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A Framework for Assessing Feasibility of Transit-Oriented Development (TOD) Project Sites

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A Framework for Assessing Feasibility of Transit-Oriented Development (TOD) Project Sites

Prepared by:

Avi Sharma, Graduate Assistant
Kelly Strong, Ph.D., Associate Professor
Mehmet E. Ozbek, Ph.D., Associate Professor

Department of Construction Management and
Department of Civil and Environmental Engineering
Colorado State University
Fort Collins, Colorado 80523

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EXECUTIVE SUMMARY

After the Second World War, the United States saw a decline in ridership on transit systems, which eventually resulted in the dismantling and abandonment of many rail systems. The primary mode of public transportation shifted from transit to buses. It used the same streets and competed with the same infrastructure capacity as automobiles. For this reason, bus systems also started to fail when people realized that if they have to wait for the traffic, they might as well wait in their own automobile that provided higher flexibility of timing and route (Ditmar, Belzer and Autler, 2004). This shift resulted in even more highway congestion, especially along commuter routes. To counter the problem of congestion resulting from modern urbanization, urban planners developed the idea of Transit-Oriented Development (TOD). TOD (or similar concepts like transit village, transit-friendly design, and transit-supportive development) is a development designed to encourage the use of public transit and creation of pedestrian-friendly environments (Cervero, Ferrell, & Murphy, 2002).

This research attempts to answer the following fundamental questions: What factors does a transit agency use to choose among alternative TOD locations in a transit network, and what is the relative importance of each factor? It aims to develop a decision support framework that can be used by different transit agencies when choosing a TOD site by incorporating their unique factors and weights using a multiple-criteria decision-making (MCDM) tool called Analytic Hierarchy Process (AHP). This paper presents two implementation examples of the developed framework, one for the Regional Transportation District (RTD) of Denver, Colorado, metro area, and another application for the Roaring Fork Transportation Authority (RFTA), in the Aspen, Colorado, region. The applications demonstrated feasibility of the AHP decision support framework for both a large, urban transit district and a smaller, more rural transit agency, with similar process, but differing factors and relative importance weights.

1. INTRODUCTION

1.1 Transportation Cost in the United States

Increasing urbanization and fast population growth have brought many challenges to society. People are spending more money on transportation and more time on roads than ever before. Transportation is more of a necessity in society than ever before. At this time, transportation is the second largest expense for an average American family. In 2014, transportation expenditures came to 17% of the overall average annual expenditure of a household in the United States. Also, transportation expenditures increased by 0.8% between 2013 and 2014 (U.S. Department of Labor, 2014).

After the Second World War, the United States saw a large investment in roads infrastructure. It automatically led to the decline of transit systems, which in turn resulted in the abandonment of many rail systems. Initially, buses became the primary mode of public transport in place of transit. Since buses were sharing the road with automobiles, the problem of congestion and less flexibility led people to use automobiles more because of flexibility and freedom of movement. Individual automobiles became the order of the day. They also became a necessity since people could not wait long for the public transport (Dittmar, Belzar, & Autler, 2004).

Decentralization made things worse for the public transportation agencies. People started to move toward suburbs, which offered cheaper and larger houses. As these suburbs contained clustered housing, these areas catered to a smaller population for whom it was not viable to run public transportation efficiently. This phenomenon is sometimes referred to as urban sprawl. It resulted in increased personal cars and dismantling of public transportation from many major cities (Belzer, Autler, & Economics, 2002).

1.2 History of Failure of Public Transportation in the United States

The failure of transit systems in the United States is of interest to the federal government. Major testimony came from Bradford C. Snell titled "American Ground Transport: A Proposal for Restructuring the Automobile, Truck, Bus, and Rail Industries," in the Subcommittee on Antitrust and Monopoly of the Committee on the Judiciary United States Senate in 1974. The committee hearing was a serious attempt to discover the reasons for the failures of transit systems. The report highlighted the role of General Motors (GM) in the decline of public transportation systems in America. It was stressed in the report that General Motors manufactured the majority of buses, bus engines, and rail locomotives. The report also showed an inherent conflict of interest, because if GM eliminated one bus, then it would sell 35 automobiles; one streetcar would translate that number to 50 and one train can make up to 1,000 cars. The report talked about switching to GM diesel units, which prevented railroads from competing efficiently with cars and trucks. It also discussed elimination of electric trains, which would have certainly competed with highway transport. Finally, the report recommended reorganizing the big automakers (called "Big Three," i.e., General Motors, Ford, and Chrysler) into small entities for a balanced overall system (Snell, 1974).

To counter the view of Bradford Snell, the committee heard the opposing view of a professor from the University of California, Los Angeles (UCLA), Dr. George W. Hilton. Dr. Hilton was considered to be one of the foremost highway transportation experts in America in the 70s. Dr. Hilton argued that conversion from public transport to automobiles had more to do with public preferences, technological upgrades, and availability of natural resources, not with an impact of monopolist automobile economy. He also disagreed with the assessment that the goal of GM to enter the transit industry was to destabilize public transport to create more demand for automobiles. He addressed the argument that removal of one bus would create demand for 35 automobiles. He said that there was more than enough literature available to conclude that people use transit mainly because of reasons such as they are too young or too old to drive, handicaps, or lack of funds to have a car. It was too simplistic to assume that if you shut down the public transport, then these people will automatically resort to automobiles (Industrial Reorganization Act, 1974).

This case was described in the book “Critical Evaluations in Business and Management” (2003), in which the authors state that street cars were obsolete by early 1950s. It also said the replacement of street cars with buses was delayed by local government regulations even though it was justified economically even before it was eventually replaced. The author also doesn’t agree with Snell’s line of argument and even says that the only question for him at the time was why it took GM so long to develop its business when circumstances were clearly in their favor? (Wood & Wood, 2003).

Some other authors, such as Burke (1980), also argued that it was incorrect to base the decline of transit systems on the conspiracy theories of GM. The decline started just after World War I when the majority of rail transit systems started to get into financial troubles due to higher operation cost. Also, the legally mandated fare of 5 cents after World War I resulted in lower revenues. To improve transit systems, President Woodrow Wilson created a commission to understand reasons for the decline of these systems. Solutions by the commission did not include some important causes for the decline of transit such as “service to the user” and the Public Utility Holding Company Act of 1935, which resulted in changes that didn’t improve the state of public transportation (Burke, 1980).

Even though the American love for an automobile is still visible today, fear about possible effects of cars- on the environment, well-being, the general standard of life, and on inter-societal interactions have possibly paved the way for discussions on revitalization of public transportations systems (STPP, 2003). One of the biggest disadvantages of the automobile culture is unrealistic allocation of free parking spaces in cities due to requirements of large parking areas related to land use rules. These free parking spaces include unshared parking in grocery stores and restaurants. The study relates free parking similar to the demand for free pizza. The pizza demand obviously goes up if it is available for free, as compared to an appropriate price. All the parking requirements are made dependent on this high demand of traffic at peak time instead of any average usage (Shoup, 2005).

As per Cervero, Ferrell, and Murphy (2004), the problem of inefficient transportation systems and higher costs of individual automobiles has resulted in many individuals getting drawn toward the idea of living near transit stations. Not only individuals, but also companies, have realized that to remain competitive to future employees, they have to build businesses near to rail/transit stops. To highlight some examples, the Discovery Channel’s headquarters is adjacent to the Silver Spring Metrorail station (Washington), BellSouth’s headquarters is also located next to the Lindberg station (Atlanta), and many other businesses are finding this proposal attractive (Cervero, Ferrell, & Murphy, 2004).

Public transportation policy, just like any other policy, experienced waves of the invention; the excitement of modern technology; dismissal of old, yet useful, technologies; and eventually revamping of old practices (Pojani & Stead, 2014). If the era after World War II resulted in the demise of public transportation in the main cities, then 1980s anti-suburb, anti-sprawl movement, which studied automobile culture with cost, pollution and global warning, led to an enormous boost for public transportation (Cervero, 1986).

To counter the problems of modern urbanization, transit-oriented development (TOD) seems to be a well-thought-out solution for a modern society. TOD or similar concepts like transit village, transit-friendly design, and transit-supportive development have common attributes of having been conceived in a fashion that encourage the use of public transit and creation of pedestrian-friendly environments (Cervero, Ferrell, & Murphy, 2004). As such, the definition of TOD varies from person to person, and a section of the literature review will try to address this topic. In general, the setup of TOD is a part of urban land use in which residents live within walking distance of a transit station. It is believed that a significant number of people who have their residence and office in or near the transit route are more likely to ride than those who are not on the route (Dittma & Poticha, 2004). This increase in transit ridership will make the project more likely to be successful regarding the financial break-even point. These projects also require granting access to job centers, educational centers, retail stores, and cultural facilities (Arrington et al., 2008). Many other factors have made the TOD more favorable to be implemented than ever before. The increase in population share of singles and single-parent families, childless couples, "empty-nesters," and the influence of immigrants who come from societies that are transit-friendly have created a ready-made consumer market for TOD as shown in Figure 1.1 (Calthorpe, 1993).

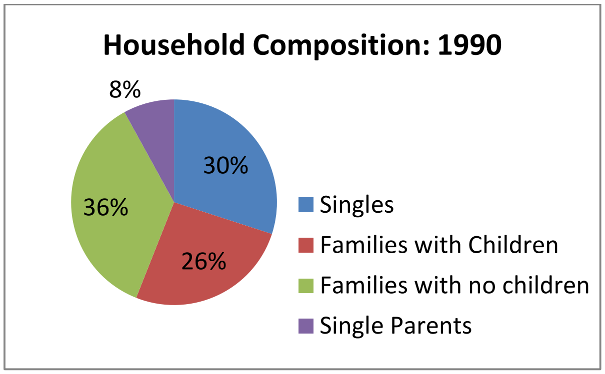

Figure 1.1 Household Compositions

Even though things look favorable for TOD, barriers need to be analyzed before developing new projects. Government and public transit authorities see risk in making large investment in transit. This might result in a financial loss to the taxpayer, because of the potential for people not using it. On the other hand, a government's policies, such as building codes, standards for building heights, density limits, and development rules that work against station-area development, might result in a failure of TOD. Some other factors, such as location liabilities, might impact the feasibility of TOD. Ridership/development might look attractive on paper, but private developers may not be as enthusiastic as authors of the TOD proposal. This could result in an unanticipated loss to the government (Paaswell et al., 1997).

The outcomes of TOD can be improved by factors that vary among authors and agencies that research the topic in-depth. Some develop success factors based on a synthesis of the literature, while some develop success factors interdependent of each other. The most basic performance factors are location efficiency, a rich mix of choices, value capture, place making, and resolution of the tension between node and place (Poticha, 2004). Even though more weight is given to factors such as higher density and a greater level of land-use mix, studies such as Zhang (2005) have shown otherwise. As per Zhang (2005), the research used regression and statistical tools to analyze the impact of these two factors specifically. Based on his case study of Atlanta Metropolitan area (Georgia), the mixed land-use played quite an insignificant role, which was opposite the normal perception that it does play a major role. Also, no particular evidence was found to conclude that higher density might result in anticipated higher financial returns Zhang (2005). This challenges the common perception of factors taken at face value and mainly left unquestioned. It highlights the need of analyzing each factor, as they vary between project and transit agencies.

This research provides an in-depth analysis of interdependent parameters that result in success and failure of a TOD project. As a result of optimism in the environment when developing a TOD, the ridership, value of the property, and other factors, are over-estimated. A mathematical model is needed that can take out the over-optimistic nature of humans in making such crucial decisions, and it is an objective of this research. Another feature of this research will be to study probable changes of factors of success for big cities with dense populations, and small towns. This research will be using Denver, Colorado, as a representation for a big city with dense population and Aspen, Colorado, as a representation of a small town, famous as a ski resort city.

1.3 Problem Statement

The introduction shows evidence that momentum is shifting in favor of public transportation. The plethora of literature on this subject is no surprise considering the issues of global warming, revitalization of community living and affordable housing. Also, related factors are directly influencing and getting influenced by TOD. The literature review uncovered few articles that address factors, which make TOD projects successful.

Carlton (2009) highlights concepts that are simple, understandable, and often are merged with other concepts primarily to satisfy the consumer's need. These problems were highlighted in the book *Transit Oriented Development: Moving from rhetoric to reality*. It states the following issues are factors in which projects do not reach the expected outcomes:

- Lack of a single definition
- No clarity on what makes a place successful for TOD
- Lack of support from market
- Lack of planning between "node" and "place"
- Complex collaboration
- Lack of coordination between policy and regulations

These problems do not disrupt the sites completely, but they reduce the efficiency and advantages that can be achieved (Belzer, Autler, & Economics, 2002).

It is universally-accepted that land use, higher density, and planning all are influential to the success of TOD projects. It must be understood that mixed-use and high-density does not guarantee higher financial returns. Also, it is not necessary that these factors weight greater than other factors, which might result in the success of a TOD project Zhang (2005).

Based on discussion in the previous section, it has been observed that mixed land-use plays an insignificant role in some of the actual TOD projects. From this literature review, it was clear that this research will play a significant role in developing a framework for transit agencies to choose a site for TOD. The goal of this research is to create a framework that can be changed by any transit agency, based on their requirements and use, for better decision making.

1.4 Research Questions and Purpose

This paper answers the fundamental question: How can a transit agency choose among alternative TOD locations in a transit network? The ultimate objective of the research is to develop a decision support framework, which can be used by different transit agencies when choosing TOD sites by incorporating their unique factors and weights using a multiple-criteria decision-making (MCDM) tool called Analytic Hierarchy Process (AHP). The broad question is answered by the following related questions:

- How can we determine the initial list of factors that should be considered in analysis of TOD alternatives?
- Once we have an initial list of factors, then what process can vet those factors based on individual transit agencies' needs and preferences?
- What are the different weights of these factors?

This research included intensive literature review to get an initial list of factors, interviews to vet factors, and use of AHP to determine weights. A list of factors was compiled based on the literature review vetted by TOD experts to create a final list of factors of success. These factors were then sent back to experts who determined their weight using AHP. We implemented this framework on two different transit agencies—Regional Transportation District (RTD), Denver and Roaring Fork Transportation Authority (RFTA), Aspen. This framework was not implemented on an actual project. That may be a possible future research addition.

Transit agencies that want to implement this framework should take note that this study cannot be generalized to a comparison of TOD success factors between all urban and non-urban transit agencies.

1.5 Organization of Report

This report is divided into five sections. The first section contains an introduction for understanding the background and reasons/motive behind this research. The next section reviews literature on the subject, including reasons for the failure of public transport sector. It also contains a review of the literature on the definition of TOD, success parameters and factors of success for a TOD project. The research methodology is discussed in Section 3, which highlights our plan and process to get desired results. Section 4 and Section 5 discuss the findings and conclusions respectively. Section 5 also contains discussions of areas of improvement and possible future research in this field.

2. LITERATURE REVIEW

2.1 Introductory Remarks

The evolution of urban planning began with the rise of ancient cities in Egypt, the Indus Valley (present day Pakistan, northwest India, and some regions of Afghanistan) and Mesopotamian civilization (Morris, 2013). Each of these civilizations had unique characteristics in their urban architecture. Some of these ancient cities had sewer and drainage, which ironically is not available today in many parts of India, Pakistan, and Afghanistan where Indus civilization existed. The characteristic of cities in these ancient civilizations included walls and structures for religious purposes.

It was not until the Renaissance that urban planners started to view cities more than just buildings and structures. The goal of urban planners began to shift towards= building order and symmetries. The classical city painting by architect Fra Carnevale is said to be the influence of the Renaissance on urban planning, which includes mainly symmetrical cities (Sajó, 2012). However, these urban planning principles changed during the late 18th century, after which industries and commerce became priorities. The combination of commerce priorities, which brought an influx of people to a certain city and individual automobiles, resulted in one of the biggest challenges of this century—failure of public transportation. The audience for urban planners shifted from commerce to common people who use the facilities and influence environment.

The idea of sustainable urban development has taken on greater urgency due to the concerns of global warming and growing urban population. For the first time in urban planning, architects are concentrating on use of public transportation by the local community. It is more than evident that a middle ground was required in the entire debate of public transportation vs. automobiles. In the early 1990s, Peter Calthorpe came up with the concept of TOD, which implied mixed development and more population living near transit lines (Calthrope, 1993). This literature review will examine the chronology of TOD, discuss important concepts of TOD, provide common definitions of TOD, and identify outcomes to define the success of a TOD project and factors affecting the outcomes of TOD projects.

