scenarios for the WFMR: The Minimum Travel Time Plan

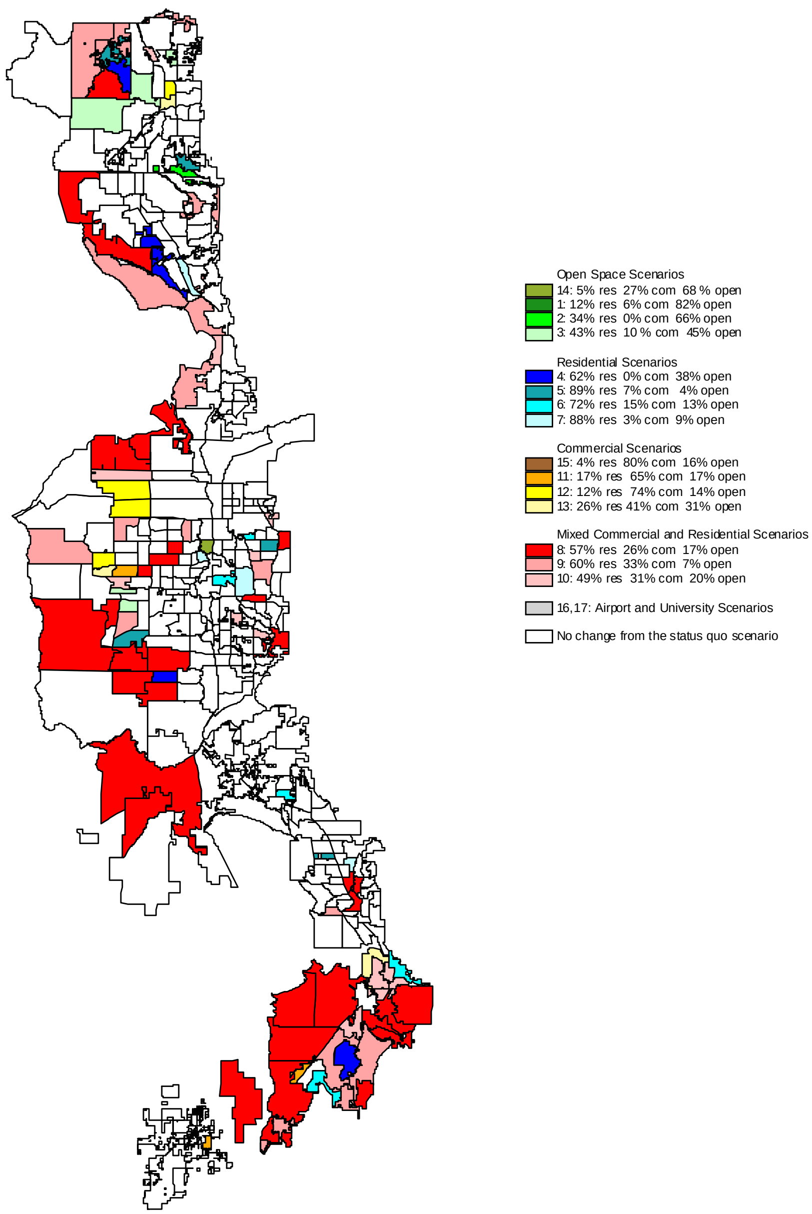


FIGURE 4.10 Scenarios for the WFMR: The Compromise Plan

Notice in each figure that the seventeen scenarios have been grouped into five categories according to their primary land use: 1) open space, 2) residential, 3) commercial, 4) mixed commercial and residential, and 5) airport and university. Table 4.9 uses these five categories to provide a simplified examination of the scenario assignments. The number of scenarios for each category is given for each plan. These numbers can be compared to the status quo plan to see how scenario assignment affected the values that were presented in Table 4.8.

TABLE 4.9 Scenarios of the Status Quo and Three Plans from the Final Generation

	Status Quo	Final Generation Plans		
		Minimum Change	Minimum Travel Time	Compromise
Predominately Open Space (scenarios 14, 1, 2, 3)	102	62	46	55
Predominately Residential (Scenarios 4, 5, 6, 7)	131	145	75	121
Predominately Commercial (Scenarios 11, 12, 13, 15)	43	51	39	47
Mixed Commercial and Residential (Scenarios 8, 9, 10)	61	79	177	114
Airport and University (Scenarios 16, 17)	6	6	6	6

In the minimum change plan, there are significantly fewer open space scenarios (agricultural and vacant lands, scenarios 1, 2, 3, and 14) than in the status quo plan. On the other hand there are more residential and commercial scenarios (scenarios 4, 5, 6, 7, 11, 12, 13, and 15). In other words, to minimize change, while still providing sufficient land for housing and employment, open space land must be developed as residential and commercial land. This is because changing open space land affects the fewest number of people, thus minimizing change. Such development patterns are commonly referred to as urban sprawl.

In the minimum travel time plan, 253 districts changed scenarios from the status quo. Table 4.9 shows that for the minimum travel time plan there are fewer scenarios than the status quo in every category except mixed commercial and residential (scenarios 8, 9, and 10). In the status quo plan, 18 percent of the districts were scenarios 8, 9, or 10, while in the minimum travel plan 52 percent of the districts were scenarios 8, 9, or 10. Mixed commercial and residential scenarios generate more intra-district trips and fewer inter-district trips. The genetic algorithm suggests that traffic congestion in the WFMR can be reduced by integrating residential and commercial land use throughout the region rather than dedicating certain districts to be predominately residential or predominately commercial.

The compromise plan represents a concession between the minimum change plan and the minimum travel time plan. Scenarios were changed from the status quo in 94 districts. Table 4.9 shows that, like the minimum change plan, most changes occurred in districts with status quo open space scenarios and, like the minimum travel plan, a significant number (33 percent) of the districts are scenarios 8, 9, and 10.

The tables and figures above were presented to regional authorities to gather feedback concerning the Urban Genetic approach. Presentations were given to:

1. Planners from the GOPB – August, 8 2002
2. Planners from Envision Utah – August, 9 2002
3. Planners from Provo and Orem Cities – August, 20 2002
4. Mayors and officials serving on QGET – August, 28 2002
5. Mayors and planners serving on MAG – August, 28 2002
6. Planners from the WFRC – September, 19 2002

Each of these organizations found the work interesting and relevant. However, there was hesitation to implement the Urban Genetic approach at this time. This cautious enthusiasm was expected since the approach is admittedly still under development and is different from traditional methods. Moreover, it is an overwhelming task to examine the final generation of 100 plans. Further work is needed to reduce the non-dominated set of plans down to a handful of plans that decision-makers can assimilate. A smaller, more manageable set of plans will facilitate the selection of a single plan for use in Stage Two of the Urban Genetic approach. For illustration in this thesis, the compromise plan, shown in Figures 4.5, 4.7 and 4.10, was selected for Stage Two.

CHAPTER 5. Stage Two: Provo and Orem Cities

This chapter illustrates Stage Two of the Urban Genetic approach on the twin cities of Provo and Orem.   These two cities constitute the primary metropolitan hub of the south portion of the WFMR as illustrated in Figure 5.1. Previous research demonstrated that because of their size and close proximity concurrent planning is more appropriate (Balling et al. 2000). The relevant portion of the compromise plan from Stage One will be used as the target plan. This includes 35 districts and 26 streets. The two sections of this chapter will present the input for the twin cities and the results from the execution of the genetic algorithm. Note that this input is very similar to that of Stage One, but that there are a few important differences that will be outlined in the chapter.

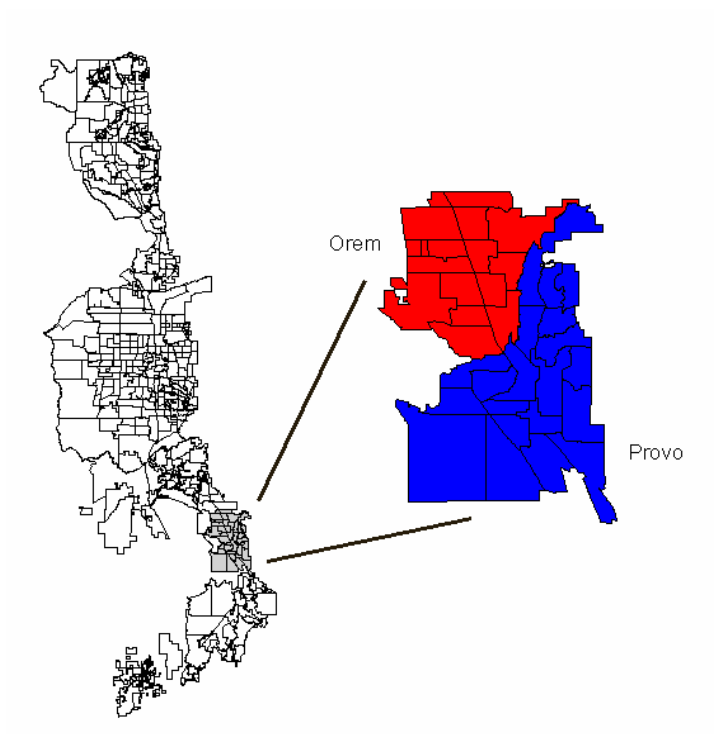


FIGURE 5.1 Provo and Orem Cities Located in the South Portion of the WFMR

5.1 Provo and Orem Cities Input

Provo and Orem cities were delineated into 190 zones. Zone boundaries were developed from the cities current zoning plan and TAZ boundaries. Twelve land use types were specified based on the Zoning Master Plans of Provo and Orem Cities. Table 5.1 presents the 12 land use types with a description of each. The status quo land use types for each zone are shown in Figure 5.2. This data and the zone areas in acres are found in Appendix B.

TABLE 5.1 Twelve Land Use Types Used for Provo and Orem Cities

Integer Value	Land Use Types	
1	FARM	Agricultural
2	VLDR	Very Low Density Residential
3	LDR	Low Density Residential
4	MDR	Medium Density Residential
5	HDR	High Density Residential
6	CBD	Central Business District
7	SC	Shopping Center
8	GC	General Commercial
9	LI	Light Industrial
10	HI	Heavy Industrial
11	MIX	Mixed Residential and Commercial
12	UNIV	University

The street network of Provo and Orem cities was divided into 45 intra-district streets. The same eleven street classes used for the WFMR, as shown previously in Table 4.2, were used for Provo and Orem. Figure 5.3 shows the status quo street class for the 45 intra-district streets. A single street maybe comprised of several links. There are 190 centroidal connector links (one for each zone) and 206 links that form the 45 streets. The status quo street class for each link, each link’s length, and the link-node connectivity data are found in Appendix B.

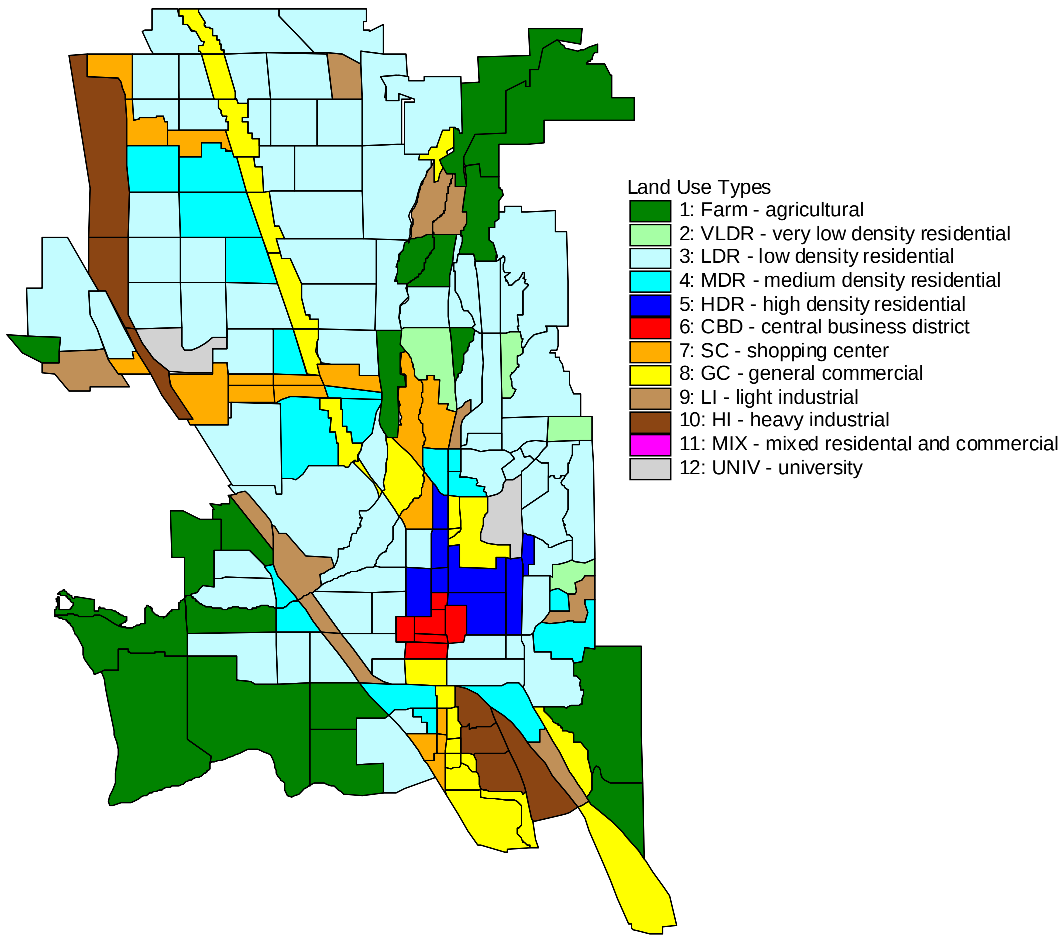


FIGURE 5.2 Land Use Types for Provo and Orem: The Status Quo

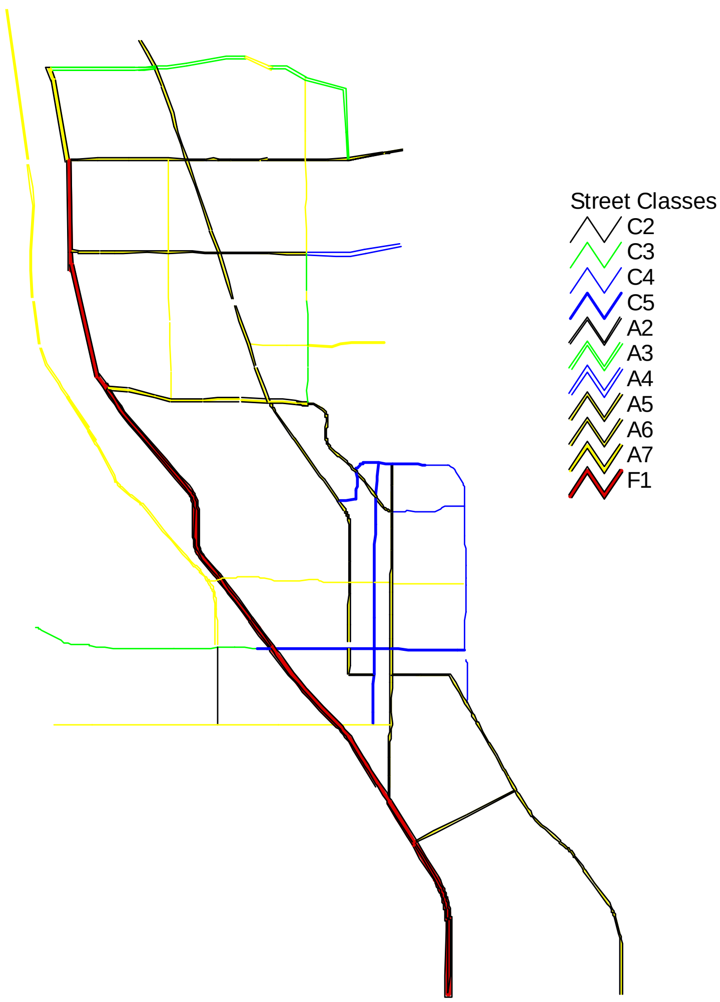


FIGURE 5.3 Street Classes for Provo and Orem: The Status Quo

Attributes were specified for each land use as shown in Table 5.2 for the analysis of the constraint functions. The housing capacity of future plans was constrained to be greater than the projected population of 327,000 for the year 2020. The employment capacity of future plans was constrained to be greater than the projected 257,608 jobs needed for the year 2020. These values were based on the growth forecasts of the 2000 census (Governor 2003). The greenspace percentage was constrained to be greater than 20 percent of the developable land.

TABLE 5.2 Land UseType Attributes For Calculating Constraint Values

Land Use Type	Housing Density (people/acre)	Employment Density (jobs/acre)	Greenspace Percentage (%)
1	0.34	0	100
2	6	0	0
3	11.6	0	0
4	34.8	0	0
5	80.8	0	0
6	0	100	0
7	0	15	0
8	0	72	0
9	0	10.4	0
10	0	8.2	0
11	34.8	4	0
12	0	17.5	100

Trip rates were created for each land use to calculate a plan's total travel time. Daily trip rates were derived from the ITE Trip Generation Manual (ITE 1997). These rates were split into attraction and production for three different trip types: HBW, HBO, and NHB (Brown 1998). The trip rates for the Peak Hour are shown in Table 5.3 and the trip rates for the Off Peak period are found in Table 5.4. Note in Table 5.3 that, as with the regional trip rates of Stage One, the only trip type considered during the peak period is HBW. In reality there would be other trip types, but they would be relatively insignificant. This allows a direct evaluation of commute trips.

TABLE 5.3 Peak Hour Trip Rates for the Land Use Types

Land Use Type	Attraction (vph per acre)			Production (vph per acre)		
	HBW	HBO	NHB	HBW	HBO	NHB
1	0.00	0.00	0.00	0.08	0.00	0.00
2	0.00	0.00	0.00	1.35	0.00	0.00
3	0.00	0.00	0.00	2.61	0.00	0.00
4	0.00	0.00	0.00	4.93	0.00	0.00
5	0.00	0.00	0.00	11.45	0.00	0.00
6	26.89	0.00	0.00	0.00	0.00	0.00
7	10.94	0.00	0.00	0.00	0.00	0.00
8	13.93	0.00	0.00	0.00	0.00	0.00
9	4.71	0.00	0.00	0.00	0.00	0.00
10	2.68	0.00	0.00	0.00	0.00	0.00
11	0.68	0.00	0.00	6.34	0.00	0.00
12	25.58	0.00	0.00	0.00	0.00	0.00

TABLE 5.4 Off-Peak Period Trip Rates for the Land Use Types

Land Use Type	Attraction (vph per acre)			Production (vph per acre)		
	HBW	HBO	NHB	HBW	HBO	NHB
1	0.00	0.04	0.04	0.12	0.46	0.00
2	0.00	0.72	0.72	2.04	8.19	0.00
3	0.00	1.39	1.39	3.94	15.81	0.00
4	0.00	2.87	2.87	9.06	32.68	0.00
5	0.00	6.65	6.65	21.03	75.85	0.00
6	2.71	124.28	22.60	0.00	0.00	22.60
7	7.42	146.46	9.76	0.00	0.00	9.76
8	9.06	90.64	20.14	0.00	0.00	20.14
9	6.90	0.00	7.53	0.00	0.00	7.53
10	0.04	0.00	0.68	0.00	0.00	0.68
11	1.18	8.45	4.22	12.67	39.70	4.22
12	168.85	0.00	27.50	0.00	0.00	27.50

Change factors were created for every possible land use type or street class change in order to calculate a plan's change from the status quo. The land use change factors are given in Table 5.5. The same street change factors used for the WFMR, as were shown previously in Table 4.7, were used for Provo and Orem. In these tables, rows correspond to the status quo, and columns correspond to the future plan. Large change factors indicate that such a change would be met with greater disdain by the public.

TABLE 5.5 Land Use Type Change Factors for Provo and Orem Cities

		Future Plan Land Use Type											
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Status Quo Land Use Type	**1**	0.0	0.1	0.1	0.4	0.6	1.0	0.4	0.4	0.2	0.2	0.5	1.0
	2	0.3	0.0	0.5	0.6	0.8	1.0	0.5	0.6	0.7	1.0	0.6	1.0
	3	0.4	0.3	0.0	0.2	0.4	0.7	0.5	0.6	0.7	0.8	0.3	1.0
	4	0.6	0.5	0.4	0.0	0.1	0.6	0.4	0.5	0.8	0.9	0.1	1.0
	5	0.9	0.8	0.6	0.3	0.0	0.4	0.6	0.6	0.7	0.9	0.4	1.0
	6	1.0	1.0	0.8	0.6	0.2	0.0	0.2	0.2	0.4	0.9	0.5	1.0
	7	0.9	0.6	0.4	0.3	0.2	0.1	0.0	0.1	0.3	0.5	0.2	1.0
	8	0.9	0.6	0.5	0.4	0.2	0.1	0.1	0.0	0.1	0.5	0.3	1.0
	9	0.9	0.8	0.6	0.5	0.4	0.2	0.2	0.2	0.0	0.3	0.4	1.0
	10	0.9	0.9	0.8	0.6	0.4	0.5	0.5	0.5	0.3	0.0	0.5	1.0
	11	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	1.0
	12	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0

Based on feedback from the planners of Provo and Orem from a previous execution, limitations were placed on the possible integer values that could be assigned to the design variables. The planners indicated that many of the zones should be limited to certain land use types (Balling, et al. 2000). These limitations were made zone by zone and can be found in Appendix B. Changes that were not allowed are marked with an X. Streets were allowed to change to any street class with an equal or greater number of lanes except to a freeway and streets that are currently freeways were not allowed to change. Furthermore, the 26 streets that correspond to inter-district streets were fixed to the street classes specified as targets by the region in Stage One. In practice, the city planners may choose not to comply with these targets, to which they may receive retribution in Stage Three.

Three additional items of input were included in Stage Two in order to calculate the deviation from the target scenario objective function. First, each zone was matched with its corresponding district. This data is displayed with the other zone identification data found in Appendix B. Second, the land use percentages for the target plan were included as found in Appendix B. The third item is a matrix of percentages defining the city land use types in terms of the regional land use types. This was necessary because the land use types used in Stage One to create the scenarios are not the same as the land use types used by the city. This is understandable because there is not a uniform set of land use classifications. It is very likely that many different classifications are used by the various planning organizations throughout the region. The two different classifications for this case study are brought into harmony as outlined in Table 5.6. In the table, the 12 city land use types are described as a percentage of the 13 regional land use types. These percentages were created through an inspection of the definition of each land use type.

TABLE 5.6 The City Land Use Types as a Percent of the Regional Land Use Types

		Regional Land Use Types												
		R1	R2	R3	R4	R5	C1	C2	C3	C4	PL	AG	PA	VA
City Land Use Types	Farm	0	0	0	0	0	0	0	0	0	0	90	10	0
	VLDR	95	0	0	0	0	0	0	0	0	0	0	5	0
	LDR	80	10	0	10	0	0	0	0	0	0	0	0	0
	MDR	20	10	70	0	0	0	0	0	0	0	0	0	0
	HDR	0	10	20	0	70	0	0	0	0	0	0	0	0
	CBD	0	0	0	0	0	30	2.5	2.5	50	15	0	0	0
	SC	0	0	0	0	0	75	0	0	25	0	0	0	0
	GC	0	0	0	0	0	35	10	10	35	10	0	0	0
	LI	0	0	0	0	0	10	60	30	0	0	0	0	0
	HI	0	0	0	0	0	0	95	0	5	0	0	0	0
	MIX	0	10	20	0	27.5	22.5	0	0	17.5	2.5	0	0	0
	UNIV	0	0	0	0	0	0	0	0	0	100	0	0	0

5.2 Provo and Orem Cities Execution and Results

The genetic algorithm was executed with a generation size of 100 plans. As in Stage One, the execution time was dominated by the analysis of the total travel time objective function. However, the execution for the cities was much faster than for the region because the street network is significantly smaller. When all three objectives were considered, execution time for a single generation required 5 minutes on a Dell Precision computer with a 1.7 GHz dual processor and 1 gigabyte of RAM. After preliminary executions were performed to create seed plans, an execution with all three objectives was performed for 200 generations. This execution was done with twice as many generations as Stage One because with three objectives the passage of more generations is required to assure a final generation of non-dominated plans. The execution for 200 generations required 17 hours.

The seeding executions for Stage Two were done in much the same way as for Stage One. Four seeding executions were performed. One with only the travel time objective for 100 generations, one with only the change objective for 10,000 generations and two with only the target objective for 10,000 generations each. One of the target executions had the streets set to maximum capacity and the other execution had the streets fixed at the status quo. The plans with the lowest objective values from the final generation of these four preliminary executions were labeled as seed plans and added to the other 96 random plans of the starting generation of the execution with all three objectives.

The same parameters for the genetic algorithm were used for the city as for the region. The tournament size for selecting parent plans was set to three. The probability of cross over was set at 0.70 and the probability of mutation was set at 0.01.

The genetic algorithm produced a diverse non-dominated final generation. The plans of the non-dominated set can be plotted according to their objective values as was done in Chapter 4 for the regional plans of Stage One. However, the city plans have three objectives, so it would be a three-dimensional plot and the non-dominated set would be a trade-off surface, rather than a trade-off curve. Alternatively, the city plans can be plotted in two-dimensions with the third objective, deviation from the target, grouped into different series with ranges of values. Figure 5.4 plots the final generation of city plans in this way. Recall that change is measured in people affected, travel time is measured in hours, and deviation from the target is measured in acres. Note that all 100 plans are non-dominated plans and that the concentric curves are merely the result of plotting the third objective as a series against the other two objectives. The range of values for each series was deliberately set to distinguish each curve.

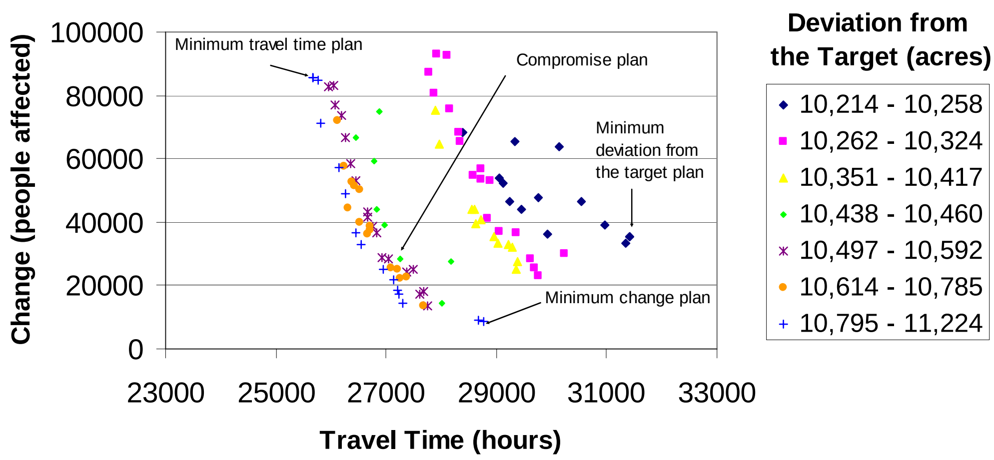


FIGURE 5.4 Plot of the City Plans from the Final Generation of Stage Two

Four plans were selected from the final generation for closer inspection. These plans are: 1) the minimum change plan, 2) the minimum travel time plan, 3) the minimum deviation from the target plan, and 4) a compromise plan. These plans are labled on the plot in Figure 5.4. This particular compromise plan was selected because it represents the scaled centroid of the three objectives for the 100 plans. In practice, city planners might use some other method to select a compromise plan. For example, the regional plans might require that the selected plan be within a certain range of deviation from the target. Table 5.7 presents the analysis of the status quo plan and the four selected plans.

TABLE 5.7 Analysis of the Status Quo and Four Plans from the Final Generation

	Status Quo	Final Generation Plans			
		Minimum Change	Minimum Travel Time	Minimum Deviation from Target	Compromise
Change (people affected)	0	8,681	85,674	35,314	28,380
Total Travel Time (hours)	24,364	28,769	25,669	31,416	27,254
Deviation from Target (acres)	10,685	11,224	10,796	10,214	10,450
Housing Capacity (people) Required = 327,000	248,381	327,008	327,006	327,197	327,719
Employment Capacity (jobs) Required = 257,608	196,189	257,747	260,571	258,295	261,580
Greenspace (acres) Required = 4,000	4,403	4,094	4,094	4,031	4,090

Note in Table 5.7 that many of the same observations can be made about the city plans as were made for the regional plans in Stage One found in Chapter 4. For example, the housing and employment capacities of the status quo plan are below the required values of 327,000 and 257,000, respectively. Once again considerable changes in the land use were needed to meet these requirements.

The minimum deviation from the target plan happens to have the worst travel time of all the plans in Table 5.7. This is interesting because the target plan that was passed down by the region had a very low travel time. Apparently the changes that improve travel time for the region as a whole do not benefit Provo and Orem individually. Another interesting finding is that of the 100 plans in the final generation, the minimum change plan has the worst deviation from the target. In other words, if Provo and Orem decide to resist change by selecting the minimum change plan, the overall region will have greater difficulty achieving their goals.

The only changes made in the streets for the minimum change plan were the changes passed down from the region as shown in Figure 5.5. Once again, significant changes were made for the street classes for the minimum travel time plan. Figure 5.6 shows that for the minimum travel time plan most of the streets were upgraded to classes with maximum speeds and capacities. There were few changes made in the street classes for the minimum deviation from the target plan and the compromise plan, but not nearly to the extent of the minimum travel time plan. Figures 5.7 and 5.8 show the street classes for the minimum deviation from the target plan and the compromise plan, respectively.