2.2 Urban Sprawl and Its Impact on Transportation Behavior

After World War II, decentralization and an increased use of cars are two phenomena which had concerned urban planners in the United States (ABAG, 1997). Higher investments and subsidies of automobile usage, in combination with lower funding for public transportation, among other factors, resulted in a preference for automobiles. Due to the availability of cheaper housing outside the metropolitan core and faster individual automobiles with the flexibility to commute, many people decided to move to suburbs outlying the core district. This phenomenon is sometimes referred to as "urban sprawl." Areas with lower population density and wider geographical dispersion, like a suburban area, make transit economically inefficient compared to commuting in a personal vehicle (Belzer, Autler, & Economics, 2002).

Some studies have tried to measure urban sprawl in different cities and study its impact on the quality of life. Ewing, Pendall, and Chen (2003) conducted a study of 83 cities. The study specifically included transportation-related questions in the investigation to understand the impact of urban sprawl. It was concluded that cities with less urban sprawl scored better than their counterparts in almost every transportation-related category, i.e., lower vehicle-miles traveled (VMT), lower automobile ownership rates, more people taking transit or walking to work, and fewer traffic accidents. It also concluded that air quality is poorer in cities with more urban sprawl. The surprising result of this study was that there was no difference in average commute times for the top 10 sprawling cities as for the 10 least sprawling cities (Ewing, Pendall, & Chen, 2013).

2.3 Definition of Transit-Oriented Development

TOD has different definitions from researchers, planners, professionals in the field, and government representatives because of its varied use and applications in various conditions. Due to lack of any single definition of TODs, many projects that do not achieve the required outcomes are still declared successful (Belzer, Autler, & Economics, 2002).

The concept of suburban streets that existed before the 1900s involved the single owner of residential development in adding value to their property. The phrase "development-oriented transit" is apt for such type of development (Dittmar, Belzar, & Autler, 2004). The post-World War II years were a transitioning period in which people went away from transit, leading to the abandonment of many rail systems. Consequently, transportation systems were formed to work explicitly with automobiles, leading to big parking lots that are mostly not shared. This meant that the region could have multiple parking spaces for retail, station, and schools, even though all these structures might be placed next to each other. The historical philosophy of development did not link transit to development (Belzer, Autler, & Economics, 2002).

In modern contexts, (TOD) is a term that emphasizes the planning of housing, commercial, retail, and public services around new or existing transit stations served by regular and efficient transit systems (Cervero, 1998; Cervero & Murakami, 2009). Some definitions, as per different transit agencies, have been highlighted in Table 2.1. Even though there is no single broad definition, most share common features, which are discussed in following paragraphs.

Examples of TOD definitions are:

- "A mixed-use community that encourages people to live near transit services and to decrease their dependence on driving" (Still, 2002, pp. 44).
- "A mixed-use residential or commercial area intended to maximize access to public transportation" (Holmes & Van Hemert,2008, pp.4).
- "A compact, mixed-use community, centered around a transit station that, by design, invites residents, workers, and shoppers to drive their cars less and ride mass transit more. The transit village extends roughly a quarter mile from a transit station, a distance that can be covered in about 5 minutes by foot. The centerpiece of the transit village is the transit station itself and the civic and public spaces that surround it. The transit station is what connects village residents to the rest of the region. The surrounding open space serves the important function of being a community gathering spot, a site for special events, and a place for celebrations (Bernick & Cervero, 1997, pp. 5).
- "A mixed-use community extending for ¼ to ½ mile from a public transit station. The elements of this community include housing, retail, offices, civic uses, and open space; pedestrian-friendly infrastructure and amenities; higher densities than surrounding areas; and compact design (i.e., narrower streets, smaller building setbacks). TOD represents a neighborhood or a collection of developments and public amenities" (The Federal Transit Administration, 2014, pp. 1-2).

Even though these definitions vary regarding complexity, it is evident that the common points in various definitions of TOD are:

1. Mixed-use development
2. Reduced dependency on automobiles by opting for development (offices, residential and retail stores) near a transit network

3. Pedestrian and cycle friendly systems
4. Public and civic spaces available near the transit station
5. Efficient transit network.

However, some features of TOD have not been agreed on and many experts use different definitions. First, there is disagreement regarding the radius in which development should take place in a TOD project, though a common range is one-quarter to one-half mile from a public transit station. Since the difference between choosing a quarter-mile and half-mile circle is subtle, researchers think this issue bears no criticality to TOD and should not be made a specific feature of TOD. Guerra, Cervero, and Tischler (2012) supplement their result by adding that quarter-mile radius works best when predicting ridership as a function of jobs. Half-mile radius works best when the function is residential units for predicting ridership (Guerra, Cervero, & Tischler, 2012).

Most definitions do not cover the importance of passenger movement for successful TOD for retail and commercial planning (Hutchings, 2013). Also, the definition that only advocates for higher density and a greater level of land use is insufficient for the success of TOD (Zhang, 2005).

Calthorpe (1993) gives a specific definition, advocating for a mixed-use community in a radius of 2,000 feet. The average 2,000-foot radius is intended to highlight a comfortable walking distance equivalent to 10 minutes of walking. See Figure 2.1.

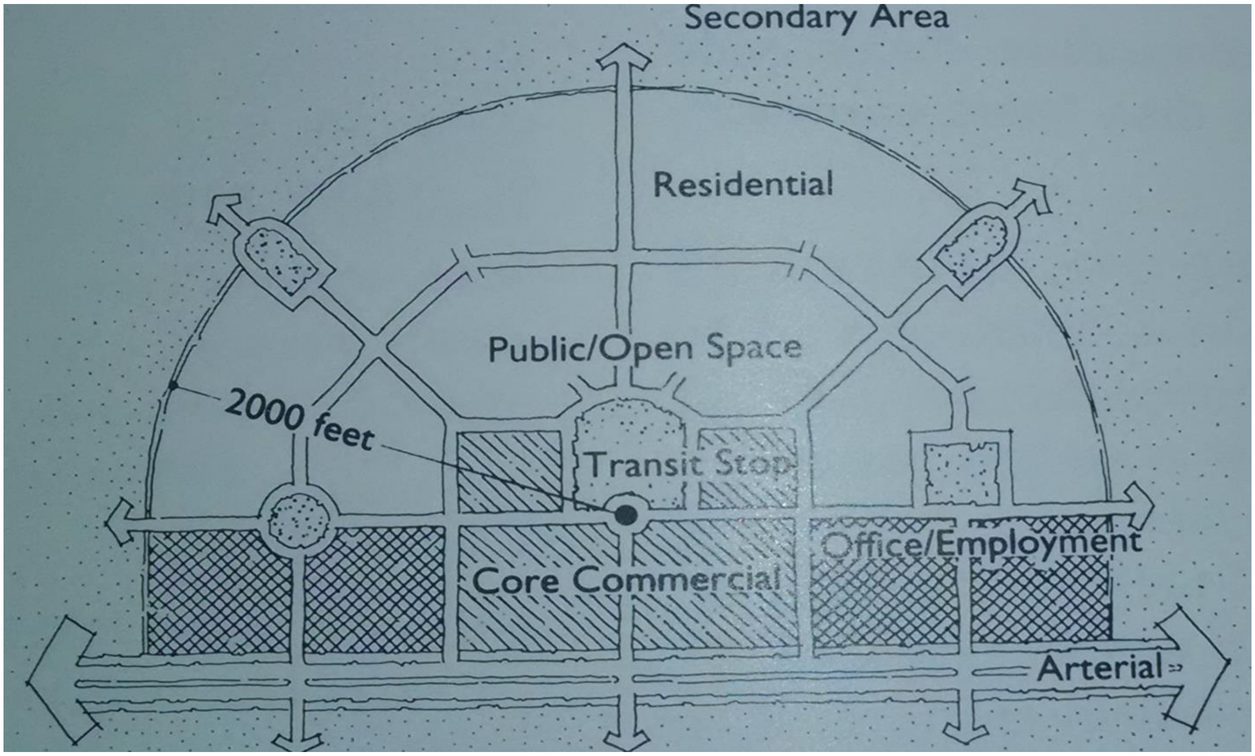

Figure 2.1 A diagram showing a TOD. (Retrieved from Calthorpe, 1993 pp. 56.)

Calthorpe advocates that each TOD must have a minimum of convenience retail and local public offices, as people are more likely to use transit to reach work if both components are combined. He also highlights that at least 10 percent of the entire TOD site and a minimum 10,000 square feet of retail space adjacent to a transit stop is necessary to make it successful. Further, he notes that residential areas should include a mix of housing types such as small-lot single-family, townhomes, condominiums, and apartments. Regarding public uses, Calthorpe advocates for parks, plazas, green, public buildings, and utilities near the transit stop. In an urban TOD, open space should contribute to approximately 5%-15%, commercial/ employment center should be around 30%-70%, and housing should contribute around 20%-60%, depending on type and design of TOD Calthorpe, 1993).

A performance-based definition of TOD created by Dittmar, Belzar, & Autler (2004) concentrated on the main goals of a TOD project. These goals were developed based on improving livability, which has appeared in many surveys trying to quantify definitions of TOD. The five prime objectives defined by (Dittmar, Belzar, & Autler, 2004) were location efficiency, a rich mix of choices, value capture, place making and resolution of the tension between node and place.

Location efficiency is the art of placing residential housing near transit systems, which is fair to people with limited wealth (Dittmar, Belzar, & Autler, 2004). Autler (2004) suggests three main components of location efficiency—density, transit accessibility, and pedestrian friendliness. Hansen (1959) concluded in a study of Washington, DC, that accessibility to any activity is proportional to the magnitude of that activity and inversely proportional to the distance. People also are more inclined to walk to a train station than a bus stop (O'Sullivan & Morrall, 1996).

The second goal described by (Dittmar, Belzar, & Autler, 2004) is a rich mix of choices within the TOD project. Autler (2004) states that the neighborhood should offer multiple activities at a walking distance to its residents so that people who cannot pay for a car or those who do not rely on cars can still be part of social activities. Also, the neighborhood should be built to offer different housing options including low incomes housing. Affordable housing in the TOD area was the main reason for residents choosing the locality (Olaru, Smith, & Taplin, 2011).

The third goal described by (Dittmar, Belzar, & Autler, 2004) is value capture to maximize benefits of TOD for different stakeholders. Some examples of value capture for various stakeholders are shown in Table 2.1.

The fourth goal described by (Dittmar, Belzar, & Autler, 2004) is place-making, which means the TOD area is not given enough consideration to make them innovative and interesting. Llewelyn-Davies (2000) published a document that supports a higher quality of urban design, giving many accounts of history when town and cities were designed carefully. In the author's opinion, the lack of will and public funding are the main reasons behind lower quality of urban design.

Last, Dittmar, Belzar, & Autler (2004) highlight that the resolution of each place as a transit station or a stop must be resolved so it becomes successful.

Table 2.1 The beneficiaries of value in good urban design
(Retrieved from Dittmar, Belzar, & Autler, 2004 pp. 27)

Stakeholders	Short-Term Value (social, economic and environmental)	Long-Term Value (social, economic and environmental)
Landowners	Potential for increased land values	
Funders (short term)	Potential for greater security of investment depending on market	
Developers	Quicker permissions (reduced cost, less uncertainty) Increased public support (less opposition) Higher sales values (profitability) Distinctiveness (greater product differentiation) Increased funding potential (public/private) Allows difficult sites to be tackled	Better reputation (increased confidence/'trademark' value) Future collaborations more likely
Design professionals	Increased workload and repeat commissions from high quality, stable clients	Enhanced professional reputation
Investors (long term)	Higher rental returns Increased asset value (on which to borrow) Reduced running costs Competitive investment edge	Maintenance of value/income Reduced maintenance costs (over life) Better re-sale values Higher quality longer term tenants
Management agents		Easy maintenance if high quality materials
Occupiers		Happier workforce (better recruiting and retention) Better productivity Increased business (client) confidence Fewer disruptive moves Greater accessibility to other uses/facilities Reduced security expenditure Increased occupier prestige Reduced running cost (energy usage)
Public Interests (from Table 1)	Regenerative potential (encouraging other development) Reduced public/private discord	Reduced public expenditure (on crime prevention/urban management/urban maintenance/health) More time for positive planning Increased economic viability for neighbouring uses/development opportunities Increased local tax revenue More sustainable environment
Community Interests (from Table 2)		Better security and less crime Increased cultural vitality Less pollution (better health) Less stress (better health) Better quality of life More inclusive public space A more equitable/accessible environment Greater civic pride (sense of community) Reinforced sense of place Higher property prices

Table 2.2 Definitions adopted by different transit agencies.
(Retrieved from Cervero, Ferrell, and Murphy, 2004 p.6)

Transit Agency	Definition
ATLANTA: Metropolitan Atlanta Rapid Transit Authority (MARTA)	Broad concept that includes any development that benefits from its proximity to a transit facility and that generates significant transit ridership.
ASPEN: Roaring Fork Transportation Authority, Colorado	Land development pattern that provides a high level of mobility and accessibility by supporting travel by walking, bicycling, and public transit.
BALTIMORE: Maryland Transit Administration	A relatively high-density place with a mixture of residential, employment, shopping, and civic uses located within an easy walk of a bus or rail transit center. The development design gives preference to the pedestrian and bicyclist.
CHARLOTTE: Charlotte Area Transit System	High-quality urban environments that are carefully planned and designed to attract and retain ridership. Typically, TODs provide for a pedestrian-friendly environment.
NEW JERSEY: New Jersey Transit Corporation (NJ TRANSIT)	An environment around a transit stop or station that supports pedestrian and transit use, created by providing a mix of land uses in a safe, clean, vibrant, and active place.
CHICAGO: Regional Transportation Authority of Northeast Illinois (RTA)	Development influenced by and oriented to transit service that takes advantage of the market created by transit patrons.
ORLANDO: Central Florida Regional Transportation Authority (LYNX)	A sustainable, economically viable, livable community with a balanced transportation system where walking, biking, and transit are as valued as the automobile.
SALT LAKE CITY: Utah Transit Authority (UTA)	Projects that enhance transit use, improve the quality of service provided to Authority riders, or generate revenue for the purpose of supporting public transit.
SAN FRANCISCO: Bay Area Rapid Transit Authority (BART)	Moderate- to higher-density development, located within an easy walk of a major transit stop, generally with a mix of residential, employment, and shopping opportunities designed for pedestrians without excluding the automobile. TOD can be new construction or redevelopment of one or more buildings whose design and orientation facilitate transit use.
WASHINGTON, D.C.: Washington Metropolitan Area Transit Authority (WMATA)	Projects near transit stops which incorporate the following smart-growth principles: reduce automobile dependence; encourage high shares of pedestrian and bicycle access trips to transit; help to foster safe station environments; enhance physical connections to transit stations from surrounding areas; and provide a vibrant mix of land-use activities.

Due to the diversity of definitions, as listed in Table 2.2, researchers have begun to categorize TOD projects. Evans et al. (2007), divided TOD into three different dimensions: regional context, land use mix, and primary transit mode. White and McDaniel (1999) divided the TOD into six different types based on geographic contexts. The six different kinds are Single-Use Corridors, Mixed-Use Corridors, Neo-Traditional Development, TOD, Hamlet or Village Concept and Purlieu (development of approximately 150 acres and 7,000 residents with detailed design guideline and restriction on land use).

2.4 Outcomes of a Transit-Oriented Development

Another aspect of multiple definitions is that it makes identifying successful TOD projects problematic. TOD is a paradigm shift in societies with auto-oriented developments and requires a change in lifestyle in some cases. Some define a successful TOD as one that results in even a minor shift in attitudes (Belzer, Autler, & Economics, 2002), while other researchers prefer quantifiable parameters. Several researchers have tried to capture the performance of TODs, as described in the following paragraphs.

The outcomes of a TOD are sub-divided into four sections by Renne (2007): travel behavior indicators, local economy indicators, natural environment indicators, and built environment indicators. One of the most important outcomes on which most people will concentrate are the vehicle kilometers traveled (VKT) or vehicle miles traveled (VMT) (Stiffler, 2011). However, given the scale of most urban TOD projects, it is logical to incorporate more factors to analyze TOD success. The major success factors are listed here in four categories. They are derived from a synthesis of the literature, as shown in Table 2.3 at the end of this section.