A closer examination of the land use changes for each plan brings understanding to the analysis presented in Table 5.7. The following figures present the land use types that changed from the status quo for each plan. Recall that the status quo land uses were shown in Figure 5.2. The scenarios for the minimum change plan, the minimum travel time plan, the minimum deviation from the target plan, and the compromise plan are shown in Figures 5.9, 5.10, 5.11, and 5.12, respectively.

FIGURE 5.5 Street Classes for Provo and Orem: The Minimum Change Plan

FIGURE 5.6 Street Classes for Provo and Orem: The Minimum Travel Time Plan

FIGURE 5.7 Street Classes for Provo and Orem: The Minimum Deviation from the Target Plan

FIGURE 5.8 Street Classes for Provo and Orem: The Compromise Plan

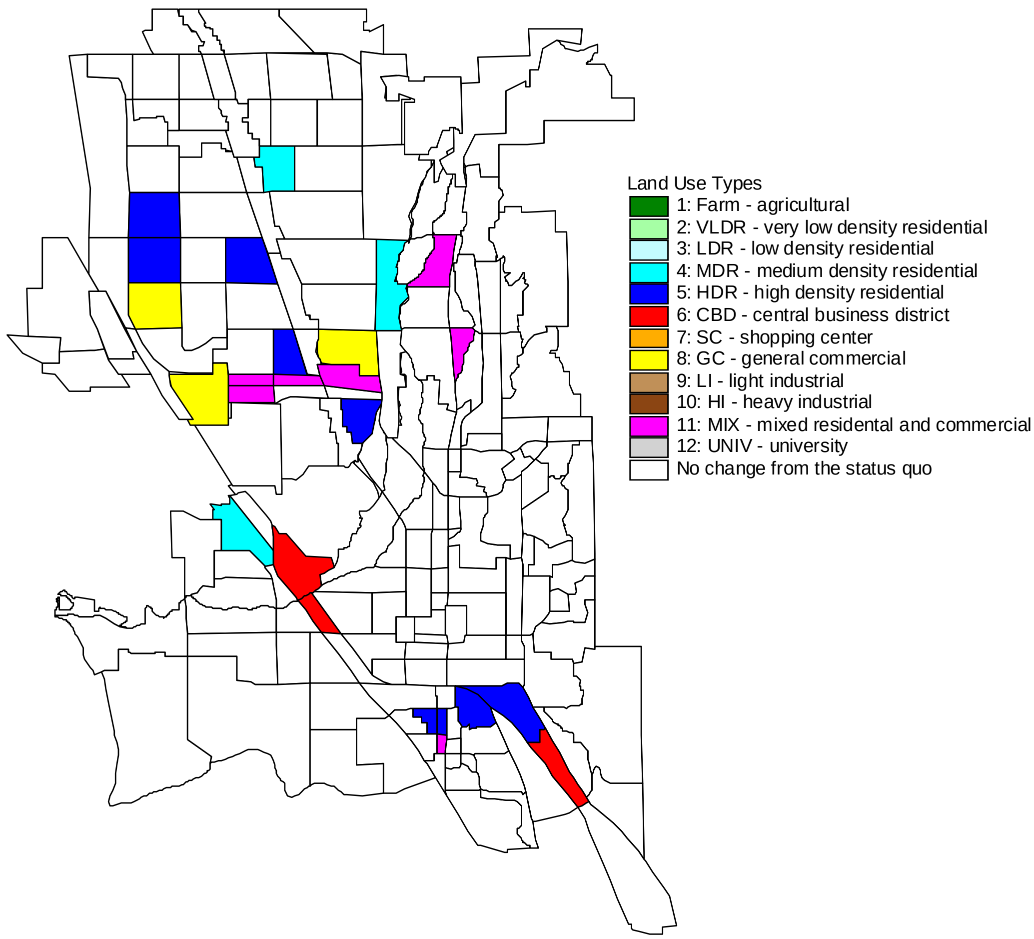


FIGURE 5.9 Land Use Types for Provo and Orem: The Minimum Change Plan

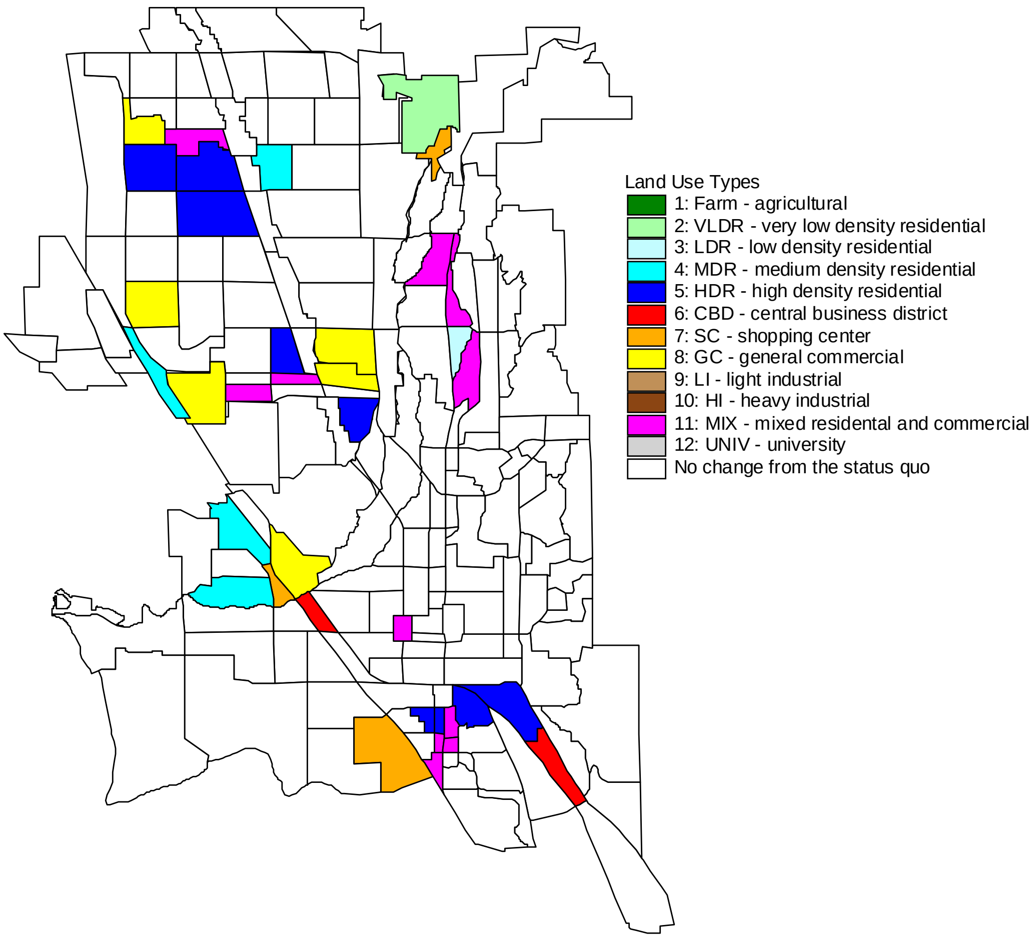


FIGURE 5.10 Land Use Types for Provo and Orem: The Minimum Travel Time Plan

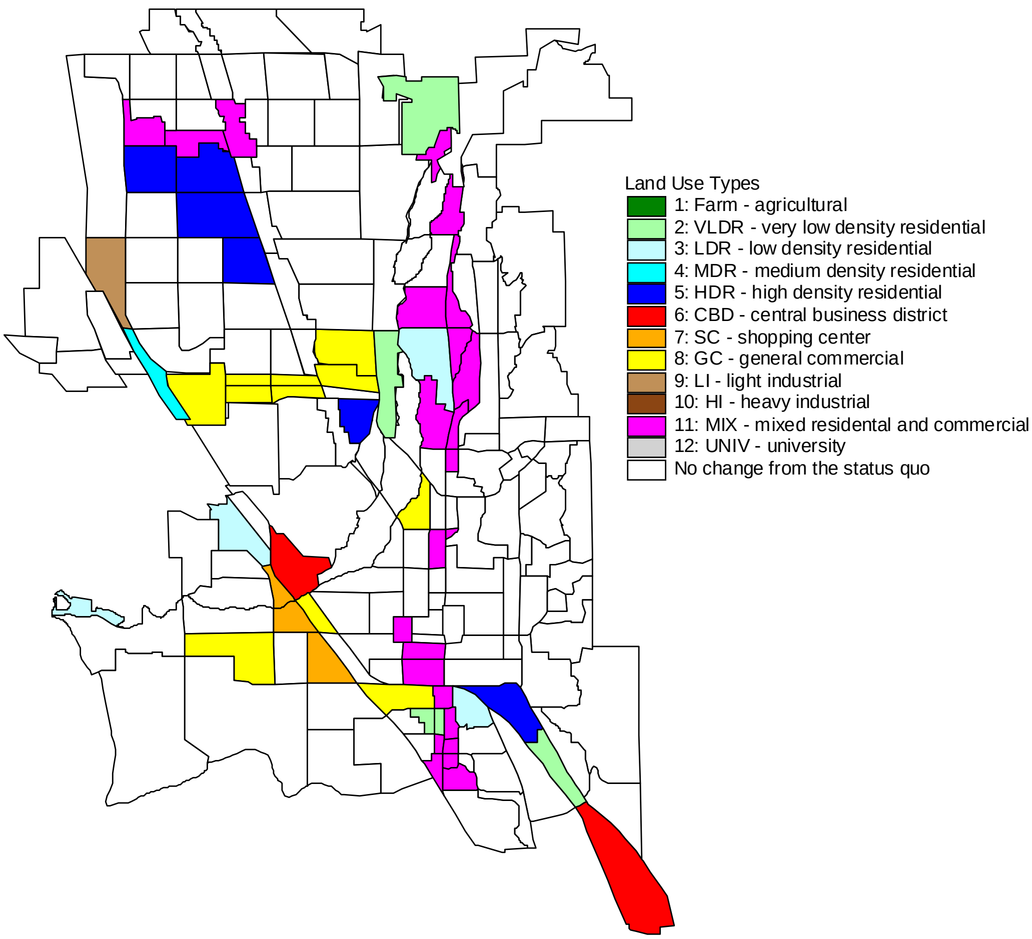


FIGURE 5.11 Land Uses for Provo and Orem: The Minimum Deviation from the Target Plan

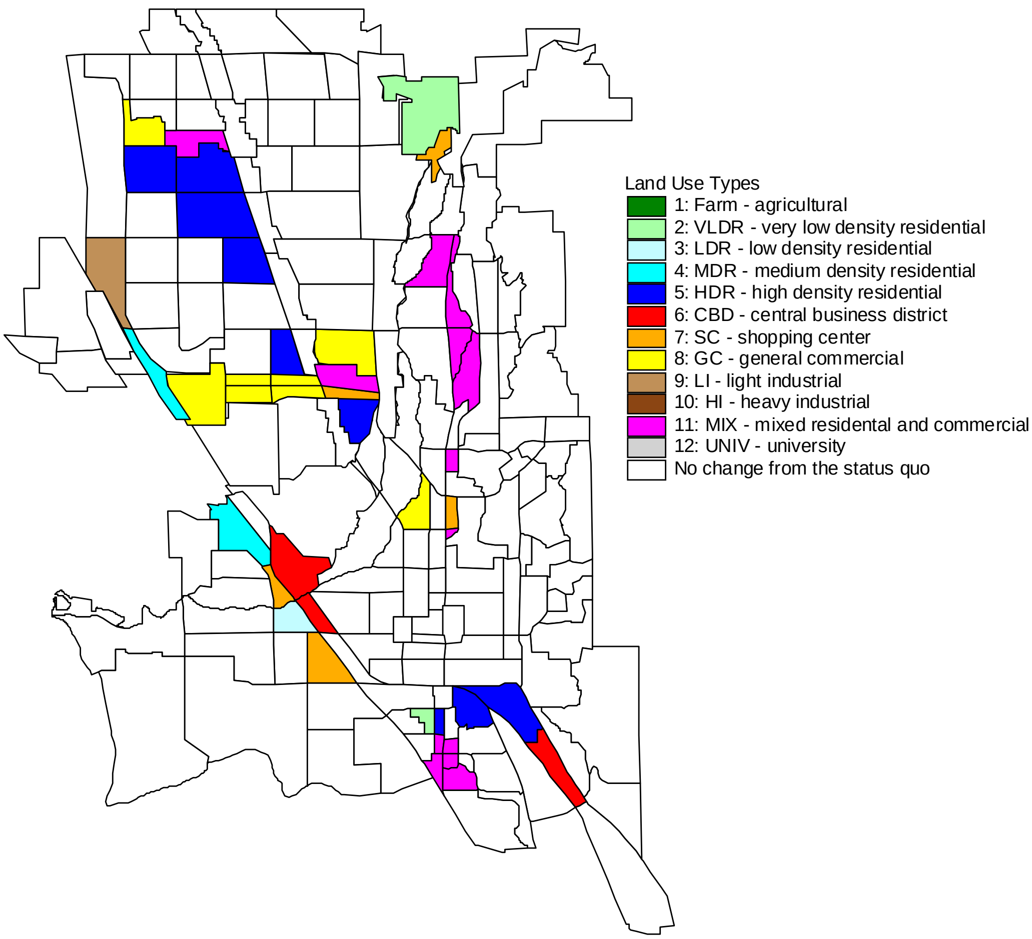


FIGURE 5.12 Land Use Types for Provo and Orem: The Compromise Plan

In the minimum change plan, only 25 zones changed land use type. Table 5.8 shows what these changes were. In this and the following three tables, rows correspond to the status quo land use type and columns correspond to the land use type of the future plan. Note that two main changes are made apparent in the table: a change from medium density residential to high density residential and a change from a low density commercial to a higher density commercial. An examination of the housing and employment densities that were presented in Table 5.2 reveals that this is the type of change that can significantly increase housing and employment capacity without changing a considerable number of zones.

TABLE 5.8 Land Use Changes for the Minimum Change Plan

		Future Plan Land Use Type												
		Farm	VLDR	LDR	MDR	HDR	CBD	SC	GC	LI	HI	MIX	UNIV	Total
Status Quo Land Use Type	Farm				1							2		3
	VLDR													0
	LDR				2	2			2					6
	MDR					5								5
	HDR													0
	CBD													0
	SC					1			1			5		7
	GC													0
	LI						3							3
	HI					1								1
	MIX													0
	UNIV													0
	Total	0	0	0	3	9	3	0	3	0	0	7	0	25

In the minimum travel time plan, most of the streets were upgraded to classes with maximum speeds and capacities. In addition to these street changes, 37 zones changed land use type from the status quo as shown in Table 5.9. Once again the majority of the changes were an increase in housing and employment densities. The changes were also influenced by the trip rates associated with each land use type. For example note in Table 5.9 that the land use type that changed the most from the status quo was Shopping Center (SC). A review of Table 5.4 reveals that SC, land use type number 7, has an extremely high Off-Peak trip rate for the HBO trip type. Recall that the HBO trip type, constitutes trips from home to something other than work such as school, shopping, recreation, and other homes. In other words, the minimum travel time plan chose land use types that increased residential and commercial land without increasing the number of trips.

TABLE 5.9 Land Use Changes for the Minimum Travel Time Plan

		Future Plan Land Use Type												
		Farm	VLDR	LDR	MDR	HDR	CBD	SC	GC	LI	HI	MIX	UNIV	Total
Status Quo Land Use Type	Farm			1	1							1		3
	VLDR													0
	LDR		1		1			1	2			2		7
	MDR					8		1						9
	HDR													0
	CBD													0
	SC					1	1		4			6		12
	GC											1		1
	LI						2		1					3
	HI				1	1								2
	MIX													0
	UNIV													0
	Total	0	1	1	3	10	3	2	7	0	0	10	0	37

The minimum deviation from the target plan had the most changes in land use type. Table 5.10 shows these changes. Notice that there is a greater variety of changes for this plan than for the previous two plans. Perhaps this is because land uses were changed at any cost (to travel time or to change) in order to meet the target. There is one change that does stand out however; the change to a mixed land use type (MIX) in the future plan. Recall from Stage One that in order to reduce traffic congestion, the region needed to convert much of the land to mixed residential and commercial. Consequently, if Provo and Orem cities want to be in compliance with the target of the region, they need to convert their land to mixed use as well.

TABLE 5.10 Land Use Changes for the Minimum Deviation from the Target Plan

		Future Plan Land Use Type												
		Farm	VLDR	LDR	MDR	HDR	CBD	SC	GC	LI	HI	MIX	UNIV	Total
Status Quo Land Use Type	Farm		1	2								1		4
	VLDR			1										1
	LDR		1					1	2			3		7
	MDR		1			6		2	1			1		11
	HDR											1		1
	CBD											2		2
	SC		1						7			5		13
	GC						1					9		10
	LI		1				1		1			2		5
	HI				1	1				1				3
	MIX													0
	UNIV													0
	Total	0	5	3	1	7	2	3	11	1	0	24	0	57

The compromise plan represents the middle ground between all three objectives. Like the minimum change plan and the minimum travel time plan, many of the changes were an increase in housing and employment densities, as is shown in Table 5.11. Likewise, many of the changes resemble those of the minimum deviation from the target plan, such as a high percentage of mixed land use in the future plan. A closer inspection of Figure 5.4 reveals that this plan is a good choice for a compromise because, relative to the other plans, it has a low change, a low travel time, and a low deviation from the target.

TABLE 5.11 Land Use Changes for the Compromise Plan

		Future Plan Land Use Type												
		Farm	VLDR	LDR	MDR	HDR	CBD	SC	GC	LI	HI	MIX	UNIV	Total
Status Quo Land Use Type	Farm				1							2		3
	VLDR													0
	LDR		1					1	1			2		5
	MDR		1	1		7		2				1		12
	HDR													0
	CBD													0
	SC					1			7			4		12
	GC							2				4		6
	LI						3							3
	HI				1	1				1				3
	MIX													0
	UNIV													0
	Total	0	2	1	2	9	3	5	8	1	0	13	0	44

Further examination of the results suggests that the planners of Provo and Orem cities were too restrictive with the allowable changes for each zone. Recall that prior to the execution of Stage Two, the planners from both city were given the opportunity to decide which land use types could be assigned to each of the 190 zones. Appendix B tabulates the allowable changes for each zone as prescribed by the planners. The planners' restrictions limited the number of possible changes. The plans presented above demonstrate this. The restrictions in turn affected the ability to meet the target. Note that the range of values for deviation from the target shown in Figure 5.4 is small compared to the range of values for the other two objectives. Since the deviation value for the status quo plan lies within this small range, one can conclude that the algorithm did not have much freedom with respect to this objective. This is unfortunate because if the planners had not been so restrictive, total travel time and deviation from the target may have been reduced much more.

The results, as well as the restrictions imposed by the city planners, would be divulged to the regional planners in Stage Three. Stage Three will not be illustrated in this thesis because it must be studied in a real life setting where the pressures of politics are free to work naturally. Further research needs to be done to determine the mechanics of the meetings that would be held. There would certainly be much debate and negotiation over the region's requests for change and the cities' insistence on preventing change. But it is this coordination, albeit forced, that the Urban Genetic approach hopes to foster.

CHAPTER 6. Conclusions

In the introduction of this thesis two questions were posed concerning city and regional planning.

1. Is it possible to achieve regional goals without infringing upon the local autonomy of city planners?

2. Is it possible to objectively analyze the thousands, even millions, of land use and transportation plans to find the best design?

This thesis has presented a new approach to planning that answers these two questions in the affirmative.

6.1 The Urban Genetic Approach

The first question was answered through a unique problem formulation and a corresponding three stage process, together referred to as the Urban Genetic approach. In this new approach, regional goals are achieved because they are cast as objectives and constraints in the first stage. Local autonomy is achieved because some of the decisions are left for the city planners to decide in the second stage. The regional planners determine scenarios for the districts and street classes for the inter-district streets, while the city planners determine the zoning for the city and the street classes for the intra-district streets. The third stage allows for negotiation between the regional and city planners.

The second question was answered through the use of a genetic algorithm. In the past, models have been used to objectively analyze plans. However, prior to this thesis, there has not been an objective way to find the best plans for analysis. Consequently, planners have had no choice but to subjectively create a handful of plans for analysis. In the Urban Genetic approach, a genetic algorithm provides the means to objectively search for the best plans for a region or city.

6.2 Future Research

This thesis not only successfully answered these two questions, but also demonstrated the Urban Genetic approach on a case study. The approach was applied to the Wasatch Front Metropolitan Region (WFMR) and two cities within the region, Provo and Orem. The results exposed valuable lessons that apply to other regions experiencing rapid growth. The results showed that for a region to minimize change, while still providing sufficient land for housing and employment, open space land must be developed as residential and commercial land. This is because changing open space land affects the fewest number of people, thus minimizing change. Such development is called suburban sprawl and is exactly what is happening in the WFMR and across the country. On the other hand, the results showed that to minimize traffic congestion, and yet provide sufficient housing and employment, mixed residential and commercial development must occur throughout the region because mixed development results in shorter travel times. Additionally, travel time can be greatly reduced with upgrades in street speed and capacity.

The presentation of the results to the planners and political officials of the WFMR provided an opportunity to visualize how the Urban Genetic approach can be advanced in future work. First, further research needs to be conducted to establish an appropriate course of action for Stage Three, the reconciliation process between a region and the cities. This would be accomplished best in a real setting where the dynamics of a political climate can be examined first hand. Second, many of the planners recommended that public transit be included into the Urban Genetic approach. Currently, the third step of the UTMS, called Modal Split, is not considered in the calculation of travel times. Further work is needed to determine how trains, buses, bikes, and walking can be incorporated into the analysis of the transportation system.

Perhaps the most interesting thing that was discovered during the presentation of the results is the need to condense the number of plans to be presented. Currently, the final generation consists of 100 plans. It is an overwhelming task to assimilate 100 plans, especially when the differences between plans are very subtle. The genetic algorithm produces a non-dominated set of plans that are diverse with respect to the different objective functions, but not necessarily diverse with respect to the design variables. In other words, the plans of the final generation may not have a diverse distribution of land uses and street classes. Further work is needed to produce a smaller set of plans that are significantly different with respect to the design variables in order to give the decision-makers a succinct and diverse set of choices.

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Appendix

APPENDIX A. Stage One Data: The WFMR

District Data

District ID	Status Quo Scenario	Area (acres)
1	1	15283
2	6	8999
3	6	1633
4	3	10811
5	8	850
6	6	1449
7	5	1918
8	5	1695
9	3	1778
10	3	5921
11	3	3097
12	3	4542
13	3	9225
14	3	7877
15	3	11060
16	6	1869
17	15	2197
18	7	1966
19	5	1938
20	3	2685
21	6	6687
22	5	1705
23	13	1469
24	14	1974
25	8	790
26	14	2172
27	13	1316
28	13	1089
29	13	1890
30	13	4225
31	6	2446
32	8	1015
33	6	707
34	6	716
35	8	648
36	8	838
37	8	363
38	8	506
39	11	501
40	13	1126
41	16	985
42	6	567
43	6	661
44	8	528
45	8	606
46	8	768
47	5	522
48	5	720
49	5	444
50	6	1775
51	15	4088
52	6	1074
53	6	549
54	5	252
55	5	619
56	5	496
57	5	560
58	13	1545
59	6	497
60	6	467
61	5	1485
62	5	605
63	5	641
64	5	2788
65	8	2545
66	8	1069
67	5	1469
68	5	981
69	5	1990
70	5	755
71	4	1032
72	6	1201
73	5	4453
74	5	1401
75	8	1000
76	13	372
77	1	11539
78	3	1300
79	3	2177
80	3	6909
81	1	27113
82	5	7258
83	3	19353
84	3	999
85	14	5642
86	6	4582
87	8	4874
88	3	5698
89	3	10584
90	3	28930
91	1	22460
92	1	3490
93	1	3893
94	3	2971
95	3	1382
96	5	1515
97	6	2099
98	8	3249
99	6	2309
100	6	1396
101	6	1961
102	8	667
103	6	701
104	8	1018
105	8	1184
106	6	1024
107	6	601
108	5	567
109	8	844
110	6	448
111	9	795
112	8	2872
113	8	1709
114	8	1523
115	12	412
116	13	615
117	12	313
118	11	252
119	8	1396
120	8	1715
121	8	2460
122	6	2765
123	3	4103

124	3	2001
125	15	982
126	1	1948
127	1	1591
128	1	1079
129	6	1649
130	17	1970
131	5	1448
132	8	1383
133	14	1003
134	8	1007
135	8	1573
136	8	787
137	6	643
138	8	1102
139	6	481
140	6	567
141	6	574
142	5	678
143	5	1294
144	5	1234
145	5	690
146	8	491
147	8	750
148	5	703
149	6	1090
150	5	1215
151	6	2435
152	8	1018
153	9	1070
154	8	1590
155	5	436
156	8	389
157	5	744
158	5	455
159	5	660
160	5	709
161	6	1043
162	6	768
163	6	1210
164	6	1085
165	1	676
166	14	1054
167	14	1248
168	14	880
169	15	4801
170	15	8125
171	1	8651
172	14	1521
173	13	1280
174	5	1359
175	5	1279
176	5	972
177	5	839

178	5	1535
179	5	965
180	9	690
181	8	924
182	5	389
183	10	457
184	8	425
185	5	510
186	8	1195
187	8	1415
188	13	777
189	11	640
190	8	823
191	8	768
192	8	1119
193	8	642
194	6	707
195	6	534
196	6	1848
197	6	678
198	5	1668
199	5	941
200	6	854
201	5	633
202	5	518
203	5	287
204	8	3648
205	6	419
206	8	1630
207	13	1228
208	8	864
209	11	908
210	5	796
211	11	823
212	14	1009
213	5	915
214	11	941
215	6	1104
216	3	1852
217	6	3757
218	15	12594
219	15	10234
220	14	4137
221	14	3226
222	14	5486
223	13	4808
224	11	2067
225	11	781
226	8	324
227	6	643
228	5	217
229	6	1204
230	5	372
231	6	138

232	6	564
233	6	249
234	5	139
235	8	335
236	2	239
237	16	1927
238	8	11561
239	13	7595
240	8	703
241	13	1765
242	17	6220
243	17	2092
244	14	2896
245	1	7139
246	1	6017
247	14	3544
248	13	2186
249	6	1818
250	3	488
251	6	721
252	6	781
253	3	2190
254	1	4886
255	3	1685
256	8	1086
257	6	643
258	6	825
259	6	1089
260	6	2526
261	14	1282
262	3	2384
263	1	3739
264	3	1883
265	3	1423
266	6	1557
267	3	1242
268	3	2081
269	1	1476
270	1	11162
271	1	5990
272	1	2309
273	3	1288
274	6	1360
275	3	1398
276	3	1247
277	6	1556
278	6	1523
279	3	2248
280	3	1648
281	14	1622
282	13	1022
283	1	5303
284	1	5996
285	1	4365

286	3	1646
287	3	1846
288	6	930
289	8	1095
290	6	934
291	3	8549
292	1	2385
293	13	393
294	6	1602
295	3	1860
296	3	565
297	1	1340
298	6	1015
299	6	1137
300	16	853
301	6	876
302	6	393
303	13	702
304	3	2580
305	8	931
306	6	1074
307	6	902
308	5	1060
309	3	1100
310	1	7704
311	3	2999
312	6	693
313	13	2095
314	11	1299
315	6	1807
316	8	963
317	8	836
318	11	599
319	11	813
320	1	3561
321	1	8136
322	1	18148
323	1	9503
324	1	3811
325	1	2078
326	3	2323
327	1	2800
328	1	3196
329	15	1724
330	8	887
331	6	1597
332	8	1271
333	6	1013
334	1	719
335	3	1509
336	1	645
337	3	1665
338	12	523
339	1	3573
340	1	4546
341	1	1318
342	3	2372
343	13	484