2.4.1 Travel Behavior Outcomes:

1. Vehicle kilometers or miles traveled (VKT or VMT)
2. Mode split
3. Frequency of public transit usage
4. Resident commuting time (reduced or increased)
5. Frequency of headways
6. Vehicles ownership
7. Condition of pedestrian path

2.4.2 Local Economy Outcomes:

1. Number of jobs by type
2. Vacancy rate
3. Home ownership vs. rental
4. Weekly housing expenses
5. Property value increase (before and after TOD)

2.4.3 Natural Environment Outcomes:

1. Transport energy consumption (computed)
2. CO_2 emissions (computed)
3. Park space
4. Percent of land cover as green space in the TOD area
5. Percent of land cover as trees

2.4.4 Built Environment Outcomes:

1. Population and housing density
2. Street quality

3. Quality of public spaces
4. Parking inventory
5. Pedestrian accessibility

The data above can result in a holistic TOD evaluation framework. The results between TODs, TODs versus non-TODs and TODs versus a regional average should be compared (Renne, 2007).

The success of a TOD is often partially defined as the extent of the shift in travel behavior from autos to transit (Stiffler, 2011). In financial terms, success can be defined as benefits of the shift in travel behavior to the total costs of infrastructure and operational cost of the TOD (Niles & Nelson, 1999). Some other studies measure success regarding community bonding and livability (Project for Public Spaces, Transit Cooperative Research Program, & Federal Transit Administration, 1997).

The California Department of Transportation tried to determine the performance criteria applicable to TOD. Based on the report, any TOD should at least meet the following three performance criteria:

- Moderate or high-density development within easy walking distance of public transportation
- Mixed development
- Pedestrian-oriented design including the automobile in the design

Similar to the definition of TOD, the parameter to define success for TOD varies between researchers and transit agencies.

To conclude this section, we can look at the comments by Peter Calthorpe. Calthorpe (2004) states that the goal of TOD is to make places more accessible to varied inhabitants, such as singles, the working poor, the elderly and the middle-class families. According to Calthrope, TOD can provide affordable living to middle-class in an environmentally responsible and cost-effective technique for businesses and government.

2.5 Factors Affecting the Outcomes of a Transit-Oriented Development

Dittmar & Ohland (2004) state that five factors define the outcome of a TOD project. These factors are: location efficiency, a rich mix of choices, value capture, place making, and resolution of the tension between node and place. Each one of them is explained as follows:

2.5.1 Location Efficiency

The appropriate placement of homes is of particular importance for a TOD project to be successful. In a study of 17 TODs, it was found that people living in TOD area use transit two to five times more often compared to people living in non-TOD areas (Arrington et al., 2008; Nasri & Zhang, 2014). The success of TOD on increased ridership is linked to the length of residency of TOD residents. Those who have lived longer in the TOD area are more likely to use public transportation than those who are new to the TOD area (Lund et al., 2004). Key components for location efficiency are density, transit accessibility, and pedestrian friendliness (Poticha, 2004).

2.5.2 Rich Mix of Choices

A range of housing options and retail stores, varying from small specialty shops to large retail outlets to different public spaces, provide a significant option for TOD users (Dittmar & Ohland, 2004).

2.5.3 Value Capture

Value capture for each stakeholder will be different. For example, local government's value capture can mean higher tax revenues from sales and property values. For a transit agency, value capture means lease revenue from development and increased revenue from fares. For residents of TOD, increased value of property and saving as a result of reduced use of automobiles can be a few value captures. It is important to map the matrix of value capture for different stakeholders and fulfill those (Dittmar & Ohland, 2004).

2.5.4 Place Making

A significant limitation or failure for many current TODs is that less attention is given to making TODs attractive and pedestrian-friendly. If transit is not convenient to reach, not appropriately frequent, or not linked to a desired destination of local mass riders, then TOD is more likely to fail (Dittmar & Ohland, 2004). Daisa (2004) states that large parking lots are also a failure and many times ironic to the concept of TOD, which aims to reduce the use of automobiles for traveling.

2.5.5 Resolving the Tension between Nodes versus Place

Understanding the role of the station is crucial for a concept of this range to be successfully implemented. The design should be such that peak and non-peak hours of ridership should not be too different. Every station should be used for multiple purposes, such as commercial, retail, shops, art and public spaces.

More factors are not included in the above five categories, but are equally important to the success of a TOD system. These factors are frequency, speed, regional context, and capacity. The frequency should be convenient for people to use the service effectively. Headway of 15-minutes is approximate to the convenience of the car. Similarly, journey times must be competitive with a travel time by auto, including the time it takes to access the system. Sometimes, regional context and capacity make or break a TOD system's ridership (Poticha, 2004).

In the case study of Washington, DC, and Baltimore, Maryland, metropolitan areas, living in areas with good transit accessibility by pedestrian path or another connecting transport encourages people to use transit. High density development and a mix of land-use also encourage people to go for a more sustainable and healthy life. A successful policy change to further improve TOD is to implement restrictive policies on automobiles and parking. The success of public transportation also depends on the frequency of transit service if it is convenient in peak and non-peak periods (Nasri & Zhang, 2014).

In another case study, Arlington County, Virginia, just outside of Washington DC, was once known to be a low-density commercial corridor. A good amount of credit for the successful implementation of TOD is due to public involvement in planning and development of the TOD. A rich mix of uses was promoted by the government, and for every square foot of commercial space built, there is one square foot of residential space. It is because of TOD that major development has taken place in the county without greatly increasing traffic numbers (Leach, 2004).

Another successful project is the Mockingbird Station and Addison Circle in Fort Worth, Texas, which is a classic example of shifting from auto-oriented development to transit and rail-based development. In 2002, Dallas Area Rapid Transit (DART) had just 20 miles of light rail and the system had only been operating since 1996. This is a unique project because Mockingbird station seems to be auto-friendly and pedestrian-friendly. Also, the public sector—unlike most projects—played a proactive role to the extent they share the cost of building by investing in infrastructure. One interesting outcome of this case study is that small developers are more likely to be successful than big developers. The reason seems to be the personal level discussion that must be done to understand users' needs. In most of the development, small developers did the physical work, while large Wall Street capital companies invested in the project. This represents a unique, but workable, financial solution to TOD development (Ohland, 2004a).

The concept of unique financing used in Dallas is not found in the study of San Diego's Barrio Logan's Mercado Project. Funding became a deterrent in the implementation of that project. The shortage of financing sources because of the lack of major credit tenants resulted in few qualified developers who able to help implement TOD. Also, political interventions might not be good for implementation of TODs, as in this case. The lessons learned from the unsuccessful project are important for new cities planning to implement TODs (Ohland, 2004b).

A flowchart (Figure 2.2) by the Southwestern Pennsylvania Commission was helpful in the planning of their TOD.

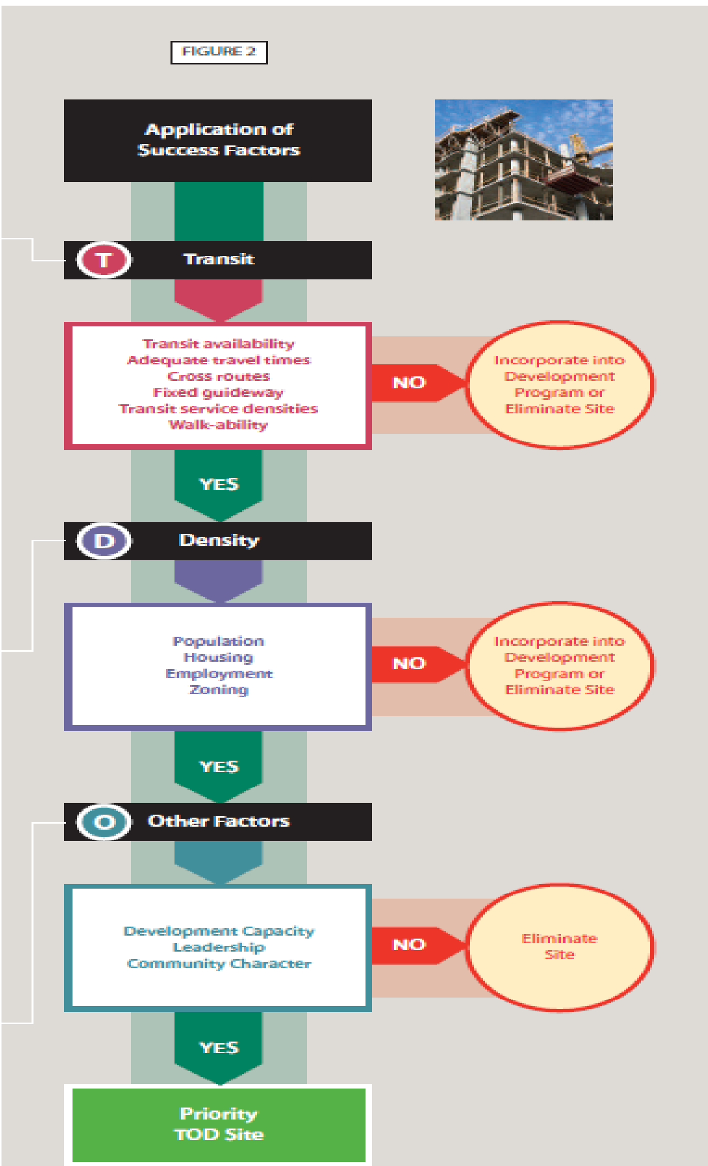

Figure 2.2 Flowchart for deciding on the implementation of TOD
(Retrieved from Southwestern Pennsylvania Commission, 2013, p. 6.)

In stage 1, any site which has planned transit infrastructure or service should not be considered for TOD, as this flowchart represents development only for existing transit sites. The ideal site for any TOD will be the one that does not have any present public transportation, but is a candidate for development of future transit infrastructure. During stage 2, density is considered. If there are no/very few jobs or commercial activities created with the development, then the site will not be successful as a TOD. TOD agencies should always avoid the "if you build it, they will come" assumption unless some special planning is done in and around the TOD. In the final stage of considering other factors, the site must be under-utilized so mixed-land use can be implemented near the TOD, which might not be possible in a place already developed (SPC, 2013).

Some factors of success are easily identifiable in the literature. The quality of walking route and bicycle lanes has been identified by Dittmar and Ohland (2004), Renne and Wells, (2005), Ewing et al. (2013), Renne and Wells, (2005), Ewing et al. (2013), and Wey and Chiu (2013). Curtis, Renne, and Bertolini (2009) highlighted the need for positive government intervention. These and other factors are summarized in Table 2.3.

Table 2.3 List of factors with literature references

Factor of Success	Reference
Quality of walking route to station and bicycle land	Dittmar and Ohland (2004); Renne and Wells (2005); Ewing et al. (2013); Bae (2002); and Wey and Chiu (2013)
Housing/Population density	Renne and Wells (2005); Curtis, Renne, and Bertolini (2009); Sung and Oh (2011); and Calthorpe (1993)
Number of shuttle and bus services provided from transit station	Dittmar and Ohland (2004); Blezer, Autler, and Economics (2002); and Messenger and Ewing (1996)
Riders per mile	Renne and Wells (2005); Curtis, Renne, and Bertolini (2009); Sung and Oh (2011); and Calthorpe (1993)
Positive Government Intervention	Curtis, Renne, and Bertolini (2009) and Leach (2004)
Number of Mixed-use structure	Cervero and Radisch (1996); Tumlin and Millard-Ball (2003); Renne and Wells (2005); Bae (2002); and Freilich (1998)
Amount of Brownfield properties	Renne and Wells (2003)
Improved landscape	Cervero (2004); Lund et al. (2004); and Jacobson and Forsyth (2008)
Subsidized housing units	Autler (2004); Calthorpe (1993); and Dena Belzer, Autler, and Economics (2002)
Number of convenience/service retail planned	Calthorpe (1993); Boarnet and Compin (1999); and Cervero and Day (2008b).
Planned new/improved cultural/artistic institution	Nelson, Niles, and Hibshoosh (2001; and Dunphy and Porter (2006).
Household disposable income	Cervero and Day (2008a, 2008b); Mu and Jong (2012); and Hess and Lombardi (2004)
Public perception	Belzer and Autler (2002b); Renne & Wells (2005)
Parking supplies on site	Renne & Wells (2005); and Tumlin and Millard-Ball (2003).
Property Taxes	Boarnet and Crane (1998)
Park Spaces	Calthorpe (1993); Dittmar and Ohland (2004); Cervero (2004); and Dittmar and Poticha (2004)

3. RESEARCH METHODOLOGY

This section examines research questions and discusses the method designed to conduct this research. The purpose of the two-phase, exploratory mixed method is to explore participants' views to develop and test an instrument with a population (Creswell & Clark, 2007).

3.1 Review of Research Question

This research is an attempt to develop a framework for choosing a TOD site by transit agencies, which can assist decision-makers to better and structured decisions. Specific questions to be considered are:

- How can we determine the initial list of factors for the success of a TOD?
- What processes can be used by individual transit agencies to vet those factors once we have an initial list of factors?
- How can the weights of those factors be determined?

The first question was addressed through a literature review to find factors that resulted in success for a TOD project. The second question was addressed through a qualitative research method applied to interviews with representatives of Denver and Aspen transit agencies. For the third question, a quantitative multi-criteria decision analysis tool called the analytic hierarchy process (AHP) was used.

3.2 Mixed Research Method Literature

The mixed research method is used in social and human sciences where quantitative and qualitative methods fall short of answering the research question(s) (Creswell, 2013). Construction is also considered a "social" process by many experts because it is seen as the application by people of methods developed by people to achieve goals established by people for the construction of a building or infrastructure. Considering that people play an important role in almost every aspect of construction, the research methods applicable to social sciences are equally applicable to construction research, as to any other similar field (Abowitz & Toole, 2010).

There has always been a debate about qualitative and quantitative research methods and which of them is superior. Various authors have exhibited preference for one research method or the other. For example, Weiss and Rein (1970) and, Guba (1978), supported qualitative methods. Weiss and Rein (1970) recommended that several approaches can be applied using qualitative techniques, which make them superior to the quantitative research method for broad-aim programs. On the other hand, Campbell and Stanley (1966) are among the authors who favor quantitative methods.

Two of the earliest evaluators to favor the mixed research method were Charles S. Reichardt and Thomas D. Cook. In their book, Cook and Reichardt (1979) strongly supported mixed research methods. They hold the view that it is research settings that help determine if a quantitative, qualitative or a mix of these methods is best suited. In writing about the debate over qualitative and quantitative research methods, Cook and Reichardt (1979, p.19) believed that a "researcher need not adhere blindly to one of the polar-extreme paradigms that have been labeled 'qualitative' and 'quantitative,' but can freely choose a mix of attributes from both paradigms so as to 'best fit' the demands of the research problem at hand."

Creswell (2013) identified main types of mixed research methods:

1. Concurrent triangulation strategy: This strategy is based on the belief that each method has a bias that can be reduced by the convergence of the results of multiple methods in the same study (Greene, Caracelli, & Graham, 1989).
2. Sequential explanatory strategy includes two phases—quantitative, followed by qualitative. In this research method, a researcher is supposed to first collect the quantitative part of research and the qualitative part is then built on the quantitative results (Ivankova, 2006).
3. Sequential exploratory strategy—the qualitative part of research is followed by the quantitative. The priority is equally given to each phase and data are integrated while analyzing (Terrell, 2012).
4. Sequential transformative strategy has two phases. The first phase consists of a theoretical lens, which is then overlaid by a sequential process (Creswell, 2013).
5. Concurrent embedded strategy, which is similar to the triangulation strategy. Both research methods are used and data are collected simultaneously. The only difference is that, in this method, one method is assigned as primary while other is secondary, and they are given different priorities (Creswell, 2013).
6. Concurrent transformative strategy consists of two stages. The researcher first shares a distant theoretical perspective and then collects the quantitative and qualitative data (Gilbert, 2006).