Inter-district Street Data

Link ID	Street #	Status[2] Quo Class	Node A	Node B	Length (miles)
501	0	cc	501	1	4.51
502	0	cc	502	2	3.69
503	0	cc	503	3	0.63
504	0	cc	504	5	4.01
505	0	cc	505	6	1.38
506	0	cc	506	6	0.63
507	0	cc	507	7	1.75
508	0	cc	508	15	0.44
509	0	cc	509	14	0.38
510	0	cc	510	11	1.50
511	0	cc	511	12	0.69
512	0	cc	512	12	2.50
513	0	cc	513	6	3.63
514	0	cc	514	8	7.88
515	0	cc	515	8	3.44
516	0	cc	516	10	1.69
517	0	cc	517	493	0.88
518	0	cc	518	17	0.31
519	0	cc	519	18	1.50
520	0	cc	520	19	0.94
521	0	cc	521	20	2.44
522	0	cc	522	26	0.88
523	0	cc	523	21	0.75
524	0	cc	524	24	0.31
525	0	cc	525	25	0.50
526	0	cc	526	27	1.44
527	0	cc	527	30	0.69
528	0	cc	528	29	0.94
529	0	cc	529	29	1.38
530	0	cc	530	31	0.56
531	0	cc	531	53	0.75
532	0	cc	532	56	1.13
533	0	cc	533	56	2.07
534	0	cc	534	32	1.06
535	0	cc	535	52	1.25
536	0	cc	536	52	0.19
537	0	cc	537	34	0.94
538	0	cc	538	34	0.56
539	0	cc	539	36	0.44
540	0	cc	540	39	0.38
541	0	cc	541	40	0.81
542	0	cc	542	41	0.31
543	0	cc	543	47	1.13
544	0	cc	544	59	0.38
545	0	cc	545	58	0.44
546	0	cc	546	57	0.63
547	0	cc	547	64	0.88
548	0	cc	548	65	0.81
549	0	cc	549	56	1.19
550	0	cc	550	488	0.56
551	0	cc	551	69	1.56
552	0	cc	552	77	1.13
553	0	cc	553	72	0.25
554	0	cc	554	88	0.38
555	0	cc	555	66	0.63
556	0	cc	556	71	0.88
557	0	cc	557	73	0.19
558	0	cc	558	75	0.56
559	0	cc	559	60	0.31
560	0	cc	560	61	0.13
561	0	cc	561	74	0.94
562	0	cc	562	77	1.13
563	0	cc	563	89	0.44
564	0	cc	564	89	1.63
565	0	cc	565	84	0.31
566	0	cc	566	82	0.94
567	0	cc	567	87	1.56
568	0	cc	568	93	0.81
569	0	cc	569	93	1.19
570	0	cc	570	91	1.25
571	0	cc	571	97	0.81
572	0	cc	572	94	0.31
573	0	cc	573	99	0.63
574	0	cc	574	102	1.13
575	0	cc	575	98	0.31
576	0	cc	576	90	0.38
577	0	cc	577	106	1.00
578	0	cc	578	105	0.63
579	0	cc	579	116	0.75
580	0	cc	580	108	2.82
581	0	cc	581	109	1.63
582	0	cc	582	110	2.25
583	0	cc	583	112	0.56
584	0	cc	584	111	0.56
585	0	cc	585	114	1.06
586	0	cc	586	122	1.23
587	0	cc	587	122	3.11
588	0	cc	588	121	2.23
589	0	cc	589	117	1.06
590	0	cc	590	243	3.17
591	0	cc	591	269	4.99
592	0	cc	592	255	1.17
593	0	cc	593	244	0.94
594	0	cc	594	241	0.41
595	0	cc	595	245	0.76

[2] cc = centroidal connector

596	0	cc	596	247	0.53	649	0	cc	649	152	1.41
597	0	cc	597	248	0.29	650	0	cc	650	152	0.65
598	0	cc	598	123	1.64	651	0	cc	651	176	0.29
599	0	cc	599	120	0.23	652	0	cc	652	164	0.76
600	0	cc	600	144	0.41	653	0	cc	653	169	1.00
601	0	cc	601	147	0.29	654	0	cc	654	168	1.59
602	0	cc	602	127	0.29	655	0	cc	655	281	0.47
603	0	cc	603	143	0.35	656	0	cc	656	315	0.47
604	0	cc	604	145	1.17	657	0	cc	657	279	0.65
605	0	cc	605	141	0.65	658	0	cc	658	279	0.47
606	0	cc	606	142	0.65	659	0	cc	659	275	0.41
607	0	cc	607	128	0.65	660	0	cc	660	290	0.59
608	0	cc	608	129	0.82	661	0	cc	661	273	0.23
609	0	cc	609	138	0.47	662	0	cc	662	291	0.76
610	0	cc	610	130	0.41	663	0	cc	663	277	0.94
611	0	cc	611	132	0.47	664	0	cc	664	277	1.00
612	0	cc	612	125	0.70	665	0	cc	665	270	1.00
613	0	cc	613	249	1.23	666	0	cc	666	270	1.00
614	0	cc	614	249	0.70	667	0	cc	667	272	0.88
615	0	cc	615	136	0.18	668	0	cc	668	271	0.65
616	0	cc	616	134	1.12	669	0	cc	669	271	2.00
617	0	cc	617	135	0.23	670	0	cc	670	300	1.06
618	0	cc	618	134	0.41	671	0	cc	671	299	1.17
619	0	cc	619	261	0.47	672	0	cc	672	298	1.35
620	0	cc	620	259	0.47	673	0	cc	673	297	0.65
621	0	cc	621	258	0.59	674	0	cc	674	302	0.65
622	0	cc	622	262	0.23	675	0	cc	675	296	0.23
623	0	cc	623	253	0.70	676	0	cc	676	304	0.82
624	0	cc	624	256	0.23	677	0	cc	677	306	0.23
625	0	cc	625	269	0.65	678	0	cc	678	295	0.29
626	0	cc	626	257	1.12	679	0	cc	679	286	0.53
627	0	cc	627	268	0.65	680	0	cc	680	318	0.53
628	0	cc	628	267	0.76	681	0	cc	681	320	0.35
629	0	cc	629	266	0.35	682	0	cc	682	318	0.41
630	0	cc	630	278	0.88	683	0	cc	683	316	0.47
631	0	cc	631	280	0.18	684	0	cc	684	316	0.70
632	0	cc	632	282	0.53	685	0	cc	685	489	0.76
633	0	cc	633	166	0.41	686	0	cc	686	168	1.00
634	0	cc	634	165	0.35	687	0	cc	687	172	1.00
635	0	cc	635	162	0.29	688	0	cc	688	197	0.70
636	0	cc	636	137	0.76	689	0	cc	689	195	0.41
637	0	cc	637	161	0.53	690	0	cc	690	201	0.12
638	0	cc	638	139	0.53	691	0	cc	691	194	0.12
639	0	cc	639	158	0.47	692	0	cc	692	177	0.41
640	0	cc	640	157	0.18	693	0	cc	693	191	0.18
641	0	cc	641	146	0.35	694	0	cc	694	187	0.41
642	0	cc	642	149	0.76	695	0	cc	695	186	0.35
643	0	cc	643	150	0.41	696	0	cc	696	179	0.23
644	0	cc	644	159	0.53	697	0	cc	697	180	0.76
645	0	cc	645	156	0.23	698	0	cc	698	181	0.41
646	0	cc	646	155	0.70	699	0	cc	699	182	0.41
647	0	cc	647	151	0.18	700	0	cc	700	184	0.76
648	0	cc	648	154	0.35	701	0	cc	701	183	0.76

702	0	cc	702	188	0.65
703	0	cc	703	189	0.35
704	0	cc	704	206	1.12
705	0	cc	705	226	0.76
706	0	cc	706	204	0.59
707	0	cc	707	197	1.41
708	0	cc	708	322	1.00
709	0	cc	709	322	0.29
710	0	cc	710	305	0.88
711	0	cc	711	310	2.06
712	0	cc	712	310	0.23
713	0	cc	713	311	0.35
714	0	cc	714	313	1.12
715	0	cc	715	312	0.23
716	0	cc	716	313	1.64
717	0	cc	717	301	1.06
718	0	cc	718	491	0.70
719	0	cc	719	331	3.99
720	0	cc	720	332	1.47
721	0	cc	721	333	0.53
722	0	cc	722	323	1.70
723	0	cc	723	325	0.76
724	0	cc	724	214	0.59
725	0	cc	725	231	0.29
726	0	cc	726	216	0.23
727	0	cc	727	218	0.23
728	0	cc	728	221	0.76
729	0	cc	729	220	0.23
730	0	cc	730	222	0.41
731	0	cc	731	224	0.29
732	0	cc	732	225	0.53
733	0	cc	733	229	0.59
734	0	cc	734	229	0.53
735	0	cc	735	228	0.65
736	0	cc	736	227	0.35
737	0	cc	737	223	1.29
738	0	cc	738	240	3.17
739	0	cc	739	236	3.29
740	0	cc	740	327	2.00
741	0	cc	741	329	1.35
742	0	cc	742	337	3.99
743	0	cc	743	337	1.53
744	0	cc	744	332	2.11
745	0	cc	745	334	2.47
746	0	cc	746	335	3.63
747	0	cc	747	344	0.25
748	0	cc	748	346	1.69
749	0	cc	749	352	1.13
750	0	cc	750	357	0.56
751	0	cc	751	352	0.56
752	0	cc	752	349	0.19
753	0	cc	753	345	1.44
754	0	cc	754	341	1.06

755	0	cc	755	358	0.88
756	0	cc	756	355	0.44
757	0	cc	757	356	0.69
758	0	cc	758	356	0.88
759	0	cc	759	361	1.56
760	0	cc	760	363	0.50
761	0	cc	761	363	1.13
762	0	cc	762	364	0.44
763	0	cc	763	368	3.50
764	0	cc	764	423	0.31
765	0	cc	765	490	0.19
766	0	cc	766	425	0.50
767	0	cc	767	368	2.81
768	0	cc	768	372	2.38
769	0	cc	769	372	1.44
770	0	cc	770	372	3.31
771	0	cc	771	383	2.44
772	0	cc	772	371	0.50
773	0	cc	773	370	1.69
774	0	cc	774	431	0.25
775	0	cc	775	427	0.31
776	0	cc	776	429	0.25
777	0	cc	777	430	0.56
778	0	cc	778	430	2.25
779	0	cc	779	432	0.44
780	0	cc	780	377	0.31
781	0	cc	781	380	0.19
782	0	cc	782	392	0.25
783	0	cc	783	381	0.44
784	0	cc	784	385	2.75
785	0	cc	785	385	0.44
786	0	cc	786	403	1.19
787	0	cc	787	403	1.13
788	0	cc	788	398	0.19
789	0	cc	789	395	1.13
790	0	cc	790	393	0.50
791	0	cc	791	436	2.31
792	0	cc	792	434	0.94
793	0	cc	793	435	0.13
794	0	cc	794	433	0.88
795	0	cc	795	438	0.81
796	0	cc	796	438	0.81
797	0	cc	797	449	1.69
798	0	cc	798	448	0.25
799	0	cc	799	452	0.31
800	0	cc	800	453	0.25
801	0	cc	801	446	0.75
802	0	cc	802	447	0.63
803	0	cc	803	447	1.50
804	0	cc	804	443	0.75
805	0	cc	805	400	0.38
806	0	cc	806	405	1.19
807	0	cc	807	401	0.19

808	0	cc	808	402	0.75
809	0	cc	809	404	0.19
810	0	cc	810	386	0.31
811	0	cc	811	404	2.06
812	0	cc	812	408	0.50
813	0	cc	813	410	0.69
814	0	cc	814	460	0.31
815	0	cc	815	455	0.44
816	0	cc	816	465	1.19
817	0	cc	817	464	0.38
818	0	cc	818	463	0.44
819	0	cc	819	469	0.69
820	0	cc	820	412	0.50
821	0	cc	821	387	0.31
822	0	cc	822	421	3.56
823	0	cc	823	390	1.13
824	0	cc	824	388	1.00
825	0	cc	825	391	0.50
826	0	cc	826	419	0.38
827	0	cc	827	419	1.13
828	0	cc	828	416	0.25
829	0	cc	829	471	1.94
830	0	cc	830	470	0.19
831	0	cc	831	466	0.44
832	0	cc	832	477	0.44
833	0	cc	833	478	0.56
834	0	cc	834	480	0.81
835	0	cc	835	479	0.56
836	0	cc	836	476	0.63
837	0	cc	837	473	0.31
838	0	cc	838	474	0.88
839	0	cc	839	418	0.56
840	0	cc	840	484	0.94
841	0	cc	841	482	0.31
842	0	cc	842	481	0.94
843	0	cc	843	1	0.25
1	1	11	4	5	3.21
2	1	11	5	6	5.50
3	1	11	6	8	5.99
4	1	11	8	22	0.95
5	1	11	22	493	0.35
8	2	11	493	23	2.35
9	2	11	23	27	1.85
10	2	11	27	29	1.55
11	3	11	29	33	2.24
12	3	11	33	55	3.38
13	3	11	55	67	1.57
14	3	11	67	70	1.01
15	3	11	70	78	1.11
16	3	11	78	80	0.42
17	3	11	80	81	2.09
18	3	11	81	90	1.18
19	3	11	90	100	2.04

20	3	11	100	104	1.17
21	3	11	104	113	4.25
22	3	11	113	119	5.75
23	4	11	119	123	1.61
24	4	11	123	133	2.22
25	5	11	133	134	1.97
26	5	11	134	166	1.57
27	5	11	166	167	1.57
28	5	11	167	168	1.44
29	5	11	168	170	1.33
30	5	11	170	197	1.71
32	5	11	197	202	1.32
33	5	11	202	234	2.98
35	5	11	234	235	0.19
36	6	11	235	340	5.23
37	7	11	340	344	1.94
38	7	11	344	345	1.57
39	7	11	345	358	0.67
40	7	11	358	365	5.58
41	7	11	365	366	0.76
42	8	11	366	367	2.16
43	8	11	367	369	2.75
44	8	11	369	376	2.81
46	8	11	376	378	1.21
47	8	11	378	394	1.21
48	8	11	394	396	1.70
49	8	11	396	399	2.57
50	8	11	399	406	0.70
51	8	11	406	407	1.05
52	8	11	407	410	1.58
53	9	11	410	413	1.19
54	9	11	413	414	1.89
55	9	11	414	417	4.19
56	9	11	417	486	2.48
57	10	8	15	13	0.67
58	10	8	13	12	2.25
59	10	8	12	10	2.48
60	10	8	10	9	1.91
61	10	8	9	22	0.68
62	11	6	18	19	1.76
63	11	6	19	20	2.14
64	12	8	20	21	1.53
65	13	6	16	21	3.30
66	14	8	21	25	0.27
67	14	8	25	28	1.70
68	14	8	28	30	1.87
69	14	8	30	37	1.38
70	15	3	37	38	0.68
71	15	3	38	40	1.29
72	15	3	40	42	0.21
73	16	2	42	47	1.00
74	17	8	29	36	1.49
75	18	4	36	44	1.27

76	18	4	44	45	0.53
77	18	4	45	48	0.52
78	19	8	48	58	0.98
79	19	8	58	63	1.40
80	19	8	63	62	0.70
81	20	4	44	43	0.57
82	20	4	43	47	0.53
83	21	6	47	59	1.37
84	21	6	59	60	0.68
85	21	6	60	62	1.11
86	22	8	62	75	0.30
87	23	4	35	46	1.94
88	23	4	46	49	0.39
89	24	10	51	34	0.28
90	24	10	34	52	1.17
91	24	10	52	56	1.83
92	25	9	56	65	1.73
93	25	9	65	71	1.07
94	25	9	71	77	1.07
95	25	9	77	88	0.38
96	26	8	88	87	1.78
97	26	8	87	86	0.57
98	26	8	86	85	0.12
99	26	8	85	92	1.75
100	26	8	92	91	0.89
101	26	8	91	98	0.60
102	26	8	98	101	0.84
103	26	8	101	100	0.34
104	27	2	57	64	1.65
105	28	6	64	73	0.52
106	28	6	73	74	0.51
107	28	6	74	76	0.88
108	29	1	31	492	0.84
109	30	5	32	53	2.27
110	30	5	53	54	1.15
111	30	5	54	488	1.08
112	30	5	488	68	0.50
113	30	5	68	69	1.02
114	30	5	69	79	1.00
115	30	5	79	80	0.27
116	30	5	80	84	0.76
117	30	5	84	83	0.67
118	30	5	83	85	0.57
119	31	5	86	93	1.49
120	31	5	93	94	2.61
121	31	5	94	95	1.19
122	32	6	82	92	1.27
123	32	6	92	97	1.92
124	32	6	97	96	2.40
125	33	2	90	91	0.92
126	34	2	98	99	3.88
127	35	3	99	122	2.21
128	36	4	101	102	0.45