The sequential exploratory strategy is used for this research, in which the qualitative method is followed by the quantitative method. Using this research strategy, in the first phase the researcher gathers qualitative data, which are analyzed and used for development/choice of a statistical method. That method is implemented in the last phase of the research. The qualitative phase of the project was carried out through interviews with the aim of finalizing the list of success factors for a TOD project. These factors were identified by an intensive literature review and then presented to a group of experts to determine which were important enough to stay on the list. The final phase was to use those factors to create a quantitative instrument. This was achieved by use of the multi-criteria decision-making (MCDM) method known as AHP. A flow chart for the research design is presented in Figure 3.1 to show Phase I and Phase II of the study.

3.3 Conducting a Literature Review

Creswell (2013) states that a literature review helps to share similar studies conducted in the past with your audience. It adds to the discussion about the field of study. Creswell (2013) also discusses the nature of literature review based on the research method. For example, the sequential exploratory strategy will have a limited literature review, but research might incorporate more at the end, based on the new understanding of the phenomenon. This is also known as inductive approach.

This research began with a literature review covering a brief history of TOD and urban sprawl. Urban sprawl is one of the biggest reasons behind TOD's existence. The term TOD was defined by presenting various definitions given by experts and transit agencies. Next, success parameters of a TOD project were identified and the last section of the literature review determined success factors for a TOD project. Factors identified in the literature review were used in the qualitative phase of the study. The literature review resulted in a list of initial factors. The list of factors and their definitions have been attached in Appendix A.

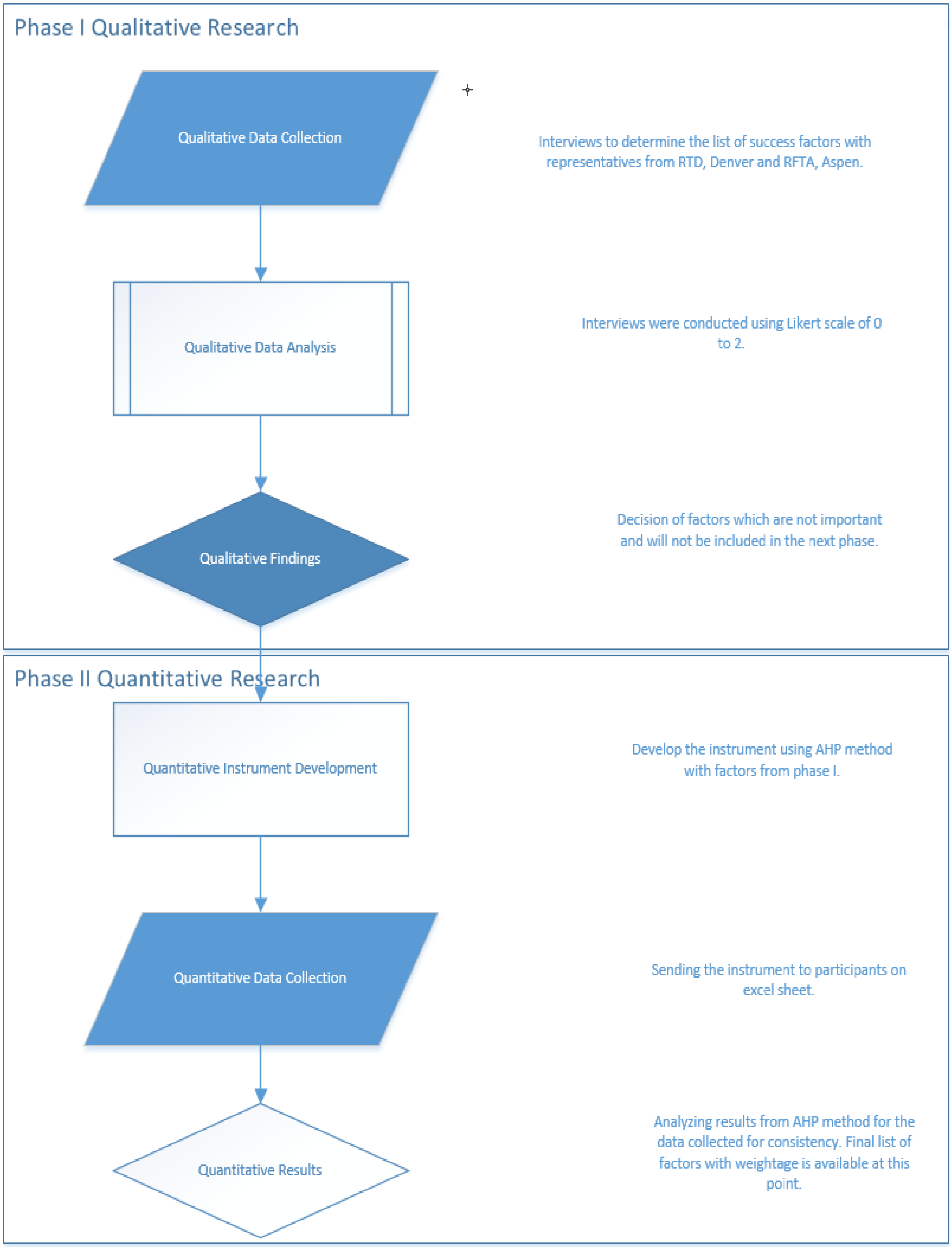

Figure 3.1 Qualitative and quantitative research

3.4 Qualitative Data Collection

After literature review, qualitative data was collected for the study. The goal of Phase I was to extract highly relevant factors out of the initial list identified from the literature review. This was done based on input from interviewees. For this study, interviews were conducted either by phone or in person. Coffey and Atkinson (1996) recommend that qualitative data should be collected and analyzed simultaneously. For this reason, interview outlines were created in which the collection of data for evaluation could go up to three rounds before the final list of factors was determined.

3.5 Participation Selection and Establishing Contact

The selection of participants for this study was straightforward. It was decided to conduct a comparative study of the transit agencies of a big city and a small town. The city of Denver was chosen to represent a big city that has multiple jurisdictions and a chain of approval from various agencies. The selection of Aspen County as a small town was chosen because Roaring Fork Transportation Authority (RFTA) of Aspen received a Federal Transit Administration grant to assess the potential for TOD.

Regional Transportation District (RTD) and RFTA transit agencies were contacted via email to identify people responsible for implementation of TOD projects. The email sent to both agencies included an introductory message (Appendix B) and consent form (Appendix C). The consent form stated that there would be a phase II and a follow-up regarding the data collected. RFTA's interview was conducted over the phone. And RTD's interview was conducted at their office.

3.6 Interview Protocol

Each interview started with an introduction and review of the research to give participants the required background. Required consents were obtained and success factors, based on the literature review, were reviewed. A short discussion ensued at this point so interviewees did not attach different definitions or meanings to any of the factors. They were asked to identify additional factors not on the original list. The list of the factors was collated from the literature review and discussion with the interviewees.

At this stage, participants were asked to rate individual factors on a 0-2 Likert scale to determine which factors could be removed from the list. Factors receiving a unanimous score of 0 were eliminated Factors receiving an average score of 0.5 or less were discussed to determine if they should be removed or merged with other factors. Eventually, a final list of factors was shown to each participant for approval before finishing the interview. In this interview, participants were also given a short demonstration for the next phase of our study (AHP) on Excel.

Presenting final results of this phase to the interviewees enhanced validity of the qualitative study.

3.7 The Analytic Hierarchy Process (AHP)

Multi-criteria decision-making (MCDM) is a method of selecting the most efficient option from various alternatives when there are conflicting criteria (pomerol & Barba-Romero, 2012). AHP is one of the leading MCDM methods (Işıklar & Büyüközkan, 2007) because of its simplicity, precision, and ability to identify inconsistency of the responses (Piantanakulchai and Saengkhao, 2003).

Numerous papers have compiled successful implementation examples of AHP in various fields (Zahedi, 1986; Shim, 1989; Vargas, 1990). Furthermore, AHP is also commonly used in the construction field (Li, Phoon, Du, & Zhang, 2013; Anagnostopoulos & Vavatsikos, 2006). Finally, when compared to other MCDM methods, it is relatively straightforward to describe to the decision-makers and therefore, can be implemented easily by them (Schmoldt et al., 2001).

AHP was developed by Saaty (1994) to solve complex decision-making processes by choosing factors that are important for the decision-maker. The factors are then arranged in a hierarchy, starting from the goal of the project at Level 1 to criteria, sub-criteria, and various options in Levels 2, 3, and 4, respectively (Saaty, 1994).

AHP involves the following operations, as suggested by Xiao (2010):

1. Simplify the decision problem into a hierarchical arrangement, including all criteria, sub-criteria, and various options.
2. Make a pairwise comparison of all options under each criterion.
3. Determine the local weight for each criterion.
4. Determine the overall weight for each option using the weights determined in Step 3.
5. Determine the consistency index to know the quality of data collected using this method.

As discussed by Saaty and Vargas (2012), two types of comparisons are identified by psychologists: absolute and relative. The AHP method uses both types, based on the strength of human mind in each comparison. For example, absolute comparisons are used to apply a score to the criteria or the magnitude of the criteria; e.g., good, very good, average, poor, etc. In the other scenario, relative comparisons are used for conducting pairwise evaluation.

Pairwise comparisons can sometimes be tricky because humans can give a random value to each comparison, resulting in confusion and, sometimes, failure of the experiment. It was necessary to establish a standardized scale for the method that can be used for any research. This fundamental scale of values to provide intensities of judgments was provided by Saaty and Vargas (2012).

Table 3.1 The fundamental scale
(Retrieved from Saaty and Vargas 2012, p. 6.)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix

One of the most important mathematical operations in AHP is determining the matrix to find the eigenvector for weights and consistency. We refer to Saaty and Vargas (2012) to provide complete literature on how to determine the eigenvector solutions. The matrix a_{ij} is formed by pairwise comparison and its reciprocal values. Once the matrix is formed, values for priority vectors are determined. There are various ways to find out the priority vectors from the matrix. If a_{ij} denotes the matrix that compares the alternative *i* over alternative *j* and a_{jk} denotes the matrix that compares the alternative *j* over *k*, then the importance of *i* over *k* alternative should be equal to $a_{ij}.\ a_{jk.}$ The derived equation eventually becomes $Aw = \lambda_{max}.w$, in which *A* is the matrix of pairwise comparisons, λ_{max} is the largest eigenvalue of *A*, and *w* represents the priorities assigned to individual criteria. The priority vector is determined by raising the matrix to a large power and then summing and normalizing the matrix. The value of λ_{max} can be easily determined by adding the columns of *A* and multiplying the vector by priority vector *w*.

The consistency index of the matrix can be determined by the formula $(\lambda_{max} - n)/(n-1)$, where *n* is the total number of criteria. The value determined by the above formula is known as the consistency index. To determine the consistency ratio, divide the consistency index by the random index. The random index is dependent on the number of criteria, as shown in Table 3.2.

Table 3.2 Average random consistency index (RI).
(Retrieved from Saaty and Vargas 2012, p. 9))

N	1	2	3	4	5	6	7	8	9	10
Random consistency index (R.I.)	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Saaty and Vargas suggest (2012) that if the consistency ratio is not less than 0.10, then there is need to revise the problem and data collection methods.

An example of AHP is shown below, in which we are trying to identify the best car based on a given set of requirements. In this hypothetical example Chris, a BIM Manager at a construction firm, plans to buy a new car. He has identified five parameters to decide which is the best car for Jim. The parameters are:

1. Price
2. Comfort
3. Power
4. Size of car
5. Color

It can be a challenging job to give accurate weights to each parameter, because Chris might give random weights without any pairwise comparisons. The AHP method is useful because it compels the user to compare only two parameters at a time. The first step for implementation of the AHP method is to identify factors or parameters by which the comparison is to be conducted. In the next phase, Chris will have to give pairwise comparisons by evaluating two parameters at a time using the fundamental scale, as shown in Table 3.3. The scale varies between 1 and 9, in which 1, 3, 5, 7, and 9 represent equal, moderate, strong, very strong, or extremely strong importance, respectively, and 2, 4, 6, and 8 represent weak, moderate plus, strong plus, and very, very strong importance, respectively.

An Excel sheet can be developed into which Chris's response to pairwise comparison can be entered. The spreadsheet which Chris used to conduct pairwise comparison asks him two questions for each pair:

1. Which parameter is more important (A or B)?
2. On a scale from 1 to 9, by how much is that parameter more important?

Results of the hypothetical AHP matrix are shown in Table 3.3.

Table 3.3 Pairwise comparison matrix for chris

Parameter	Price	Comfort	Power	Size	Color
Price	1	7	0.333333333	0.5	5
Comfort	0.142857143	1	0.142857143	0.2	0.5
Power	3	7	1	2	7
Size	2	5	0.5	1	4
Color	0.2	2	0.142857143	0.25	1

The first comparison is between Price vs. Price. They are obviously of equal importance because they are comparing the same parameter. The value in the first row and second column represents Price vs. Comfort, in which Price is important by a magnitude of 7. Similarly, the value lower than 1 shows that the parameter on the column heading is more important than that on the row heading.

The next step is to calculate the row product for each parameter. For the parameter Price, the product can be calculated by 1 x 7 x 0.33333 x 0.5 x 5 = 5.83 (refer to Table 3.4). Step 2 in the calculation is to find the nth product, which is derived by the formula: Product ^ (1/Total number of Parameters).

Table 3.4 Calculating product, nth product, and priority vector

Parameter	Product	nth product	**Priority Vector**
Price	5.83	1.42	**0.20**
Comfort	0.00	0.29	**0.04**
Power	294.00	3.12	**0.44**
Size	20.00	1.82	**0.26**
Color	0.01	0.43	**0.06**

Taking the example of Price again, the nth product can be found by taking the Product of the Price parameter (5.83) to an exponential of 1 over the number of factors (1/5), which is equal to 1.43 (refer to Table 3.4). Step 3 in the calculation is to determine the priority vector, also called the normalized eigenvector or just the eigenvector. The formula for calculating priority vector is (nth product of that row) / (sum of nth product). Again, to take the example of Price, the priority vector is calculated by 1.42 / (1.42 + 0.29 + 3.12 + 1.82 + 0.43) = 1.42 / 7.08 = 0.20 (refer to Table 3.4). The sum of the priority vectors of all rows will be equal to 1. This shows the preference of Chris if priority vector is converted to a percentage. The weights based on Chris's pairwise comparisons give the following results:

1. Price: 20%
2. Comfort: 4%
3. Power: 44%
4. Size: 26%
5. Color: 6%

Once the weights have been calculated, the last step is to check the consistency ratio. The consistency ratio is used to determine if Chris was consistent while choosing weightages or if he just randomly assigned weights. The consistency ratio should be less than 10% to prove consistency in the results. This consistency ratio might be little higher if there are many parameters.

To calculate the consistency ratio, sums for each column of Price, Comfort, Power, Size, and Color are calculated. The next step is to multiply the sum of each column with the priority vector for that parameter. For example, to calculate Sum x PV for Price, multiply 6.34 by 0.20, which gives the value of 1.28 (refer to Table 3.5). The next step is to determine the Lambda Max, which is calculated as Sum * PV. In the hypothetical case, Lambda Max is calculated as 1.28 + 0.90 + 0.93 + 1.02 + 1.05 = 5.18. The next step is to determine the consistency index, using the formula (Lambda Max – Total Number of Parameters)/(Total Number of Parameters - 1). The consistency index is calculated as (5.18 – 5)/(5 – 1) = 0.046. The last step in determining the Consistency Ratio is to divide the Consistency Index by the Random Index. The random index is determined by using Table 3.5, which gives a unique value based on the number of parameters. In the example above, there are five parameters, which correspond to a random index of 1.11. This gives a consistency ratio of 0.04 or 4%, which is less than 10% and hence suggests a reliable data collection and analysis process has occurred.

Table 3.5 Calculation table including consistency ratio

Parameters	Price	Comfort	Power	Size	Color	Product	nth product	Priority Vector
Price	1.00	7.00	0.33	0.50	5.00	5.83	1.42	**0.20**
Comfort	0.14	1.00	0.14	0.20	0.50	0.00	0.29	**0.04**
Power	3.00	7.00	1.00	2.00	7.00	294.00	3.12	**0.44**
Size	2.00	5.00	0.50	1.00	4.00	20.00	1.82	**0.26**
Color	0.20	2.00	0.14	0.25	1.00	0.01	0.43	**0.06**
Sum	6.34	22.00	2.12	3.95	17.50		7.08	1.00
Sum*PV	1.28	0.90	0.93	1.02	1.05		5.18	
Lambda Max	5.18							
CI	0.046							
RI	1.11							
CR	0.04	ok, <0.10						

The AHP process was implemented on a hypothetical TOD for RTD in Denver and RFTA in Aspen. The list of TOD success factors from Phase I were subjected to a pairwise comparison by RTD and RFTA experts and factor weights were calculated using the AHP method. The final step of the AHP method is to evaluate the choices based on the weights determined in the pairwise comparison. To continue the example from above, assume four cars are compared in terms of price, comfort, power, size, and color. Table 3.6 lists characteristics of four hypothetical cars:

Table 3.6 Different cars and their features

Cars → / Factors ↓	Car 1	Car 2	Car 3	Car 4
Price	$33,215	$27,995	$23,590	$19,595
Comfort	Excellent	Good	Good	Average
Power	202 hp	707 hp	178 hp	148 hp
Size	Luxury Car	Small	Small SUV	Small SUV
Color	Blue	Not Blue	Not Blue	Not Blue

To illustrate the implementation of this framework, the factor of price from the example above is analyzed using the AHP method. Alternatives must all fit within a boundary constraint. For example, if Chris has a budget of $24,000 for the purchase of the new car, Table 3.7 illustrates the alternatives relative to a boundary condition.

Table 3.7 Prices of different choices

Cars	Price	Comparison to Budget
Car 1	$33,215	$9,215 over
Car 2	$27,995	$3,995 over
Car 3	$23,590	$410 under
Car 4	$19,595	$4,405 under

When Chris is comparing Car 1 to Car 2 arithmetically, he should say that Car 2 is 1.56 times better than Car 1 due to the price difference of $5,220 between them. But the reality is that both Car 1 and Car 2 are beyond the budget set by Chris. Also, there is no way to know if Chris wants to save more and would have higher preference for a car that is cheaper than his budget. To manage this problem, we need to define lower, mid, and higher extremes for this factor. Let's assume that being $1,000 under budget is slightly preferred, but a $4,000 difference is strongly preferred and an $8,000 difference is extremely preferred. If both cars are over budget, then each is equally not preferred. A pairwise comparison for price of each car under these boundary conditions is shown in Table 3.8:

Table 3.8 Different choices based on price

A	B	Price (A)	Price (B)	Over/Under Budget (A)	Over/Under Budget (B)	Better Car	Intensity	Reason
Car 1	Car 2	$33,215	$27,995	$9,215	$3,995	B	1	Both are over budget
Car 1	Car 3	$27,995	$23,590	$9,215	$410	B	9	A is over budget
Car 1	Car 4	$23,590	$19,595	$9,215	$4,405	B	9	A is over budget
Car 2	Car 3	$27,995	$23,590	$3,995	$410	B	7	A is over budget
Car 2	Car 4	$27,995	$19,595	$3,995	$4,405	B	9	A is over budget
Car 3	Car 4	$23,590	$19,595	$410	$4,405	B	7	$3,995 price advantage over A

The final calculation on the pairwise comparison for different choices based on price is shown in Table 3.9. These are the local priorities for the individual factor of Price.

Table 3.9 Pairwise comparison for various cars based on price

Choices	Car 1	Car 2	Car 3	Car 4	Product	nth product	Priority Vector
Car 1	1.00	1.00	0.11	0.11	0.01	0.33	**0.05**
Car 2	1.00	1.00	0.14	0.11	0.02	0.35	**0.05**
Car 3	9.00	7.00	1.00	0.14	9.00	1.73	**0.24**
Car 4	9.00	9.00	7.00	1.00	567.00	4.88	**0.67**
Sum	20.00	18.00	8.25	1.37		7.30	**1.00**

To determine the global vector for each car, we will have to multiply the priority vector for each car with the individual weighting of Price. The individual weight for price was 0.20 as shown in Table 3.5. Table 3.10 shows the global vectors for each car.

Table 3.10 Global vectors for each car

Choices	Local Vector	Global Weighting	Global Vector
Car 1	0.05	0.20	0.01
Car 2	0.05	0.20	0.01
Car 3	0.24	0.20	0.05
Car 4	0.67	0.20	0.13
Sum	**1**	**-**	**0.20**

The pairwise comparisons for each individual factor is repeated to determine global vectors/priority for each car. The global vectors can be added for each car to determine the option that is closest to the goals finalized by Chris. The higher the global vector, the closer it is to being the ideal fit for the user.

The example provided above is intended to explain how the AHP framework can be implemented to assist decision makers in identifying the best choice among several alternatives. In the context of this research, this step would have been the implementation of the framework on an actual project in which transit agencies were trying to finalize a site selection from among several potential alternatives. It was not possible to include this final step as part of this research. Neither agency had a sufficient number of actual project sites they were considering for TOD development to pursue implementation. However, the factor weighting matrix developed in this research can be implemented on any future TOD site selection, with the addition of boundary conditions and specific site parameters.

4. DATA COLLECTION AND FRAMEWORK IMPLEMENTATION

The aim of this research is to identify a framework that can be applied by transit agencies for choosing the best TOD sites. Section 3 presented the research methodology used to implement this research, which included four major steps. The first step was to conduct a thorough literature review to identify a list of factors that can be used to guide the research. These formed the initial list of factors for success of a TOD project site. The second step was to conduct interviews in which experts could vet the factors. The next step was to send an Excel sheet to the same experts so they could make a pairwise comparison to determine individual weightages for the factors. The final step in a comprehensive decision support system development would be to implement the framework on a set of alternatives, but such an application exceeds the scope of this research.

4.1 Regional Transportation District (RTD) Implementation

As discussed in Section 3, the first phase of the research was to conduct a literature review and determine factors of success for a TOD project, which formed the basis for the expert interviews. An initial list of factors was determined from the extensive literature review. The next stage in Phase I was to conduct interviews with an RTD expert panel on TOD to vet existing factors, remove redundant factors, and add factors relevant to the transit agencies. The participants were first introduced to the success factors identified through literature review to have a consistency of definition for each factor (see Appendix A for the initial list of factors). An important aspect of this stage was to identify additional factors that should be included in the factor list. A facilitated discussion was also conducted to bring more clarity to the naming and categorization of factors. Some factors added to the list was travel time to offices, market perception, and age demographics in the TOD region. Some factors were renamed to bring more clarity to their definition. For example, “Amount of brownfield properties” was renamed “Amount of underutilized properties.” Similarly, "Planned subsidized housing units" was renamed “Planned mixed-income housing units” to incorporate housing under 100% area median income (AMI). In some cases, renaming was done to indicate that access to retail stores or to cultural/artistic institutions is equally important as building/planning in the TOD radius. Table 4.1 represents the vetted list of factors with final scores and their selection status. The final list of factors was shown to the participant at RTD for validation and final vetting for inclusion in Phase II of the research.

Table 4.1 Final List of factors for RTD implementation

SR. No.	Factor Name	Score	Selected (Yes/No)
1	Population/housing density	2	Yes
2	Amount of underutilized properties	NA	No
3	Parking supplies on site	2	Yes
4	Household disposable income within 0.5 miles	1.25	Yes
5	Incentive mechanisms offered to private players	1	Yes
6	Market perception	2	Yes
7	Planned mixed-income housing units	1.5	Yes
8	Quality of bicycle lanes	1.25	Yes
9	Access/planned convenience/service retail store	1	Yes
10	New property and sales taxes expected	1.5	Yes
11	Access/planned cultural/artistic institutions/entertaining centers	0.5	Yes
12	Planned/access to improved parking areas	0.5	No
13	Government interventions regarding incentives or approval process	2	Yes
14	Travel time to offices/employment centers	2	Yes
15	Community support	1.5	Yes
16	Number of mixed-use structures	1	Yes
17	Access to/planned green spaces	0.5	Yes
18	Quality and length of walking route to station	2	Yes
19	Number of shuttle and bus services proved from transit station	1.25	Yes
20	Age demographics	0.5	Yes

Population/housing density, parking supplies, market perception, government interventions, travel time to offices/employment centers, and quality/length of the walking route to the station were given the perfect score of 2. Even though they received a perfect score, they may not be the most important factors, as it merely represents majority consensus among participants for inclusion of these factors. A significant discussion was conducted to determine if the number of underutilized properties should be included as a success factor for a TOD project. Even though participants accepted the positive influence of having underutilized properties, it was not practical for RTD to plan TODs in underutilized parts of the transit region. Most of the TOD projects were implemented in densely populated areas with constraints of an existing infrastructure. For this reason, the factor related to underutilized properties was removed from the list of factors for RTD.

The next discussion involved whether the incentives and public/private investment ratio should be a factor for the success of TOD projects. In Denver, most of the investment before 2008 came from the public sector, with little support from the private sector. The potential of private investment is considered important by participants, for whom many incentives are given now. Some public finance methods, such as tax increment financing (TIF), are being used to incentivize redevelopment or infrastructure projects in TOD regions. Some of the other incentives include assistance in the approval process, which can attract private sector investors to places like downtown Denver, where it can take years to approve projects. For this reason, market perception was added to the list of final factors of success for RTD.

The final discussion was about perceptions of TOD projects and its impact on the success of such projects. The factors were split into public perception and market perception, since they can vary from area to area. It was clear that there is no standardized solution to improve the perception of any region, so it might not be as significant a factor as others discussed, if people have a positive outlook. However, this might become one of the most important factors, if the local community is opposed to the project. Public perception was added to the final list of factors for RTD because, even though positive public perception may not help a project achieve success, the negative impact of public perception can damage the prospect of success for the project.

The next step in implementing the framework was to conduct a secondary survey, which was developed based on the principles of the AHP MCDM method. The survey instrument was sent to the same participants in RTD to maintain consistency of results. Factors were aggregated into four categories to make pairwise comparisons easier for the participants. This was proven beneficial, since it resulted in a consistency ratio of less than 10% for each category. Following is the list of categories with their included factors:

1. Travel Behavior
    a. Population/housing density
    b. Parking supplies on site
    c. Travel time to offices/employment centers
    d. Number of shuttle and bus services provided from transit station
    e. Access/planned convenience/service retail store
2. Built Environment
    a. Quality and length of walking route to station
    b. Quality of bicycle lanes
    c. Number of mixed-use structure
    d. Access to/planned green spaces
3. Economics
    a. Government interventions
    b. Market perception
    c. New property and sales taxes expected
    d. Incentive mechanisms offered to private players
4. Social Diversity
    a. Planned mixed-income housing (different from mixed-use structures)
    b. Community support
    c. Household disposable income within 0.5-mile radius
    d. Access to planned cultural/entertainment centers
    e. Age demographics

These categories are consistent with those used by Renne, and Wells (2005) to determine a strategy to measure success of the TOD project. The pairwise comparisons were first done in each category and then between categories.

The first category was travel behavior, which had five factors. The participants were asked to compare each factor with another one to identify which one was more important and to ascertain magnitude. The pairwise comparison of Travel Behavior is shown in Table 4.2. To illustrate, in the first row of Table 4.2, the participants compared population/housing density (Item A) and parking supplies on site (Item B); they judged Item A to be more important by a degree of 7 (where 7 means very strong importance, as shown in Section 3, Table 3.1).

Table 4.2 Pairwise Comparison for Travel Behavior

Item A	Item B	More Important Item	Degree of Importance
Population/housing density	Parking supplies on site	A	7
Population/housing density	Travel time to offices/employment centers	B	3
Population/housing density	Number of shuttle and bus services provided from transit station	B	2
Population/housing density	Access/planned convenience/service retail store	A	5
Parking supplies on site	Travel time to offices/employment centers	B	7
Parking supplies on site	Number of shuttle and bus services provided from transit station	B	5
Parking supplies on site	Access/planned convenience/service retail store	B	2
Travel time to offices/employment centers	Number of shuttle and bus services provided from transit station	A	2
Travel time to offices/employment centers	Access/planned convenience/service retail store	A	7
Number of shuttle and bus services provided from transit station	Access/planned convenience/service retail store	A	4

Once the data have been received from participants, the next step was analysis based on the AHP method, as discussed in Section 3. The product, nth product, and priority vector were analyzed to determine overall weight of each factor in that category. In Table 4.3, results of the priority vectors for the factors are shown for travel behavior. To illustrate, the population/housing density of 0.20 represents the influence of population/housing density on the overall category of travel behavior. Which means that the weight of population/housing density is 20% of the overall category of travel behavior. The complete calculation is shown in Appendix D. The most important factor in travel behavior is travel time to office/employment centers, at a weight of 44%. The least important factor in travel Behavior is parking supplies on site, at a weight of 4%.

Table 4.3 Priority vectors for factors in travel behavior

Factors	Priority Vector
Population/housing density	**0.20**
Parking supplies on site	**0.04**
Travel time to offices/employment centers	**0.44**
Number of shuttle and bus services provided from transit station	**0.26**
Access/planned convenience/service retail store	**0.06**
Sum	1.00

The other part of the AHP method is to check for consistency of responses. The consistency ratio, as discussed in Section 3, should be less than 10%. For travel behavior in this implementation, the consistency ratio was 4%.

The second category was built environment, which contains four factors. The pairwise comparison for built environment is shown in Table 4.4. To illustrate, in the first row of Table 4.4, the participant compared Quality and length of walking route to the station (Item A) and quality of bicycle lanes (Item B) in which they judged Item A to be more important by a degree of 3 (where 3 means moderate importance).

Table 4.4 Pairwise comparison for built environment

Item A	Item B	More Important Item	Degree of Importance
Quality and length of walking route to station	Quality of bicycle lanes	A	3
Quality and length of walking route to station	Number of mixed use structures	A	4
Quality and length of walking route to station	Access to/planned green spaces	A	5
Quality of bicycle lanes	Number of mixed use structures	B	2
Quality of bicycle lanes	Access to/planned green spaces	A	4
Number of mixed use structures	Access to/planned green spaces	A	4

In Table 4.5, the results for priority vectors are determined for the built environment category. To illustrate, quality and length of walking route to station has a score of 0.53, which represents the influence of this factor on the overall category of built environment. In other words, the weight of quality and length of walking route to station is 53% in the overall category of built environment. The complete calculation is shown in Appendix E. The most important factor in built environment is quality and length of walking route to station at a weight of 53%. The least significant factor in built environment is access to/planned green spaces at a weight of 6%.

Table 4.5 Priority vectors for factor in built environment

Factors	**Priority Vector**
Quality and length of walking route to station	**0.53**
Quality of bicycle lanes	**0.17**
Number of mixed use structures	**0.22**
Access to/planned green spaces	**0.06**
Sum	1.00

As discussed, the reliability of AHP analysis is informed by the AHP the consistency ratio of the survey. For built environment in this implementation, the consistency ratio came out to be 9%.

The third category was economics, which contains four factors. The pairwise comparison for economics is shown in Table 4.6. To illustrate, in the first row of Table 4.6, the participants compared government interventions regarding incentives or approval process (Item A) and market perception (Item B), in which they judged Item B to be more important by a degree of 4 (where 4 means moderate to strong importance).

Table 4.6 Pairwise comparison for economics

Item A	**Item B**	**More Important Item**	**Degree of Importance**
Government interventions regarding incentives or approval process	Market perception*	B	4
Government interventions regarding incentives or approval process	New property and sales taxes expected	A	1
Government interventions regarding incentives or approval process	Incentive mechanisms offered to private players	A	1
Market perception	New property and sales taxes expected	A	2
Market perception	Incentive mechanisms offered to private players	A	4
New property and sales taxes expected	Incentive mechanisms offered to private players	B	1

*Market Perception = Strong Market perception

In Table 4.7, the results of the factors in priority vector are determined for economics. To illustrate, government interventions regarding incentives or approval process of 0.15 represents the influence of this factor on the overall category of economics. This means that government interventions regarding incentives or approval represent 15% of the overall importance in the category of economics. The complete calculation is shown in Appendix F. The most important factor in economics is market perception at a weight of 51%. The least important factor in economics is government interventions regarding incentives or approval process, and incentive mechanism offered to private players at a weight of 15%.

Table 4.7 Priority vector for factors in economics

Factors	**Priority Vector**
Government interventions regarding incentives or approval process	0.15
Market perception	0.51
New property and sales taxes expected	0.18
Incentive mechanisms offered to private players	0.15
Sum	1.00

The reliability assessment for economics in this evaluation was good, with a, consistency ratio of 2.6%. The fourth category was Social Diversity, which contains five factors. The pairwise comparison of social diversity is shown in Table 4.8. To illustrate, in the first row of Table 4.8, the participants compared planned mixed-income housing (Item A) to community support (Item B), in which they judged Item A to be of importance by a degree of 1 (where 1 means equal importance).