129	36	4	102	103	0.77
130	37	8	116	115	2.03
131	38	8	108	107	2.09
132	39	6	107	117	6.25
133	39	6	117	118	2.06
134	39	6	118	248	0.38
135	39	6	248	247	1.00
136	40	4	247	250	2.72
137	40	4	250	260	1.74
138	40	4	260	263	1.48
139	40	4	263	282	0.62
140	40	4	282	281	1.30
141	40	4	281	283	0.44
142	41	4	283	315	0.57
143	41	4	315	489	0.55
144	41	4	489	317	0.45
145	41	4	317	318	0.38
146	41	4	318	319	0.60
147	41	4	319	320	0.50
148	41	4	320	321	0.49
149	41	4	321	322	1.07
150	41	4	322	323	0.78
151	42	4	323	324	1.85
152	42	4	324	325	0.66
153	42	4	325	326	0.35
154	43	4	326	327	1.27
155	43	4	327	329	1.36
156	44	2	329	339	2.08
157	45	2	339	344	1.10
158	45	2	344	343	0.83
159	45	2	343	342	1.53
160	46	5	112	110	5.03
161	47	5	1	2	4.95
162	47	5	2	3	1.46
163	47	5	3	5	1.07
164	48	8	6	7	1.27
165	48	8	13	14	1.15
166	49	8	10	11	1.30
167	50	6	8	9	0.71
168	50	6	9	16	1.00
169	51	8	16	17	1.28
170	51	8	17	18	2.21
171	52	2	23	24	1.00
172	52	2	24	25	0.91
173	52	2	25	26	1.26
174	53	2	27	28	1.93
175	54	2	29	30	1.55
176	55	2	492	32	0.96
177	55	2	32	33	0.52
178	56	4	33	34	0.92
179	57	4	51	35	0.29
180	57	4	35	36	0.18
181	57	4	36	37	1.01

182	58	1	38	39	0.38
183	59	1	40	41	0.67
184	60	4	54	55	0.45
185	60	4	55	56	1.82
186	60	4	56	57	0.45
187	61	4	57	50	0.83
188	61	4	50	46	0.46
189	61	4	46	45	0.22
190	62	3	43	42	0.69
191	63	4	50	49	0.35
192	63	4	49	48	0.14
193	63	4	48	47	0.13
194	64	4	68	67	0.43
195	65	4	67	66	0.58
196	65	4	66	65	1.04
197	66	8	65	64	0.98
198	66	8	64	63	1.03
199	67	1	60	61	0.81
200	68	8	69	70	0.46
201	69	8	70	72	0.45
202	69	8	72	71	0.84
203	70	8	71	74	1.31
204	70	8	74	75	1.15
205	71	6	79	78	0.26
206	71	6	78	77	1.30
207	71	6	77	76	1.68
208	72	3	88	89	0.78
209	73	2	82	83	1.30
210	73	2	83	87	0.49
211	260	2	81	82	0.33
212	74	5	111	110	4.20
213	74	5	110	109	3.33
214	74	5	109	107	3.35
215	75	5	107	106	2.22
216	75	5	106	105	0.91
217	75	5	105	104	1.24
218	75	5	104	103	0.35
219	76	6	113	114	1.36
220	76	6	114	115	1.77
221	76	6	115	99	2.43
222	77	6	99	96	0.62
223	77	6	96	95	1.15
224	78	6	243	269	5.17
225	78	6	269	268	2.34
226	78	6	268	270	1.97
227	78	6	270	271	1.30
228	79	8	271	298	2.28
229	79	8	298	301	0.98
230	80	8	300	299	2.02
231	81	8	241	245	1.00
232	81	8	245	253	1.53
233	81	8	253	252	1.29
234	82	10	252	262	0.69

235	82	10	262	258	1.00
236	82	10	258	265	1.47
237	82	10	265	278	0.95
238	82	10	278	276	1.01
239	83	10	276	275	0.49
240	83	10	275	274	0.54
241	83	10	274	290	0.47
242	83	10	290	289	0.52
243	83	10	289	295	0.48
244	83	10	295	294	0.46
245	83	10	294	304	1.00
246	83	10	304	311	0.52
247	83	10	311	310	1.19
248	83	10	310	309	0.32
249	84	8	309	336	2.79
250	84	8	336	337	0.57
251	85	1	254	256	1.25
252	85	1	256	257	0.69
253	86	6	303	312	0.51
254	86	6	312	313	0.74
255	86	6	313	314	0.72
256	86	6	314	333	1.00
257	86	6	333	332	2.14
258	87	8	332	334	2.24
259	87	8	334	335	2.37
260	88	2	246	251	2.74
261	88	2	251	259	1.73
262	88	2	259	264	1.47
263	88	2	264	280	0.47
264	88	2	280	279	1.47
265	88	2	279	285	1.00
266	89	3	285	286	0.46
267	89	3	286	287	0.54
268	89	3	287	293	0.97
269	89	3	293	306	0.39
270	89	3	306	305	0.60
272	90	4	124	132	1.50
273	90	4	132	131	0.67
274	90	4	131	136	0.94
275	90	4	136	135	1.03
276	90	4	135	165	1.57
277	90	4	165	164	1.44
278	91	10	164	169	1.62
279	91	10	169	172	0.60
280	91	10	172	171	0.65
281	91	10	171	195	0.86
282	91	10	195	199	0.87
283	91	10	199	204	1.24
284	91	10	204	214	2.30
285	91	10	214	232	0.60
286	91	10	232	237	0.59
287	92	4	237	236	2.09
288	93	3	198	213	3.54

290	94	10	213	233	0.60
291	94	10	233	236	2.34
292	95	4	236	346	3.67
293	95	4	346	347	1.55
294	96	3	347	350	0.71
295	97	2	350	354	0.95
296	97	2	354	360	0.66
297	98	2	125	130	2.21
298	99	3	130	138	1.10
299	99	3	138	137	0.85
300	99	3	137	162	2.36
301	99	3	162	163	0.58
302	100	3	163	174	2.42
303	101	10	174	173	0.74
304	102	10	173	194	0.44
305	102	10	194	193	0.42
306	102	10	193	201	0.45
307	102	10	201	200	0.42
308	103	10	200	205	1.29
309	103	10	205	218	1.17
310	103	10	218	217	0.39
311	103	10	217	216	0.30
312	103	10	216	215	0.39
313	103	10	215	231	0.61
314	104	9	231	238	0.58
315	105	4	126	127	0.48
316	105	4	127	128	1.24
317	105	4	128	129	0.54
318	105	4	129	139	1.49
319	105	4	139	161	1.33
320	106	2	161	175	4.17
321	107	1	184	160	0.68
322	108	2	175	177	1.04
323	108	2	177	192	0.86
324	108	2	192	191	0.33
325	108	2	191	190	0.55
326	109	4	190	206	1.38
327	110	2	206	221	1.49
328	110	2	221	219	0.69
329	111	4	219	220	0.15
330	111	4	220	230	0.31
331	111	4	230	239	0.71
332	111	4	239	240	1.54
333	112	2	141	140	1.02
334	113	4	140	158	1.10
335	113	4	158	159	0.50
336	113	4	159	155	0.78
337	113	4	155	154	0.59
338	114	10	154	153	0.55
339	114	10	153	176	1.00
340	115	4	176	175	1.15
341	115	4	175	174	0.68
342	116	3	144	145	1.01

343	116	3	145	146	1.35
344	116	3	146	157	0.78
345	116	3	157	156	1.53
346	116	3	156	155	0.89
347	117	2	148	149	1.94
348	117	2	149	150	0.45
349	117	2	150	151	1.13
350	118	4	151	152	1.76
351	119	2	152	179	1.96
352	119	2	179	178	0.82
353	119	2	178	186	0.52
354	119	2	186	185	0.34
355	119	2	185	187	0.50
356	119	2	187	188	0.37
357	120	8	181	160	0.78
358	121	4	208	226	0.41
359	121	4	226	225	1.84
360	122	10	225	224	0.33
361	122	10	224	223	0.33
362	123	3	229	228	1.17
363	124	11	235	326	1.32
364	124	11	326	328	0.64
365	125	11	328	336	1.79
366	125	11	336	332	2.10
367	126	11	332	331	4.89
368	126	11	331	330	4.76
369	127	8	491	314	5.48
370	127	8	314	309	1.97
371	128	9	309	308	1.85
372	129	9	308	323	0.63
373	129	9	323	202	1.88
375	130	11	202	204	0.82
376	130	11	204	205	0.89
377	130	11	205	206	0.90
378	130	11	206	207	1.86
379	131	11	207	208	0.86
380	131	11	208	210	0.94
381	132	11	207	209	0.91
382	133	6	210	211	0.70
383	134	8	208	209	0.20
384	135	11	209	211	0.46
385	136	11	211	183	0.51
386	136	11	183	184	0.88
387	136	11	184	180	0.82
388	136	11	180	152	2.58
389	136	11	152	153	1.34
390	136	11	153	163	1.63
391	120	8	160	182	0.65
392	136	11	163	164	1.21
393	136	11	164	167	0.83
394	137	11	167	283	1.86
395	137	11	283	288	1.77
398	137	11	288	307	1.97

399	137	11	307	308	1.92
400	138	11	308	328	2.75
401	139	11	328	338	4.14
402	140	11	338	339	0.89
403	140	11	339	340	1.02
404	141	11	338	341	4.07
405	141	11	341	365	6.94
406	142	2	243	242	1.26
407	143	2	242	241	3.73
408	144	3	241	118	2.33
409	144	3	118	119	2.48
410	144	3	119	120	1.56
411	144	3	120	121	1.33
412	145	2	242	244	1.45
413	146	3	244	245	2.44
414	146	3	245	246	1.26
415	146	3	246	247	1.01
416	146	3	247	123	2.56
417	147	3	123	124	0.10
418	147	3	124	125	0.85
419	147	3	125	126	0.98
420	148	3	255	254	0.85
421	148	3	254	252	2.53
422	148	3	252	251	1.02
423	148	3	251	250	0.98
424	148	3	250	249	1.50
425	148	3	249	133	0.66
426	149	10	133	131	0.36
427	150	3	131	130	0.91
428	150	3	130	129	1.02
429	150	3	129	142	0.98
430	150	3	142	143	1.17
431	150	3	143	144	0.73
432	151	2	257	258	3.11
433	152	3	258	259	1.01
434	152	3	259	260	0.99
435	152	3	260	261	0.68
436	152	3	261	134	1.35
437	153	10	134	135	0.45
438	154	3	135	137	0.97
439	154	3	137	139	1.15
440	154	3	139	140	0.94
441	155	2	140	146	0.95
442	155	2	146	147	1.44
443	155	2	147	148	0.79
444	156	2	268	267	1.00
445	156	2	267	266	1.15
446	156	2	266	265	1.94
447	157	4	265	264	1.00
448	157	4	264	263	1.01
449	157	4	263	166	1.79
450	158	4	166	165	0.68
451	159	2	277	276	2.49

452	160	3	276	279	0.98
453	160	3	279	281	1.01
454	161	2	271	272	1.60
455	162	3	272	273	2.56
456	162	3	273	274	0.67
457	162	3	274	285	1.22
458	162	3	285	315	1.02
460	162	3	315	168	1.92
461	163	10	168	169	0.69
462	164	4	291	289	1.73
463	164	4	289	287	1.22
464	164	4	287	288	0.31
465	165	4	288	317	0.70
466	165	4	317	316	1.47
467	165	4	316	170	0.53
468	166	4	170	171	0.69
469	167	10	171	173	0.88
470	168	2	173	177	0.91
471	168	2	177	178	1.54
472	168	2	178	180	1.25
473	169	8	180	181	0.89
474	170	2	298	297	2.49
475	170	2	297	296	1.48
476	171	4	296	294	1.75
477	171	4	294	293	1.21
478	171	4	293	319	1.02
480	171	4	319	195	2.64
482	171	4	195	193	0.88
483	171	4	193	192	0.90
484	171	4	192	185	1.54
485	172	2	185	184	1.39
486	173	2	301	302	2.77
487	173	2	302	303	0.71
488	174	4	303	304	2.23
489	175	10	304	305	1.21
490	175	10	305	307	0.31
491	176	4	307	321	0.70
492	177	10	321	197	1.91
493	178	10	197	198	0.14
494	178	10	198	199	0.59
495	179	4	199	200	0.88
496	179	4	200	190	0.90
497	179	4	190	189	0.80
498	179	4	189	188	0.73
499	179	4	188	183	1.52
500	180	4	183	182	0.70
501	181	2	217	221	0.90
502	181	2	221	225	1.37
503	182	2	324	213	2.04
505	183	4	213	214	0.59
506	183	4	214	215	0.90
507	183	4	215	219	0.90
508	183	4	219	222	0.71

509	183	4	222	223	0.51
510	184	4	223	227	0.30
511	184	4	227	228	0.71
512	185	4	325	234	1.25
513	186	10	234	233	0.78
514	186	10	233	232	0.58
515	186	10	232	231	0.91
516	186	10	231	230	0.93
517	186	10	230	223	1.41
518	187	3	237	238	0.91
519	187	3	238	239	0.90
520	188	2	346	348	2.04
521	189	3	348	349	0.25
522	189	3	349	351	0.54
523	189	3	351	355	0.96
524	190	2	355	362	0.65
525	191	4	350	353	0.94
526	191	4	353	359	0.67
527	192	6	361	363	2.82
528	192	6	363	364	3.44
529	192	6	364	423	1.58
530	192	6	423	424	1.41
531	193	6	424	425	1.50
532	193	6	425	426	0.88
533	194	3	426	374	2.15
534	194	3	374	375	1.05
535	194	3	375	379	1.57
536	194	3	379	392	0.52
537	194	3	392	393	0.69
538	195	3	393	395	0.90
539	195	3	395	397	0.62
540	195	3	397	398	1.14
541	195	3	398	400	1.47
542	195	3	400	405	0.30
543	195	3	405	408	1.66
544	195	3	408	409	0.44
545	195	3	409	411	0.52
546	195	3	411	412	1.39
547	195	3	412	415	1.30
548	196	5	415	416	1.35
549	196	5	416	418	2.84
550	196	5	418	485	2.18
551	197	4	366	422	1.89
552	197	4	422	424	1.53
553	197	4	424	490	0.98
554	197	4	490	428	1.10
555	197	4	428	429	1.09
556	197	4	429	430	0.62
557	197	4	430	433	1.63
558	197	4	433	434	1.18
559	197	4	434	437	1.95
560	198	4	437	438	0.69
561	198	4	438	450	0.70