In Table 4.9, the results for the priority vectors are determined for factors in social diversity. To illustrate, planned mixed-income housing of 0.38 represents the influence of this factor on the overall category of social diversity. This means that planned mixed-income housing represents 38% of the importance in the overall category of social diversity. The complete calculation is shown in Appendix G.

Table 4.8 Pairwise comparison for social diversity

Item A	Item B	More Important Item	Degree of Importance
Planned mixed-income housing	Community support	A	1
Planned mixed-income housing	Household disposable income in 0.5 miles radius	A	4
Planned mixed-income housing	Access to/planned cultural/entertainment Centers	A	4
Planned mixed-income housing	Age demographics	A	4
Community support	Household disposable income in 0.5 miles radius	A	2
Community support	Access to/planned cultural/entertainment centers	A	4
Community support	Age demographics	A	2
Household disposable income in 0.5 miles radius	Access to/planned cultural/entertainment Centers	A	2
Household disposable income in 0.5 miles radius	Age demographics	B	2
Access to/planned cultural/entertainment centers	Age demographics	B	3

The most important factor in social diversity is planned mixed-income housing at a weight of 38%. The least important factor in social diversity is Access to/planned cultural/entertainment centers at a weight of 7%.

Table 4.9 Priority vectors for factors in social diversity

Factors	Priority Vector
Planned mixed-income housing	0.38
Community support	0.29
Household disposable income in 0.5 miles radius	0.11
Access to/planned cultural/entertainment centers	0.07
Age demographics	0.16
Sum	1.00

The reliability of the data for social diversity in this implementation is good, with a consistency ratio of be 3.8%.

The last pairwise comparison is made between categories to understand which is more important than the others. The pairwise comparison of categories is shown in Table 4.10. To illustrate, in the first row of Table 4.10, the participants compared travel behavior (Item A) and built environment (Item B) where they assigned Item B to be more important by a degree of 4 (where 4 means moderate to strong importance).

In Table 4.11, the results for the priority vectors of the categories are determined. To illustrate, travel behavior of 0.15 represents the influence of this factor on the overall evaluation of alternatives. In simple language, the category of travel behavior represents 15% of the overall weight in the ultimate decision between alternative sites. The complete calculation is attached in the Appendix H.

Table 4.10 Pairwise comparison for each category

Item A	**Item B**	**More Important Item**	**Degree of Importance**
Travel behavior	Built environment	B	4
Travel behavior	Economics	A	2
Travel behavior	Quality/Social Diversity	B	2
Built environment	Economics	A	2
Built environment	Quality/Social Diversity	A	3
Economics	Quality/Social Diversity	B	2

The most important category is built environment, with a weight of 15%. The least important category is quality/social diversity, with a weightage of 13% for RTD implementation.

The reliability of data analysis at the categorical level is acceptable with a consistency ratio of 8.8%.

Table 4.11 Priority vectors for categories

Categories	**Priority Vector**
Travel Behavior	0.15
Built Environment	0.48
Economics	0.13
Quality/Social Diversity	0.23
Sum	1.00

The global vector for each factor can be calculated by multiplying the priority vector for that factor by the priority vector for that category. For example, global vector for “Planned mixed-income housing” can be calculated by multiplying 0.38 (priority vector for planned mixed-income housing) by 0.23 (priority vector for quality/social diversity), which is equal to 0.087. Global vectors for each factor, under the category heading, are shown in Table 4.12.

Table 4.12 Global vector for each factor

Factors	Local Vector	Category Weighting	Global Vector
Travel Behavior			
Population/housing density	**0.20**	0.15	0.03
Parking supplies on site	**0.04**	0.15	0.006
Travel time to offices/employment centers	**0.44**	0.15	0.066
Number of shuttle and bus services provided from transit station	**0.26**	0.15	0.039
Access/planned convenience/service retail store	**0.06**	0.15	0.009
Built Environment			
Quality and Length of walking route to station	**0.53**	0.48	0.2544
Quality of bicycle lanes	**0.17**	0.48	0.0816
Number of mixed-use structure	**0.22**	0.48	0.1056
Access to/planned green spaces	**0.06**	0.48	0.0288
Economics			
Government interventions regarding incentives or approval process	**0.15**	0.13	0.0195
Market perception	**0.51**	0.13	0.0663
New property and sales taxes expected	**0.18**	0.13	0.0234
Incentive mechanisms offered to private players	**0.15**	0.13	0.0195
Quality/Social Diversity			
Planned mixed-income housing	**0.38**	0.23	0.0874
Community Support	**0.29**	0.23	0.0667
Household disposable income in 0.5 miles radius	**0.11**	0.23	0.0253
Access to/planned cultural/entertainment centers	**0.07**	0.23	0.0161
Age demographics	**0.16**	0.23	0.0368
Sum			1

The final step of this implementation would be to conduct pairwise comparisons for each category and factor for actual TOD site alternatives using site parameter estimates of each category. Due to availability constraints at the time of this research, analysis of actual alternatives was not conducted, as discussed at the end of this section.

4.2 Roaring Fork Transportation Authority (RFTA) Implementation

Phase I of the research plan was identical for RFTA to that of RTD described above. The final factor list for RFTA is shown in Table 4.13.

Table 4.13 Final list of factors for RFTA implementation

SR. No.	Factor Name	Selected (Yes/No)
1	Population/housing density	Yes
2	Amount of underutilized properties	No
3	Parking supplies on site	Yes
4	Household disposable income in 0.5 miles	No
5	Incentive mechanisms offered to Private players	Yes
6	Market perception	Yes
7	Planned mixed-income housing units	Yes
8	Quality of bicycle lanes	Yes
9	Access/planned convenience/service retail store	Yes
10	New property and sales taxes expected	Yes
11	Access/planned cultural/artistic institutions/entertaining centers	No
12	Planned/access to improved parking areas	No
13	Government interventions regarding incentives or approval process	Yes
14	Community support	Yes
15	Number of mixed-use structures	Yes
16	Access to/planned green spaces	Yes
18	Quality and length of walking route to station	Yes
19	Number of shuttle and bus services proved from transit station	Yes

Based on RFTA criteria, the most important factors of success for a TOD project are quality of walking route to the station, population/housing density, quality of bicycle lanes, number of shuttle and bus services from transit station, and the number of mixed-use structures. The participant saw a clear linkage between safety and quality of the walking route to/from the transit station, without which people are inclined to use private automobiles more often. Similar observations were also highlighted for safe bicycle lanes. In addition, the need for a frequent, reliable, and efficient transit system that goes where people need to go is one of the most important factors for the success of RFTA TOD project. Last, the right mix of commercial, residential, civil, and other spaces is also critical to the success of a TOD project in the RFTA.

The next discussion was based on whether the number of underutilized properties should be a success factor for TOD projects. The participant saw no clear link between brownfield/underutilized properties and success of a TOD project for the RFTA.

Whether the incentives and public/private investment ratio should be a factor for success for TOD projects was the subject of the next discussion. The region suffers from a dearth of affordable housing, which can be remedied by private investment. Some infrastructure requirements, such as street, transit, walking, and bicycling infrastructure, etc., can also be completed by a private partnership with some incentives. For these reasons, market perception was added to the final list of factors for RFTA implementation.

The next discussion was about the perception of TOD projects and their impact on the success of such projects. Similar to the RTD implementation, it might not be as significant a factor if people have a generally positive outlook. However, this might become one of the most important factors, if the local community is opposed to the project. The safety and quality should not be compromised in a TOD project at any cost. For these reasons, public perception/community support was added to the final list of factors for RFTA implementation.

The last discussion was about some of the factors that were not included in the list, such as Household disposable income within a half-mile radius, and cultural/artistic institutions. The participant stated that the land-constrained regions must build communities for average-salaried American families. The higher cost of housing and other living expenses inhibit high disposable income, but do not inhibit the success of TOD. On the other factor of cultural institutions, the participant believes that, even though they are important, they are not the highest priority.

The next step in implementing the framework was to conduct a survey developed and based on principles of AHP MCDM method. The survey instrument was sent to the same participant in RFTA to maintain consistency of results. The factors were distributed in four categories to make pairwise comparisons easier for the participant. This proved beneficial, since it resulted in a consistency ratio of less than 10% for each category analysis, except one.

The following is the list of categories with their factors:

1. Travel Behavior
    a. Population/housing density
    b. Parking supplies on site
    c. Number of shuttle and bus services provided from transit station
    d. Access/planned convenience/service retail store
2. Built Environment
    a. Quality and length of walking route to station
    b. Quality of bicycle lanes
    c. Number of mixed-use structures
    d. Access to/planned green spaces
3. Economics
    a. Government interventions
    b. Market perception
    c. New property and sales taxes expected
    d. Incentive mechanisms offered to private players
4. Social Diversity
    a. Planned mixed-income housing (different from mixed-use structures)
    b. Community support

These categories are consistent with those used by Renne & Wells (2005) to determine a strategy for measuring the success of a TOD project. The pairwise comparisons were done within each category first and then between categories.

The first category was travel behavior, which had four factors. The participants were asked to compare one factor with another to identify which one was more important and its magnitude. The pairwise comparison of travel behavior is shown in Table 4.14. To illustrate, in the first row of Table 4.14, the participant compared number of shuttle and bus services provided from transit stations (Item A) and parking supplies on site (Item B) and judged Item A to be more important by a degree of 7, where 7 means very strong importance.

Table 4.14 Pairwise comparison for travel behavior

Item A	Item B	More Important Item	Degree of Importance
Number of shuttle and bus services provided from transit station	Parking supplies on site	A	7
Number of shuttle and bus services provided from transit station	Population/housing density	A	2
Number of shuttle and bus services provided from transit station	Planned convenience/service retail near station	A	2
Parking supplies on site	Population/housing density	B	7
Parking supplies on site	Planned convenience/service retail near station	B	7
Population/housing density	Planned convenience/service retail near station	A	3

After receiving data from the participant, the next step was analysis based on the AHP method discussed in Section 3. The product, nth product, and priority vector were analyzed to determine the overall weight of each factor in each category. In Table 4.15, the results of the priority vectors for the factors are determined for travel behavior. To illustrate, the priority vector for number of shuttle and bus services provided from transit stations is 0.43, which represents the influence of number of shuttle and bus services offered from transit stations within the overall category of travel behavior. In simple language, the weight of number of shuttle and bus services offered from transit stations represents 43% of the importance in the overall category of travel behavior. The complete calculation is attached in the Appendix I. The most important factor in travel behavior is number of shuttle and bus services provided from transit stations at a weight of 43%. The least significant factor in travel behavior is parking supplies on site at a weight of 4%.

Table 4.15 Priority vectors for factor in travel behavior

Factors	Priority Vector
Number of shuttle and bus services provided from transit station	0.43
Parking supplies on site	0.04
Population/housing density	0.34
Planned convenience service retail near station	0.19
Sum	1.00

The other part of the AHP method is to check consistency of our survey. The consistency ratio, as discussed in Section 3, should be less than 10%. For travel behavior in this implementation, the consistency ratio came out to be 8.3%.

The second category was built environment, which contains four factors. The pairwise comparison for built environment is shown in Table 4.16. To illustrate, in the first row of Table 4.16, the participant compared quality and length of walking route to the station (Item A) with quality of bicycle lanes (Item B) and judged Item A to be more important by a degree of 5 (where 5 means strong importance).

Table 4.16 Pairwise comparison for built environment

Item A	Item B	More Important Item	Degree of Importance
Quality and length of walking route to station	Quality of bicycle lanes	A	5
Quality and length of walking route to station	Number of mixed use structures	A	4
Quality and length of walking route to station	Access to/planned green spaces	A	5
Quality of bicycle lanes	Number of mixed use structures	A	2
Quality of bicycle lanes	Access to/planned green spaces	A	5
Number of mixed-use structure	Access to/planned green spaces	A	5

In Table 4.17, the priority vectors for the factors are determined for built environment. To illustrate, quality and length of walking route to station's rating of 0.57 represents the influence of this factor on the overall category of built environment. This means that the weight of quality and length of walking route to station represents 57% of the total importance in the overall category of built environment. The complete calculation is attached in the Appendix J. The most important factor in built environment is quality and length of walking route to station, with a weight of 57%. The least significant factor in built environment is access to/planned green spaces, with a weight of 5%.

Table 4.17 Priority vectors for factor in built environment

Factors	Priority Vector
Quality and length of walking route to station	0.57
Quality of bicycle lanes	0.21
Number of mixed use structures	0.16
Access to/planned green spaces	0.05
Sum	1

The reliability of the AHP method is checked by examining the consistency of the survey. For built environment in this implementation, the consistency ratio came out to be 14%, which is higher than 10%. The reliability of factor weights within this category may not be stable over repeated measures.

The third category was economics, which contains four factors. The pairwise comparison for economics is shown in Table 4.18. To illustrate, in the first row of Table 4.18, the participant compared government interventions regarding incentives or approval process (Item A) to market perception (Item B) and judged Item B to be more important, but only by a degree of 1, which means equal importance between the two factors.

Table 4.18 Pairwise comparison for economics

Item A	Item B	More Important Item	Degree of Importance
Government interventions regarding incentives or approval process	Market perception	A	1
Government interventions regarding incentives or approval process	New property and sales taxes expected	A	3
Government interventions regarding incentives or approval process	Incentive mechanisms offered to private players	A	1
Market perception	New property and sales taxes expected	A	3
Market perception	Incentive mechanisms offered to private players	A	3
New property and sales taxes expected	Incentive mechanisms offered to private players	B	3

In Table 4.19, the results of the priority vectors are determined for factors in Economics. To illustrate, government interventions regarding incentives or approval process at 0.29 represents the influence of this factor on the overall category of economics. This means that government interventions regarding incentives or approval process ranks at 29% of the overall category of economics. The complete calculation is shown in Appendix K. The most important factor in economics is the strong market perception, with a weight of 39%. The least important factor in economics is new property and sales tax expected, with a weight of 10%.

Table 4.19 Priority vectors for factors in economics

Factors	Priority Vector
Government interventions regarding incentives or approval process	0.29
Market perception	0.39
New property and sales taxes expected	0.10
Incentive mechanisms offered to private players	0.22
Sum	1.00

The reliability of the AHP method is evaluated by checking the consistency of our survey. For economics in this implementation, the consistency ratio came out to be 6.4%.

The fourth category was social diversity, which contains two factors. The pairwise comparison of social diversity is shown in Table 4.20. To illustrate, in the first row of Table 4.20, the participant compared planned mixed-income housing (Item A) and community support (Item B) and judged Item B to be more important by a degree of 2 where 2 means slightly more significant.

In Table 4.21, the results of priority vectors are shown for factors in the social diversity category. To illustrate, planned mixed-income housing priority vector of 0.33 represents the influence of this factor on the overall category of social diversity. This means that planned mixed-income housing represents 33% of the importance within the overall category of social diversity. The complete calculation is shown in Appendix L.

Table 4.20 Pairwise comparison for social diversity

Item A	Item B	More Important Item	Degree of Importance
Planned mixed-income housing (including subsidized housing)	Community support/public perception	B	2

The most important factor in social diversity is community support/public perception, with a weight of 67%. The least significant factor in social diversity is planned mixed-income housing, with a weight of 33%.

Table 4.21 Priority vectors for factors in social civersity

Factors	Priority Vector
Planned mixed-income housing (including subsidized housing)	0.33
Community support/public perception	0.67

The last pairwise comparison is made between categories to understand the rank and relative importance of each category. The pairwise comparison of categories is shown in Table 4.22. To illustrate, in the first row of Table 4.22, the participant compared travel behavior (Item A) and built environment (Item B) and judged Item A to be more important by a degree of 2, where 2 means slightly more important.

Table 4.22 Pairwise comparison of categories

Item A	Item B	More Important Item	Degree of Importance
Travel Behavior	Built Environment	A	2
Travel Behavior	Economics	A	3
Travel Behavior	Quality/Social Diversity	A	2
Built Environment	Economics	A	3
Built Environment	Quality/Social Diversity	A	2
Economics	Quality/Social Diversity	A	1

Table 4.23 shows the priority vectors for the categories. As an example, travel behavior's rating of 0.42 represents the influence of this factor on the overall decision framework. In simple language, travel behavior is 42% of the overall weight in deciding between alternatives. The complete calculation is shown in Appendix M.

Table 4.23 Priority vectors for categories

Categories	**Priority Vector**
Travel behavior	0.42
Built environment	0.29
Economics	0.13
Quality/Social Diversity	0.16
Sum	1.00

The most important category is travel behavior, with a weight of 42%. The least important category is economics, with a weight of 13% for RFTA implementation.

The reliability of the AHP method is checked by analyzing the consistency of the survey. For categories in this implementation, the consistency ratio came out to be 3.3%.

The global vector for each factor can be calculated by multiplying the priority vector for that factor by the priority vector for that category. For example, global vector for planned mixed-income housing can be calculated by multiplying 0.33 (priority vector for planned mixed-income housing) by 0.16 (priority vector for quality/social diversity), which is equal to 0.05. Global vectors for RFTA are shown in Table 4.24.

Table 4.24 Global vector for each factor

Factors	Local Vector	Category Weighting	Global Vector
Travel Behavior			
Number of shuttle and bus services provided from transit station	**0.43**	0.42	0.18
Parking supplies on site	**0.04**	0.42	0.017
Population/housing density	**0.34**	0.42	0.143
Planned convenience/service retail near station	**0.19**	0.42	0.08
Built Environment			
Quality and length of walking route to station	**0.57**	0.29	0.1711
Quality of bicycle lanes	**0.21**	0.29	0.0609
Number of mixed-use structures	**0.16**	0.29	0.0464
Access to/planned green spaces	**0.05**	0.29	0.015
Economics			
Government interventions regarding incentives or approval process	**0.29**	0.13	0.038
Market perception	**0.39**	0.13	0.051
New property and sales taxes expected	**0.10**	0.13	0.013
Incentive mechanisms offered to private players	**0.22**	0.13	0.029
Quality/Social Diversity			
Planned mixed-income housing (including subsidized housing)	**0.33**	0.16	0.0528
Community support/public perception	**0.67**	0.16	0.1072
Sum			1

4.3 Final Step: Implementing AHP Decision Support on an Actual Project

The final step of AHP method is evaluating a set of alternatives based on the weights determined in the previous step. To illustrate an example, assume there two potential TOD sites to compare in terms of travel behavior, built environment, economics, and quality/social diversity. Table 4.25 lists relevant characteristics for each of the TOD sites:

Table 4.25 Travel behavior factors

TOD Sites **Factors**	**Site 1**	**Site 2**
Number of shuttle and bus services provided from transit station	10/hour	12/hour
Parking supplies on site	150	70
Population/housing density	5 residential units/acre	30 residential units/acre
Planned convenience/service retail near station	Yes	Yes

The hypothetical implementation of this framework will take the example of travel behavior factors to identify pairwise comparisons using the AHP method. Assume that a transit agency has decided to construct a TOD and is trying to decide between two available sites. In terms of factors, the agency has decided that shuttle and bus services provided from transit station should be more than five/hour, as identified from a sample survey of local people. The agency decision-makers also decided that parking supplies of over 125 is good enough for the region. For population/housing density, the decision-makers decided that anything over 25 residential units/acre is an industry standard for a TOD. Last, there must be planned convenience/service retail facilities near the station. To add more complexity to the model, the transit agency came to the conclusion that an increase in number of shuttles and bus services by two/hour is strongly preferred and a five/hour or more is extremely preferred. Similarly, with parking supplies, the transit agency decided that 30 more parking supplies on site is strongly preferred and 70 more parking supplies on site is extremely preferred. Last, population/housing density of more than 10 residential units/acre is going to make the site strongly preferable and more than 20 residential units/acres is going to make the TOD extremely preferred. Table 4.26 presents the hypothetical pairwise comparisons for number of shuttles and bus services for each site.

Table 4.26 A pairwise comparison for number of shuttles and bus services for each site

A	B	Number of shuttle and bus services provided from transit station (A)	Number of shuttle and bus services provided from transit station (A)	Over/Under Requirement (A)	Over/Under Requirement (B)	Better Site	Intensity	Reason
Site 1	Site 2	10/hr.	12/hr.	5/hr.	7/hr.	B	7	B is having a greater number of shuttle and bus services provided from transit station

The final calculation on the pairwise comparison for different site alternatives based on number of shuttle and bus services provided from transit station is shown in Table 4.27. These are the local priorities for the individual factor.

Table 4.27 Pairwise comparison for sites based on number of shuttle and bus services

Choices/Sites	**Site 1**	**Site 2**	**Product**	**nth product**	**Priority Vector**
Site 1	1.00	0.14	0.14	0.38	0.125
Site 2	7.00	1.00	7.00	2.65	0.875

To determine the global vector for each site, the priority vector for each site is multiplied by the individual weighting of the factor number of shuttle and bus services provided from transit station. Assume the analysis was conducted in a transit agency with similar preferences to RFTA, which had a global weight of 0.18 Number of shuttle and bus services provided from transit station. Table 4.28 shows the global vectors for each site.

Table 4.28 Choices of site with local and global vectors

Choices	Local Vector	Global Weighting	Global Vector
Site 1	0.125	0.18	0.0225
Site 2	0.875	0.18	0.1575
Sum	1	-	0.18

The pairwise comparisons for each individual factor will be repeated as shown above to determine global vectors/priority for each factor at each site. Then all the global vectors for each site can be added to determine the choice which is closest to the goals identified by the transit agency. The higher the global vector, the closer it is to being the ideal fit for the agency.

The final step is not part of the implementation for this research, as neither agency had actual project sites under consideration for TOD development.

5. CONCLUSION AND AREAS OF FUTURE RESEARCH

5.1 Conclusion

The goal of this research was to develop a framework for transit agencies to use when choosing a TOD site. The framework can assist decision-makers in making better, more structured decisions. The first stage of our research was to conduct a thorough literature review to understand dynamics of public transportation, travel behaviors leading to frequent use of public transportation, concepts of TOD, outcomes of successful TODs, and factors affecting those outcomes. Specific research questions that were addressed were:

- How can the initial list of factors for the success of a TOD be determined?
- What process can be used by individual transit agencies to vet those factors once an initial list of factors is identified?
- How can the weights of those factors be determined?

The first question was addressed through literature review to determine the initial list of factors of success for a TOD project. The literature review was conducted to understand various definitions of TOD, outcomes from successful TODs, and factors of success in achieving those outcomes. The literature review was also an effort to understand the concept of urban sprawl, which has contributed to the growth in TOD. In the literature review, three case studies were investigated to understand the relationship between individual factors and outcomes of those factors on the categories. Based on this literature, an initial list of factors was identified to be used in the next part of the research.

The second question was answered through qualitative data as part of mixed-method research model. The goal of this qualitative study was to create a short list from among the initial factors identified in the literature, based on input from the interviewees. Interviews were conducted either by phone or in person.

The last question was answered by the quantitative part of this research. This was done by implementing analytic hierarchy process (AHP) which is a multi-criteria decision-making (MCDM) method. In this research, several other MCDM methods were considered, but it was eventually decided to follow AHP because of its past success in similar research. A survey instrument was sent to transit agencies for pairwise comparisons between each factor and between categories. Almost all the AHP weights met the consistency threshold of 0.10, resulting in reliable factor and category weights to answer the research question satisfactorily.

5.1.1 Implementation Examples

The framework was implemented for two transit agencies: Regional Transportation District (RTD), Denver, Colorado, and Roaring Fork Transportation Authority (RFTA), Aspen, Colorado. The objective was to determine factors of success for each transit agency and then determine weights of each factor individually. The implementation of the framework is described briefly below, for each transit agency:

Step 1: A thorough literature review was conducted to determine the factors of success for a TOD project. There was initial list of factors that were identified from the literature review.

Step 2: Once the initial list of factors was established, interviews were conducted with each transit agency to vet those factors and to include new ones determined important for consideration. Also, some factors were renamed and combined to give more clarity to the list of factors. In this implementation stage, RTD eliminated two factors from the initial list, but also included two new factors, bringing the number of total factors to 21. After further discussion, some factors were merged, resulting in a final list of 18 factors. Similarly, RFTA eliminated three factors from the initial list of factors, bringing the total number of factors to 18. Some other factors were renamed and merged to bring the final list down to 14 factors.

Step 3: Based on the final list of factors determined from Step 2, an AHP survey was sent to representatives of both transit agencies to calculate weights for each factor. After individual pairwise comparison for each factor in the category, pairwise comparison was conducted for each category to also calculate weights for each category. Last, global weights were calculated by multiplying individual factor weights (local vector) with category weighs. The sum of these global weights is equal to 1.

Step 4: The final step of the AHP decision support process would be to implement the framework on an actual project. This step exceeded the scope of this research and is recommended for inclusion as part of a future research project. The process used to measure individual weights has been shown in Section 4 to illustrate an example of how AHP decision support could be implemented.

5.2 Findings

Comparison between various factors in different categories is shown in the following tables. Table 5.1 shows the comparison between factors of travel behavior for RTD and RFTA. Travel behavior is the most important category for RFTA, Aspen, and contains two out of the three top factors of the entire study. For RTD, the most important factor was travel time to offices/employment centers.

Table 5.1 Global weightage for travel behavior

Agency/Factors	**RTD**			**RFTA**		
	Local Vector	**Category Weight**	**Global Vector**	**Local Vector**	**Category Weight**	**Global Vector**
Number of shuttle and bus services provided from transit station	0.26	0.15	0.039	0.43	0.42	0.18
Parking supplies on site	0.04	0.15	0.006	0.04	0.42	0.017
Population/housing density	0.2	0.15	0.03	0.34	0.42	0.143
Planned convenience/service retail near station	0.06	0.15	0.009	0.19	0.42	0.08
Travel time to offices/employment centers	0.44	0.15	0.066	NA	NA	NA

Table 5.2 shows the comparison between factors of built environment for RTD and RFTA. Built environment is the most important category for RTD, Denver, and contains two out of the three top factors of the entire study. This is similar to travel behavior, which was most important category for

RFTA, and also contained the same number of top factors. On the other hand, RFTA also contains one of the three top factors, which is quality and length of walking route to station. In comparison, RTD and RFTA share the same importance for the top factor for built environment.

Table 5.2 Global Weightage for Built Environment

Agency/Factors	**RTD**			**RFTA**		
	Local Vector	**Category Weight**	**Global Vector**	**Local Vector**	**Category Weight**	**Global Vector**
Quality and length of walking route to station	**0.53**	0.48	0.2544	**0.57**	0.29	0.171
Quality of bicycle lanes	**0.17**	0.48	0.0816	**0.21**	0.29	0.061
Number of mixed-use structures	**0.22**	0.48	0.1056	**0.16**	0.29	0.046
Access to/planned green spaces	**0.06**	0.48	0.0288	**0.05**	0.29	0.015

Table 5.3 shows the comparison between factors of economics for RTD and RFTA. Economics have the exact same global weight for both RTD, Denver, and RFTA, Aspen. Also, the top factor for economics is market perception, which is the same for both RTD and RFTA.

Table 5.3 Global Weightage for Economics

Agency/Factors	**RTD**			**RFTA**		
	Local Vector	**Category Weight**	**Global Vector**	**Local Vector**	**Category Weight**	**Global Vector**
Government interventions regarding incentives or approval process	**0.15**	0.13	0.0195	**0.29**	0.13	0.038
Market perception	**0.51**	0.13	0.0663	**0.39**	0.13	0.051
New property and sales taxes expected	**0.18**	0.13	0.0234	**0.1**	0.13	0.013
Incentive mechanisms offered to private players	**0.15**	0.13	0.0195	**0.22**	0.13	0.029

Table 5.4 shows the comparison between factors of quality/social diversity for RTD and RFTA. Quality/social diversity is more important for RTD, Denver, than RFTA, Aspen. RTD, Denver, contains five factors, which is three more than RFTA, Aspen to show the level of interest in quality/social diversity for Denver. Even though there are many differences in this category, the two factors in the category remains the same for both transit agencies. Planned mixed-incomes housing and community supports are the two top factors for quality/social diversity.

Table 5.4 Global Weightage for Quality/social diversity

Agency/Factors	RTD			RFTA		
	Local Vector	**Category Weight**	**Global Vector**	**Local Vector**	**Category Weight**	**Global Vector**
Planned mixed-income housing	0.38	0.23	0.0874	0.33	0.16	0.053
Community Support	0.29	0.23	0.0667	0.67	0.16	0.107
Household disposable income in 0.5 miles radius	0.11	0.23	0.0253	NA	NA	NA
Access to/planned cultural/entertainment centers	0.07	0.23	0.0161	NA	NA	NA
Age demographics	0.16	0.23	0.0368	NA	NA	NA

The top three factors for both transit agencies can lend insight into some important conclusions of this study. For RFTA, Number of shuttle and bus services provided from transit station, quality and length of walking route to station, and population/housing density are the three most important factors. For RTD, quality and length of walking route to station, number of mixed use structures, and planned mixed-income housing are the three most important factors.

When category weights between Denver and Aspen are compared, it can be concluded that travel behavior is an important factor for Aspen, with an approximate weight of 42%. Results from Denver indicate that the built environment is as important for the city as travel behavior is for Aspen. Surprisingly, both transit agencies showed equal weights for economics. In line with expectations, Quality/social diversity is a little more important category for Denver than for Aspen. Quality/social diversity includes factors such as mixed income and community support, which, to some extent, are more important for Denver, with its more diverse population, than for a small ski town like Aspen.

5.3 Limitations

One of the limitations of this research is that only one member from RFTA, Aspen, was involved and the RFTA interview was conducted over the phone, which could have limited the discussion and exchange of ideas to some extent. The research tried to address those concerns by receiving written comments from the RFTA participant to check any incorrect inferences from the phone interview transcripts.

One of the greatest limitations of this study is that only transit agency personnel were involved in surveys and framework implementation. It was also decided that only the personnel dealing with TOD would be part of this study. Last, the framework was not implemented on an actual project because there were no active TOD site evaluations underway at the time of the research. Implementation on an actual project could bring out some problems not been considered in this study.

5.4 Future Research

The implementation of this framework to choose a viable TOD site is a logical step towards rigorous decision-making. The framework can be diversified by the inclusion of more factors in each category to get more accurate results.

Another possible future research project may be to compare weights by using different MCDM methods, such as improved AHP (IAHP), PROMETHEE, and PROMETHEE-2. It would be interesting to study the differences between MCDM methods and vet those weights to understand the need for transit agencies in respect to each MCDM method.

Another project that could be conducted by future researchers is to add more projects to the framework to generalize the results for big cities and smaller towns. There has not been much focus on comparing cities and smaller towns for TOD implementations. It will also be beneficial to understand anomalies between different big cities regarding how they calculate the success of a TOD project.

Overall, TOD is an important issue that is likely to be the topic of many more research projects in the future. With many developing countries such as India and China showing interest in the implementation of TOD projects, the shape and definitions of TOD projects will keep changing, depending on who is talking about it. With so many favorable circumstances driving people closer to public transportation, TOD will play a significant role in the field of transportation research for many years to come.

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APPENDIX A

Which of the following factors result in success of transit-oriented development project which should be included in the framework? (check mark as many you think are necessary)

Factor	Yes/No	Reason
Quality of Walking Route to Station		
Population/Housing Density		
Number of bicycle lanes		
Number of shuttle and bus services provided from transit station		
resident in 1 mile radius/planned traveler ratio		
Population/Housing Density		
Number of Mixed-use structure		
Amount of Brownfield properties		
Length of Improved streetscape planned.		
Quality of bicycle lanes		
Planned subsidized housing units		
Public to Private investment ratio		
Number of convenience/service retail planned		
Planned new/improved cultural/artistic institutions		
Household disposable income in 0.5 mile radius		
Public Perception		
Parking supplies on site		
Number of new or improved park areas		
New property taxes expected		

APPENDIX B: INTRODUCTORY EMAIL

Dear Mr. Johnson,

Now that we have received the official approval from the Colorado State University to conduct our study, I wanted to reach out and ask for your help. As we discussed earlier, Dr. Kelly Stong and Dr. Mehmet Ozbek, along with me, are working on a project funded by the Mountain-Plains Consortium which is a competitively selected university program sponsored by the U.S. Department of Transportation through its Research and Innovative Technology Administration. We are trying to create a framework to assess the feasibility of Transit Oriented Development (TOD) projects. As a part of our research, we would like to conduct an interview within you and other TOD experts in RFTA to determine factors of success for a transit oriented development project. We already have identified 21 factors based on literature review and case studies; and we would like to vet those by the RFTA participants and potentially identify other factors that we might have missed based on RFTA's opinions. As participants are required to make decisions on factors of success for a TOD project, it is important that participants have previously worked on TOD projects and/or have some research experience on such projects in RTD.