562	198	4	450	449	0.57
563	199	4	449	451	0.96
564	199	4	451	453	1.18
565	199	4	453	454	0.71
566	199	4	454	455	0.86
567	199	4	455	465	0.83
568	199	4	465	466	1.31
569	200	3	376	432	1.11
570	200	3	432	436	0.99
571	201	4	449	448	0.64
572	202	4	448	447	1.50
573	202	4	447	446	1.03
574	202	4	446	445	0.46
575	202	4	445	444	0.18
576	203	10	444	457	0.53
577	203	10	457	458	0.15
578	203	10	458	463	0.85
579	203	10	463	468	1.44
580	203	10	468	472	1.01
581	204	4	472	471	0.93
582	204	4	471	473	0.78
583	204	4	473	474	1.98
584	204	4	474	483	2.25
585	204	4	483	487	0.42
586	205	2	456	464	0.83
587	206	3	464	467	1.54
588	206	3	467	477	1.04
589	206	3	477	478	1.33
590	207	8	478	479	1.27
591	207	8	479	480	0.80
592	207	8	480	481	1.99
593	207	8	481	482	1.56
594	207	8	482	483	4.02
595	208	3	472	476	2.54
596	208	3	476	475	0.71
597	209	2	475	484	1.92
598	209	2	484	483	1.68
599	210	4	460	459	0.16
600	210	4	459	462	0.85
601	210	4	462	469	1.45
602	210	4	469	470	0.73
603	210	4	470	471	1.09
604	211	2	368	367	0.40
605	212	2	372	370	1.00
606	213	2	370	371	1.54
607	214	2	381	403	3.44
608	214	2	403	402	1.52
609	214	2	402	404	2.27
610	214	2	404	411	1.53
611	215	2	411	413	1.55
612	216	6	383	382	3.48
613	217	6	384	385	1.95
614	217	6	385	386	4.39

615	217	6	386	387	4.68
616	217	6	387	388	2.25
617	218	3	388	389	2.41
618	218	3	389	420	1.19
619	219	2	343	344	1.45
620	220	3	344	347	0.32
621	220	3	347	348	0.63
622	221	2	350	351	0.74
623	221	2	351	352	1.70
624	222	2	341	342	0.74
625	223	3	342	345	1.72
626	224	3	345	353	0.21
627	224	3	353	354	0.37
628	224	3	354	355	0.71
629	224	3	355	356	0.90
630	224	3	356	357	1.47
631	225	4	358	359	0.23
632	225	4	359	360	0.38
633	225	4	360	361	0.27
634	225	4	361	362	0.43
635	226	2	370	369	1.95
636	227	3	369	426	0.52
637	228	2	426	427	0.75
638	228	2	427	428	0.78
640	229	2	374	431	0.60
641	229	2	431	430	2.37
642	230	3	377	375	0.48
643	230	3	375	376	0.18
644	231	3	384	382	0.97
645	231	3	382	381	1.16
646	231	3	381	380	1.60
647	231	3	380	379	1.60
648	231	3	379	378	0.57
649	232	3	378	432	0.90
650	233	2	432	433	3.14
651	234	4	393	394	0.59
652	235	4	394	436	1.59
653	235	4	436	435	1.12
654	235	4	435	434	2.27
655	236	2	402	401	0.93
656	236	2	401	400	1.04
657	237	3	400	399	0.15
658	238	4	405	406	0.49
659	239	4	406	443	0.58
660	240	4	443	444	2.69
661	241	11	407	443	0.70
662	241	11	443	437	5.57
667	242	2	447	451	1.45
668	242	2	451	452	1.32
669	243	4	446	453	1.18
670	244	2	445	454	1.13
671	245	4	409	410	1.95
672	245	4	410	461	0.39

673	246	4	461	460	0.56
674	246	4	460	457	0.43
675	246	4	457	456	0.60
676	247	3	461	459	0.63
677	247	3	459	458	0.43
678	247	3	458	456	0.57
679	248	2	456	455	0.57
680	249	3	413	462	1.38
682	249	3	462	463	0.42
683	249	3	463	464	0.58
684	250	2	464	465	0.56
685	251	4	415	414	0.50
686	252	4	414	469	1.90
687	252	4	469	468	0.44
688	252	4	468	467	0.85
689	252	4	467	466	0.45
690	253	5	421	420	4.32
691	254	3	420	419	1.04
692	254	3	419	418	2.32
693	254	3	418	417	0.11
694	255	3	417	474	1.01
695	255	3	474	475	1.88
696	127	8	330	491	3.21
697	256	8	16	493	1.15
698	62	3	45	43	0.13
699	257	4	299	298	2.64
700	258	2	390	389	0.41
701	258	2	389	391	1.70
702	259	2	397	396	0.16

APPENDIX B. Stage Two Data: Provo and Orem Cities

Zone Data

Zone ID	Status Quo Land Use	Area (acres)	District	Allowable Land Uses									
1	1	156	30										
2	3	517	32										
3	3	93	31										
4	3	122	31										
5	1	209	31	2	3	11							
6	3	72	30	11									
7	3	143	30	11									
8	9	146	30										
9	2	209	18	3	11								
10	7	78	18										
11	7	8	18	8	11								
12	4	30	14	11									
13	9	107	30	11									
14	3	116	17	11									
15	4	17	16	11									
16	3	352	17										
17	2	32	17										
18	3	167	17										
19	3	96	16										
20	3	70	15										
21	3	23	16										
22	3	128	16										
23	3	0	14										
24	3	0	14										
25	3	6	14										
26	3	173	15										
27	3	230	15										
28	2	51	13										
29	3	85	13										
30	5	11	13										
31	12	181	14										
33	4	6	14	11									
34	8	19	9	7	11								
36	5	46	9	11									
37	8	6	9	7	11								

38	8	2	14										
40	3	39	13										
41	5	20	9	11									
42	3	33	9	11									
43	7	82	9	8	11								
44	3	97	9	11									
45	8	43	6	7	11								
46	8	159	9	7	11								
47	3	531	6										
48	9	159	8	6	7	8	10	11					
49	3	191	8	4									
50	3	50	9	11									
51	3	127	9	4									
52	3	147	10										
53	9	54	10	6	7	8	10	11					
54	3	79	10	11									
55	5	31	9	11									
56	6	22	12	11									
57	5	64	10	11									
58	5	156	14										
59	5	108	14										
60	5	86	14										
61	6	23	12	11									
62	6	55	12	11									
63	6	24	12	11									
64	3	29	12										
65	3	97	12										
67	6	17	12	11									
68	6	55	11	11									
69	3	110	11										
70	9	75	11	6	7	8	10	11					
71	3	94	3	7									
72	3	132	4	4	7								
73	3	232	4	4	8								
74	1	187	7	3	4	7							
75	4	60	7	3	7								
76	4	42	7	3	7								
77	3	101	7	4	7								
78	1	318	4	8	9								
79	1	231	4										
80	1	278	3	3	7								
81	4	129	11	7	8								
82	7	42	2										
83	3	52	11										
84	8	84	11	7	11								
85	8	36	2	7	11								
86	3	145	12										
87	4	122	1	5									

88	10	71	2										
89	3	212	13										
90	1	221	1	3	4								
92	4	1	13										
93	8	96	1										
94	1	155	1	3	4	8							
95	8	402	1	1	2	3	4	5	6	7	9	10	11
96	4	17	13										
97	9	5	13										
98	3	48	11	4									
99	8	76	2	7									
100	10	244	2										
101	3	264	3	7									
102	1	181	3	3	7								
103	1	236	6	3	7								
104	3	165	7	4	7								
106	1	4	4	3	7								
107	1	150	6	3	4	7							
108	9	72	6										
109	1	868	4	8	9								
110	2	11	16										
111	3	104	31										
112	1	58	18	2	3	11							
113	9	23	16	11									
114	1	102	30	2	3	11							
115	1	81	30										
116	9	106	1	1	2	3	4	5	6	7	8	10	11
117	10	81	2	3	4	5							
118	8	32	2	7	11								
119	7	20	2	1	2	3	4	5	6	8	9	10	11
120	4	30	11	1	2	3	5	6	7	8	9	10	11
121	8	17	2	7	11								
122	8	17	2	7	11								
123	8	16	2										
124	8	57	2	7	11								
125	10	70	2										
126	8	61	2										
127	7	12	2	8	11								
128	7	35	2	8	11								
131	3	141	26	4									
132	3	103	24	4									
133	3	165	24	4									
134	10	573	24										
135	3	107	24	4									
136	7	91	24	8	11								
137	7	103	24	8	11								
138	4	197	25	5									
139	4	186	25	5									

140	4	265	27	5									
141	3	181	27	4	5								
142	4	155	21	5									
143	3	160	21	4									
144	3	182	23	4	5								
145	3	210	21	4									
146	3	219	21	4									
147	3	184	23	4	5	7	8	11					
148	10	205	23	9									
149	4	95	22	5	6	11							
150	3	178	22	4									
151	7	41	22	8	11								
152	7	39	22	8	11								
153	12	188	23										
154	3	140	23	4									
155	3	319	23										
156	7	51	5	6	8	11							
157	7	62	5	8	11								
158	4	328	5	11									
159	3	318	5	4									
160	7	181	5	5	8	11							
162	4	101	19	5	6	11							
163	4	40	19	6	7	8	11						
164	8	64	22	6	7	11							
165	7	97	19	6	8	11							
166	3	174	19	4	5	8							
167	1	161	19	2	3								
168	8	127	21	7	11								
169	3	248	20	4									
170	3	305	20	4									
171	3	174	19	4									
172	8	90	27	7	11								
173	3	328	28	4									
174	3	123	28	4									
175	3	246	28	4									
176	3	414	29	4									
177	8	109	24	7	11								
178	3	165	34	4									
179	3	165	33	4									
180	8	49	26	7	11								
181	3	140	34	4									
182	3	219	34	4									
183	9	106	33										
184	3	288	35	4									
185	3	295	35	4									
186	3	269	33	4									
187	8	50	33	7	11								
188	1	361	33										

189	8	80	24	7	11								
190	7	96	24										
191	3	75	24	4									
192	3	77	34	4									
193	8	51	25	7	11								
194	10	96	23	4	7								
195	7	42	23										
196	9	177	23										
197	1	79	23										
264	8	93	5	6	7	11							
199	3	246	33	2	4								

Intra-district Street Data

Link ID	Stree t #	Status Quo class	Node A	Node B	Length (miles)
501	0	cc	1	201	1.05
502	0	cc	188	201	0.94
503	0	cc	5	202	0.21
504	0	cc	13	202	0.10
505	0	cc	8	202	0.36
506	0	cc	2	203	1.00
507	0	cc	6	203	0.03
508	0	cc	114	203	0.17
509	0	cc	3	204	0.69
510	0	cc	4	204	0.47
511	0	cc	111	204	0.26
512	0	cc	7	204	0.24
513	0	cc	17	205	0.62
514	0	cc	9	205	0.21
515	0	cc	112	205	0.08
516	0	cc	18	206	0.43
517	0	cc	16	206	0.94
518	0	cc	14	206	0.21
519	0	cc	11	207	0.26
520	0	cc	113	207	0.05
521	0	cc	15	208	0.10
522	0	cc	36	209	0.09
523	0	cc	34	209	0.06
524	0	cc	38	210	0.26
525	0	cc	37	210	0.06
526	0	cc	41	210	0.15
527	0	cc	59	211	0.29
528	0	cc	55	211	0.09
529	0	cc	58	212	0.35
530	0	cc	56	212	0.09
531	0	cc	61	213	0.05
532	0	cc	117	215	0.29
533	0	cc	85	215	0.09
534	0	cc	118	216	0.07
535	0	cc	119	216	0.05
536	0	cc	120	216	0.16
537	0	cc	121	217	0.06
538	0	cc	88	217	0.38
539	0	cc	82	217	0.21
540	0	cc	127	217	0.06
541	0	cc	124	218	0.25
542	0	cc	128	218	0.11
543	0	cc	123	218	0.24
544	0	cc	122	218	0.06
545	0	cc	86	219	0.13
546	0	cc	89	220	0.29
547	0	cc	87	220	0.16
548	0	cc	90	221	0.64
549	0	cc	93	222	0.12
550	0	cc	116	222	0.09
551	0	cc	94	223	0.19
552	0	cc	95	224	0.21
553	0	cc	92	225	0.45
554	0	cc	64	225	0.15
555	0	cc	29	226	0.15
556	0	cc	60	226	0.09
557	0	cc	28	227	0.54
558	0	cc	40	227	0.31
559	0	cc	30	228	0.06
560	0	cc	27	229	0.67
561	0	cc	26	229	0.28
562	0	cc	25	230	0.13
563	0	cc	20	230	0.47
564	0	cc	23	231	0.24
565	0	cc	110	231	0.68
566	0	cc	19	231	0.40
567	0	cc	24	231	0.04
568	0	cc	22	232	0.19
569	0	cc	21	232	0.10
570	0	cc	33	233	0.11
571	0	cc	31	234	0.09
572	0	cc	65	236	0.13
573	0	cc	84	239	0.14
574	0	cc	67	240	0.05
575	0	cc	62	240	0.10
576	0	cc	57	241	0.17
577	0	cc	42	242	0.15
578	0	cc	43	243	0.12
579	0	cc	12	244	0.04
580	0	cc	115	245	0.29
581	0	cc	187	246	0.06
582	0	cc	199	247	0.27
583	0	cc	186	249	0.19
584	0	cc	176	250	0.27
585	0	cc	171	251	0.28
586	0	cc	167	252	0.41
587	0	cc	10	253	0.45