Within this context, we wanted to reach out to you and ask for a **1-hour long phone meeting.** We would also appreciate if you could let us know if you feel that there are other people at RFTA who we should invite to this meeting.

We have identified the following three days/times that work for us:

1) Monday, 11/16/15 – Any one-hour block starting at 2:00 pm and ending at 4:00 pm
2) Wednesday, 11/18/15 – Any one-hour block after 2:30 pm.
3) Friday, 11/20/15 – Any one-hour block starting at 9:00 am and ending at 1:00 pm

If the above dates don't work for you please get back to us with alternative dates/times for early December. Also, please provide the phone number that we could reach you.

Attached is the official invitation letter and the consent form providing more information about the study.

Many thanks for your consideration.

Warm Regards,

Avi Sharma,

Graduate Student

APPENDIX C

Consent to Participate in a Research Study
Colorado State University

TITLE OF STUDY: *Development of a Framework to Assess the Feasibility of Transit-Oriented Development (TOD) Project*

PRINCIPAL INVESTIGATOR: *Dr. Mehmet E. Ozbek, Ph.D., Construction Management, Mehmet.ozbek@colostate.edu*

CO-PRINCIPAL INVESTIGATOR: *Avi Sharma, Master's Student, Construction Management, Avi.Sharma@colostate.edu*

WHY AM I BEING INVITED TO TAKE PART IN THIS RESEARCH? *This study is going to develop a framework for conducting feasibility analysis of a transit-oriented development project. Your experience in the field of transit-oriented development and transit agency will benefit the study to get practical views and comments.*

WHO IS DOING THE STUDY? *This study is being conducted in the Construction Management Department at Colorado State University. This study is being supported by Mountain-Plain Consortium which is funded by US Department of Transportation.*

WHAT IS THE PURPOSE OF THIS STUDY? *There are two major objectives of this study: a. Identify and weigh the parameters that result in the success of a transit-oriented project. b. Develop a macros based decision tool which can be used by decision makers.*

WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST? *You will be a part of one-on-one interview (1 hour), complete a survey which will be on electronic media using MS excel (1 hour), and may be asked for a follow-up interview to clarify your comments (1 hour). Total time commitment for participant will be at maximum 3 hours. This includes time for interviews, survey and any follow up in the future. Both the interview and survey can be completed by the participant in her/his office or location that is convenient for you.*

WHAT WILL I BE ASKED TO DO? *You will be asked about factors of success for a transit-oriented development project in the one-on-one interview in which you will have to choose which factors are important and which are not. You will have an initial list of factors of success for a transit-oriented development project based on the literature review conducted by the researcher. You will rate each of the factor on 0-2 Likert scale on how important is that factor for the success of a TOD project. In the survey, you will be asked to describe the relationship between one factor to another on a scale and which one is important than the other. You will be provided with an excel sheet to make this comparison that will be sent through email. You will have to complete the survey and send back that excel sheet to the researcher.*

ARE THERE REASONS WHY I SHOULD NOT TAKE PART IN THIS STUDY? *You should only participate in this research if you have experience in the field of transit-oriented development.*

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?
It is not possible to identify all potential risks in research procedures, but the researcher(s) have taken reasonable safeguards to minimize any known and potential, but unknown, risks.

ARE THERE ANY BENEFITS FROM TAKING PART IN THIS STUDY? *While there is no direct benefit to you, the end result of this study will be a framework for analyzing the feasibility of transit-oriented development proposed sites. Any transit agency in the country can use this framework and software for their own feasibility study.*

CSU#: 15-6134H
APPROVED: 11/5/2015 * EXPIRES: 10/12/2016

DO I HAVE TO TAKE PART IN THE STUDY? *Your participation in this research is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participating at any time without penalty or loss of benefits to which you are otherwise entitled.*

WHO WILL SEE THE INFORMATION THAT I GIVE? The researcher will take notes on the one-on-one interviews with the participant's permission and the surveys will be on electronic media using MS Excel. The researcher will securely store the taken notes as well as the electronic files in Dr. Mehmet Ozbek's office at Colorado State University during and following the study.

For this study, we will assign a code to your data (example: MPC-485/1) so that the only place your name will appear in our records is on the consent and in our data spreadsheet which links you to your code. Only the principal investigator (Dr. Mehmet Ozbek) will have access to the link between you, your code, and your data. The only exceptions to this are if we are asked to share the research files for audit purposes with the CSU Institutional Review Board ethics committee, if necessary. When we write about the study to share with other researchers, we will write about the combined information we have gathered. You will not be identified in these written materials unless you give us permission. We may publish the results of this study; however, we will keep your name and other identifying information private unless you give us permission.

WHAT ELSE DO I NEED TO KNOW?
Use of Direct Quotes:
Please let us know if you would like your comments to remain confidential or attributed to you. Please initial next to your choice below.

- ☐ I give permission for comments I have made to be shared using my exact words and to include my (name/position/title). ______ (initials)
- ☐ You can use my data for research and publishing, but do NOT associate my (name/position/title) with direct quotes. ______ (initials)

Please initial by each research activity listed below that you are volunteering to participate in.

___ *One-on-one Interview* ____*Survey* _____*Follow-up*

WHAT IF I HAVE QUESTIONS? Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions about the study, you can contact the investigator, Dr. Mehmet E. Ozbek at Mehmet.Ozbek@colostate.edu 970-491-4101. If you have any questions about your rights as a volunteer in this research, contact the CSU IRB at: RICRO_IRB@mail.colostate.edu; 970-491-1553. We will give you a copy of this consent form to take with you.
Your signature acknowledges that you have read the information stated and willingly sign this consent form. Your signature also acknowledges that you have received, on the date signed, a copy of this document containing 2 pages.

_______________________________________ _________________
Signature of person agreeing to take part in the study Date

____
Printed name of person agreeing to take part in the study

_______________________________________ _________________
Name of person providing information to participant Date

____
Signature of Research Staff

CSU#: 15-6134H
APPROVED: 11/5/2015 * EXPIRES: 10/12/2016

APPENDIX D

CALCULATION OF TRAVEL BEHAVIOR FOR REGIONAL TRANSPORTATION DISTRICT (RTD)

Travel Behavior								
Total Factors	5							
	Population/Housing density	Parking supplies on site	Travel time to offices/employment centers	Number of shuttle and bus services provided from transit station	Access/planned convenience/service retail store	Product	nth product	Priority Vector
Population/Housing density	1	7	0.333333333	0.5	5	5.833333333	1.422929	0.201056
Parking supplies on site	0.142857143	1	0.142857143	0.2	0.5	0.002040816	0.289708	0.040935
Travel time to offices/employment centers	3	7	1	2	7	294	3.116517	0.440356
Number of shuttle and bus services provided from transit station	2	5	0.5	1	4	20	1.820564	0.257241
Access/planned convenience/service retail store	0.2	2	0.142857143	0.25	1	0.014285714	0.427544	0.060411
Sum	6.342857143	22	2.119047619	3.95	17.5		7.077262	1
Sum*PV	1.275272533	0.900571464	0.933135902	1.016103182	1.05719027		5.182273	
Lambda Max	5.182273352							
CI	0.045568338							
RI	1.12							
CR	0.040686016	ok, <0.10						

APPENDIX E

CALCULATION OF BUILT ENVIRONMENT FOR REGIONAL TRANSPORTATION DISTRICT (RTD)

Built Environment							
Total Factors	4						
	Quality & Length of walking route to station	Quality of bicycle lanes	Number of Mixed Use structure	Access to/Planned green spaces	Product	nth product	Priority Vector
Quality & Length of walking route to station	1	3	4	5	60	2.783157684	0.534161
Quality of bicycle lanes	0.333333333	1	0.5	4	0.666666667	0.903602004	0.173425
Number of Mixed Use structure	0.25	2	1	4	2	1.189207115	0.22824
Access to/Planned green spaces	0.2	0.25	0.25	1	0.0125	0.334370152	0.064174
Sum	1.783333333	6.25	5.75	14		5.210336955	1
Sum*PV	0.952586735	1.083905431	1.312379789	0.898441344		4.247313299	
Lambda Max	4.247313299						
CI	0.082437766						
RI	0.9						
CR	0.091597518	ok, <0.10					

APPENDIX F

CALCULATION OF ECONOMICS FOR REGIONAL TRANSPORTATION DISTRICT (RTD)

Economics							
Total Factors	4						
	Government interventions in terms of incentives or approval process	Market Perception	New Property and sales taxes expected	Incentive mechanisms offered to private players	Product	nth product	Priority Vector
Government interventions in terms of incentives or approval process	1	0.25	1	1	0.25	0.707106781	0.152607
Market Perception	4	1	2	4	32	2.37841423	0.513306
New Property and sales taxes expected	1	0.5	1	1	0.5	0.840896415	0.181481
Incentive mechanisms offered to private players	1	0.25	1	1	0.25	0.707106781	0.152607
Sum	7	2	5	7		4.633524208	1
Sum*PV	1.068246813	1.026611332	0.907404793	1.068246813		4.070509752	
Lambda Max	4.070509752						
CI	0.023503251						
RI	0.9						
CR	0.026114723	ok, <0.10					

APPENDIX G

CALCULATION OF SOCIAL DIVERSITY FOR REGIONAL TRANSPORTATION DISTRICT (RTD)

Social Diversity								
Total Factors	5							
	Planned mixed-income housing	Community Support	Household disposable income in 0.5 miles radius	Access to/Planned Cultural/Entertainment centers	Age demographics	Product	nth product	Priority Vector
Planned mixed-income housing	1	1	4	4	4	64	2.297397	0.38013
Community Support	1	1	2	4	2	16	1.741101	0.288085
Household disposable income in 0.5 miles radius	0.25	0.5	1	2	0.5	0.125	0.659754	0.109164
Access to/Planned Cultural/Entertainment centers	0.25	0.25	0.5	1	0.333333333	0.010416667	0.401371	0.066411
Age demographics	0.25	0.5	2	3	1	0.75	0.944088	0.15621
Sum	2.75	3.25	9.5	14	7.833333333		6.04371	1
Sum*PV	1.045358044	0.936275662	1.037055466	0.929758518	1.223644428		5.172092	
Lambda Max	5.172092119							
CI	0.04302303							
RI	1.12							
CR	0.038413419	ok, <0.10						

APPENDIX H

CALCULATION OF CATEGORIES FOR REGIONAL TRANSPORTATION DISTRICT (RTD)

Overall Factors							
Total Factors	4						
	Travel Behavior	Built Environment	Economics	Quality/Social Diversity	Product	nth product	Priority Vector
Travel Behavior	1	0.25	2	0.5	0.25	0.707106781	**0.154066**
Built Environment	4	1	2	3	24	2.213363839	**0.482252**
Economics	0.5	0.5	1	0.5	0.125	0.594603558	**0.129553**
Quality/Social Diversity	2	0.333333333	2	1	1.333333333	1.074569932	**0.234129**
Sum	7.5	2.083333333	7	5		4.58964411	1
Sum*PV	1.155492829	1.004691117	0.906873126	1.170646248		4.237703321	
Lambda Max	4.237703321						
CI	0.07923444						
RI	0.9						
CR	0.088038267	ok, <0.10					

APPENDIX I

CALCULATION OF TRAVEL BEHAVIOR FOR ROARING FORK TRANSPORTATION AUTHORITY (RFTA)

Travel Behavior							
Total Factors	4						
	Number of Shuttle and bus services provided from transit station	Parking Supplies on site	Population/Housing Density	Planned convenience / service retail near station	Product	nth product	Priority Vector
Number of Shuttle and bus services provided	1	7	2	2	28	2.300326634	0.4282
Parking Supplies on site	0.142857143	1	0.142857143	0.142857143	0.002915452	0.23236808	0.043255
Population/Housing Density	0.5	7	1	3	10.5	1.800102872	0.335084
Planned convenience / service retail near	0.5	7	0.333333333	1	1.166666667	1.039289878	0.193461
Sum	2.142857143	22	3.476190476	6.142857143		5.372087463	1
Sum*PV	0.917570943	0.951603599	1.164817308	1.188403817		4.222395667	
Lambda Max	4.222395667						
CI	0.074131889						
RI	0.9						
CR	0.082368766	ok, <0.10					

APPENDIX J

CALCULATION OF BUILT ENVIRONMENT FOR ROARING FORK TRANSPORTATION AUTHORITY (RFTA)

Built Environment							
Total Factors	4						
	Quality & Length of walking route to station	Quality of bicycle lanes	Number of Mixed Use structure	Access to / Planned green spaces	Product	nth product	Priority Vector
Quality & Length of walking route to station	1	5	4	5	100	3.16227766	0.57084
Quality of bicycle lanes	0.2	1	2	5	2	1.189207115	0.21467
Number of Mixed Use structure	0.25	0.5	1	5	0.625	0.889139705	0.160503
Access to / Planned green spaces	0.2	0.2	0.2	1	0.008	0.299069756	0.053987
Sum	1.65	6.7	7.2	16		5.539694236	1
Sum*PV	0.941885584	1.438290153	1.155624409	0.863787042		4.399587188	
Lambda Max	4.399587188						
CI	0.133195729						
RI	0.9						
CR	0.147995255						

APPENDIX K

CALCULATION OF ECONOMICS FOR ROARING FORK TRANSPORTATION AUTHORITY (RFTA)

Economics							
Total Factors	4						
	Government interventions in terms of incentives or approval process	Market Perception	New Property and sales taxes expected	Incentive mechanisms offered to private players	Product	nth product	Priority Vector
Government interventions in terms of incentives or approval process	1	1	3	1	3	1.316074013	**0.29332**
Market Perception	1	1	3	3	9	1.732050808	**0.386031**
New Property and sales taxes expected	0.333333333	0.333333333	1	0.333333333	0.037037037	0.438691338	**0.097773**
Incentive mechanisms offered to private players	1	0.333333333	3	1	1	1	**0.222875**
Sum	3.333333333	2.666666667	10	5.333333333		4.486816158	**1**
Sum*PV	0.977734149	1.029416404	0.977734149	1.188667676		4.173552377	
Lambda Max	4.173552377						
CI	0.057850792						
RI	0.9						
CR	0.064278658	ok, <0.10					

APPENDIX L

CALCULATION OF SOCIAL DIVERSITY FOR ROARING FORK TRANSPORTATION AUTHORITY (RFTA)

Social Diversity					
Total Factors	2				

	Planned mixed-income housing (inclding subsidized housing)	Community Support / Public Perception	Product	nth product	Priority Vector
Planned mixed-income housing (inclding subsidized housing)	1	0.5	0.5	0.707106781	0.333333333
Community Support / Public Perception	2	1	2	1.414213562	0.666666667
Sum	3	1.5		2.121320344	1
Sum*PV	1	1		2	
Lambda Max	2				
CI	0				
RI	0				
CR	0%				

APPENDIX M

CALCULATION OF EACH CATEGORY FOR ROARING FORK TRANSPORTATION AUTHORITY (RFTA)

Overall Factors							
Total Factors	4						

	Travel Behavior	Built Environment	Economics	Quality/Social Diversity	Product	nth product	Priority Vector
Travel Behavior	1	2	3	2	12	1.861209718	**0.417149**
Built Environment	0.5	1	3	2	3	1.316074013	**0.294969**
Economics	0.333333333	0.333333333	1	1	0.111111111	0.577350269	**0.1294**
Quality/Social Diversity	0.5	0.5	1	1	0.25	0.707106781	**0.158482**
Sum	2.333333333	3.833333333	8	6		4.461740782	**1**
Sum*PV	0.97334715	1.130713466	1.035201815	0.950893585		4.090156016	
Lambda Max	4.090156016						
CI	0.030052005						
RI	0.9						
CR	0.033391117	ok, <0.10					