588	0	cc	46	254	0.03
589	0	cc	49	255	0.14
590	0	cc	50	256	0.12
591	0	cc	54	257	0.21
592	0	cc	63	258	0.02
593	0	cc	68	259	0.12
594	0	cc	69	259	0.31
595	0	cc	83	259	0.26
596	0	cc	81	260	0.16
597	0	cc	98	260	0.13
598	0	cc	101	261	0.51
599	0	cc	44	263	0.34
600	0	cc	45	263	0.11
601	0	cc	162	264	0.29
602	0	cc	158	264	0.43
603	0	cc	165	285	0.14
604	0	cc	163	285	0.07
605	0	cc	166	267	0.21
606	0	cc	169	267	0.30
607	0	cc	170	268	0.21
608	0	cc	173	268	0.26
609	0	cc	175	269	0.24
610	0	cc	179	269	0.31
611	0	cc	183	270	0.22
612	0	cc	182	271	0.39
613	0	cc	185	271	0.30
614	0	cc	184	272	0.27
615	0	cc	181	272	0.31
616	0	cc	178	273	0.32
617	0	cc	174	273	0.24
618	0	cc	192	274	0.28
619	0	cc	180	275	0.03
620	0	cc	189	276	0.05
621	0	cc	135	277	0.36
622	0	cc	177	278	0.03
623	0	cc	193	279	0.06
624	0	cc	172	280	0.06
625	0	cc	168	281	0.04
626	0	cc	164	282	0.08
627	0	cc	149	282	0.30
628	0	cc	156	283	0.06
629	0	cc	151	283	0.05
630	0	cc	51	284	0.16
631	0	cc	47	285	0.58
632	0	cc	48	286	0.19
633	0	cc	52	287	0.25
634	0	cc	70	288	0.30
635	0	cc	53	288	0.26

636	0	cc	75	289	0.15
637	0	cc	72	290	0.18
638	0	cc	71	291	0.37
639	0	cc	102	292	0.18
640	0	cc	80	292	0.50
641	0	cc	109	293	0.06
642	0	cc	73	294	0.14
643	0	cc	74	294	0.19
644	0	cc	104	295	0.34
645	0	cc	77	296	0.30
646	0	cc	107	297	0.14
647	0	cc	108	297	0.30
648	0	cc	103	297	0.41
649	0	cc	159	298	0.52
650	0	cc	157	298	0.08
651	0	cc	152	298	0.05
652	0	cc	150	299	0.24
653	0	cc	145	300	0.31
654	0	cc	146	300	0.24
655	0	cc	142	301	0.24
656	0	cc	143	301	0.26
657	0	cc	140	302	0.07
658	0	cc	138	303	0.15
659	0	cc	132	304	0.27
660	0	cc	131	305	0.23
661	0	cc	136	306	0.03
662	0	cc	133	307	0.24
663	0	cc	137	308	0.10
664	0	cc	139	308	0.27
665	0	cc	191	309	0.60
666	0	cc	190	310	0.13
667	0	cc	134	311	0.23
668	0	cc	141	312	0.30
669	0	cc	144	313	0.28
670	0	cc	194	367	0.07
671	0	cc	147	314	0.72
672	0	cc	153	315	0.21
673	0	cc	79	317	0.06
674	0	cc	78	318	0.10
675	0	cc	195	320	0.17
676	0	cc	196	320	0.31
677	0	cc	154	321	0.21
678	0	cc	197	321	0.66
679	0	cc	148	322	0.30
680	0	cc	155	322	0.52
681	0	cc	160	323	0.16
682	0	cc	106	324	0.14
683	0	cc	99	325	0.05

684	0	cc	100	200	0.48	43	8	8	341	325	0.27
685	0	cc	125	200	0.43	44	8	8	325	200	0.38
686	0	cc	126	200	0.15	45	8	8	200	340	0.62
687	0	cc	96	226	0.43	46	9	2	289	364	0.19
688	0	cc	76	295	0.08	47	9	2	364	294	0.33
689	0	cc	97	226	0.59	48	9	2	294	318	1.13
1	1	8	201	202	0.72	49	9	2	318	324	0.60
2	1	8	202	327	0.28	50	9	2	365	291	0.07
3	1	8	327	203	0.46	51	9	2	291	289	0.27
4	1	8	203	204	0.30	52	10	4	332	240	0.16
5	1	8	204	328	0.26	53	10	4	344	355	0.29
6	1	8	328	205	0.27	54	10	4	355	287	0.62
7	1	8	205	206	0.35	55	10	4	287	288	0.17
8	1	8	206	207	0.48	56	10	4	288	365	0.10
9	1	8	207	329	0.27	57	10	4	240	344	0.02
10	2	4	329	347	0.14	58	11	4	332	235	0.07
11	2	4	347	348	0.31	59	11	4	235	236	0.25
12	2	4	348	254	0.28	60	11	4	236	237	0.37
13	2	4	254	357	0.37	61	11	4	237	338	0.09
14	3	8	329	208	0.24	62	12	8	358	264	0.55
15	3	8	208	330	0.28	63	12	8	264	263	0.64
16	3	8	330	209	0.17	64	12	8	263	357	0.13
17	3	8	209	210	0.25	65	12	8	357	255	0.27
18	3	8	210	331	0.35	66	12	8	255	256	0.48
19	3	8	331	211	0.13	67	12	8	256	356	0.19
20	3	8	211	212	0.25	68	12	8	356	262	0.12
21	3	8	212	213	0.26	69	12	8	262	257	0.34
22	3	8	213	332	0.09	70	12	8	257	258	0.22
23	4	8	332	333	0.27	71	12	8	258	355	0.05
24	4	8	333	214	0.12	72	12	8	355	259	0.17
25	4	8	214	215	0.35	73	12	8	259	354	0.10
26	4	8	215	334	0.06	74	13	8	339	219	0.62
27	4	8	334	216	0.10	75	13	8	219	333	0.36
28	4	8	216	217	0.27	76	13	8	333	343	0.13
29	4	8	217	218	0.18	77	13	8	343	354	0.28
30	4	8	218	335	0.35	78	14	8	339	220	0.14
31	5	1	331	345	0.18	79	14	8	220	221	0.45
32	5	1	345	356	0.28	80	14	8	221	222	0.39
33	5	1	356	284	0.38	81	14	8	222	340	0.10
34	5	1	284	285	0.57	82	14	8	340	223	0.82
35	5	1	285	286	0.26	83	14	8	223	224	0.55
36	5	1	286	366	0.32	84	14	8	224	377	0.21
37	6	1	331	337	0.82	85	15	4	342	238	0.15
38	7	2	334	342	0.17	86	15	4	238	239	0.25
39	7	2	342	260	0.25	87	15	4	239	343	0.15
40	7	2	260	261	0.49	88	15	4	343	344	0.28
41	7	2	261	292	0.36	89	15	4	344	241	0.36
42	7	2	292	363	0.62	90	15	4	241	345	0.37

91	15	4	345	242	0.21
92	15	4	242	243	0.42
93	15	4	243	346	0.29
94	15	4	346	244	0.18
95	15	4	244	347	0.19
96	16	8	330	346	0.25
97	16	8	346	348	0.46
98	16	8	348	253	0.10
99	16	8	253	252	0.41
100	16	8	252	349	0.35
101	17	4	350	328	0.92
102	18	7	327	245	0.38
103	18	7	245	351	0.63
104	19	3	228	227	0.19
105	19	3	227	337	0.06
106	19	3	337	226	0.23
107	19	3	226	338	0.41
108	19	3	338	225	0.12
109	19	3	225	339	0.46
110	19	3	232	231	0.40
111	19	3	329	232	0.41
112	19	3	231	230	0.24
113	19	3	230	336	0.06
114	19	3	336	229	0.35
115	19	3	229	228	0.31
116	20	1	363	293	0.30
117	20	1	293	317	1.06
118	20	1	317	374	0.44
119	21	5	364	295	0.43
120	21	5	295	366	0.33
121	21	5	366	296	0.15
122	21	5	296	297	0.41
123	21	5	297	316	0.62
124	21	5	316	373	0.31
125	22	1	363	290	0.56
126	22	1	290	364	0.27
127	23	3	330	233	0.15
128	23	3	233	234	0.51
129	23	3	234	336	0.13
130	24	11	378	341	0.22
131	24	11	341	335	0.47
132	24	11	335	365	2.67
133	24	11	365	367	3.38
134	25	9	362	275	0.23
135	25	9	275	376	0.12
136	26	9	362	276	0.24
137	26	9	276	277	0.43
138	26	9	277	278	0.21

139	26	9	278	361	0.21
140	27	9	361	279	0.33
141	27	9	279	280	0.45
142	27	9	280	360	0.29
143	28	9	360	281	0.64
144	28	9	281	359	0.42
145	28	9	359	282	0.28
146	28	9	282	358	0.39
147	29	10	349	285	0.22
148	29	10	285	358	0.23
149	29	10	358	283	0.27
150	29	10	283	298	0.53
151	29	10	298	326	0.27
152	29	10	326	323	0.27
153	29	10	323	315	0.25
154	29	10	315	367	0.25
155	30	2	379	303	0.34
156	30	2	303	302	0.40
157	30	2	302	380	0.28
158	30	2	380	301	0.26
159	30	2	301	300	0.51
160	30	2	300	299	0.51
161	30	2	299	326	0.36
162	31	8	360	380	0.56
163	31	8	380	314	0.64
164	31	8	314	312	0.13
165	31	8	312	313	0.12
166	31	8	313	368	0.17
167	32	8	351	268	0.46
168	32	8	268	360	0.50
169	33	2	350	267	0.24
170	33	2	267	359	0.42
171	34	8	201	246	0.28
172	34	8	246	265	0.38
173	34	8	265	248	0.22
174	34	8	248	352	0.25
175	34	8	352	269	0.42
176	34	8	269	273	0.53
177	34	8	273	274	0.11
178	34	8	274	261	0.24
179	35	8	361	379	0.21
180	35	8	379	306	0.41
181	35	8	306	308	0.44
182	35	8	308	369	0.24
183	36	6	309	307	0.15
184	36	6	362	304	0.23
185	36	6	304	305	0.21
186	36	6	305	309	0.08

187	36	6	307	310	0.39
188	36	6	310	370	0.11
189	37	6	362	272	0.31
190	37	6	271	353	0.45
191	37	6	353	247	0.97
192	37	6	247	265	0.37
193	38	11	369	370	1.05
194	39	11	368	369	0.98
195	40	11	367	368	1.54
196	41	5	371	375	1.05
197	42	5	321	320	0.31
198	42	5	371	311	0.26
199	42	5	311	322	1.27
200	42	5	322	321	0.62
201	43	5	320	372	0.13
202	43	5	373	319	0.60
203	43	5	319	372	0.51
204	44	2	349	266	0.39
205	44	2	266	350	0.26
206	44	2	350	251	0.60
207	44	2	251	351	0.41
208	45	2	270	353	0.26
209	45	2	351	250	0.62
210	45	2	250	352	0.38
211	45	2	249	270	0.28
212	45	2	249	352	0.34

Target Land Use Percentages

District	R1	R2	R3	R4	R5	C1	C2	C3	C4	PL	AG	PA	VA
1	0.21	0.01	0.02	0.01	0.00	0.08	0.08	0.00	0.01	0.24	0.04	0.02	0.24
2	0.21	0.01	0.02	0.01	0.00	0.08	0.08	0.00	0.01	0.24	0.04	0.02	0.24
3	0.21	0.01	0.02	0.01	0.00	0.08	0.08	0.00	0.01	0.24	0.04	0.02	0.24
4	0.21	0.01	0.02	0.01	0.00	0.08	0.08	0.00	0.01	0.24	0.04	0.02	0.24
5	0.49	0.03	0.05	0.01	0.00	0.12	0.04	0.00	0.01	0.08	0.03	0.08	0.06
6	0.68	0.02	0.01	0.00	0.00	0.04	0.01	0.00	0.00	0.10	0.07	0.02	0.04
7	0.57	0.01	0.02	0.00	0.00	0.29	0.01	0.00	0.00	0.03	0.01	0.01	0.05
8	0.49	0.03	0.05	0.01	0.00	0.12	0.04	0.00	0.01	0.08	0.03	0.08	0.06
9	0.49	0.03	0.05	0.01	0.00	0.12	0.04	0.00	0.01	0.08	0.03	0.08	0.06
10	0.49	0.03	0.05	0.01	0.00	0.12	0.04	0.00	0.01	0.08	0.03	0.08	0.06
11	0.49	0.03	0.05	0.01	0.00	0.12	0.04	0.00	0.01	0.08	0.03	0.08	0.06
12	0.13	0.02	0.02	0.00	0.00	0.32	0.22	0.02	0.01	0.08	0.00	0.02	0.15
13	0.21	0.01	0.02	0.01	0.00	0.08	0.08	0.00	0.01	0.24	0.04	0.02	0.24
14	0.21	0.01	0.09	0.00	0.00	0.04	0.00	0.00	0.10	0.48	0.00	0.05	0.01
15	0.68	0.02	0.01	0.00	0.00	0.04	0.01	0.00	0.00	0.10	0.07	0.02	0.04
16	0.68	0.02	0.01	0.00	0.00	0.04	0.01	0.00	0.00	0.10	0.07	0.02	0.04
17	0.49	0.03	0.05	0.01	0.00	0.12	0.04	0.00	0.01	0.08	0.03	0.08	0.06
18	0.49	0.03	0.05	0.01	0.00	0.12	0.04	0.00	0.01	0.08	0.03	0.08	0.06
19	0.49	0.03	0.05	0.01	0.00	0.12	0.04	0.00	0.01	0.08	0.03	0.08	0.06
20	0.86	0.02	0.01	0.00	0.00	0.04	0.01	0.00	0.00	0.01	0.02	0.00	0.02
21	0.86	0.02	0.01	0.00	0.00	0.04	0.01	0.00	0.00	0.01	0.02	0.00	0.02
22	0.86	0.02	0.01	0.00	0.00	0.04	0.01	0.00	0.00	0.01	0.02	0.00	0.02
23	0.68	0.02	0.01	0.00	0.00	0.04	0.01	0.00	0.00	0.10	0.07	0.02	0.04
24	0.68	0.02	0.01	0.00	0.00	0.04	0.01	0.00	0.00	0.10	0.07	0.02	0.04
25	0.86	0.02	0.01	0.00	0.00	0.04	0.01	0.00	0.00	0.01	0.02	0.00	0.02
26	0.86	0.02	0.01	0.00	0.00	0.04	0.01	0.00	0.00	0.01	0.02	0.00	0.02
27	0.86	0.02	0.01	0.00	0.00	0.04	0.01	0.00	0.00	0.01	0.02	0.00	0.02
28	0.86	0.02	0.01	0.00	0.00	0.04	0.01	0.00	0.00	0.01	0.02	0.00	0.02
29	0.42	0.46	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.09	0.00	0.00
30	0.21	0.01	0.02	0.01	0.00	0.08	0.08	0.00	0.01	0.24	0.04	0.02	0.24
31	0.68	0.02	0.01	0.00	0.00	0.04	0.01	0.00	0.00	0.10	0.07	0.02	0.04
32	0.68	0.02	0.01	0.00	0.00	0.04	0.01	0.00	0.00	0.10	0.07	0.02	0.04
33	0.86	0.02	0.01	0.00	0.00	0.04	0.01	0.00	0.00	0.01	0.02	0.00	0.02
34	0.86	0.02	0.01	0.00	0.00	0.04	0.01	0.00	0.00	0.01	0.02	0.00	0.02
35	0.86	0.02	0.01	0.00	0.00	0.04	0.01	0.00	0.00	0.01	0.02	0.00	0.02