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Texas Urban Triangle: Creating a Spatial Decision Support System for Mobility Policy and Investments that Shape the Sustainable Growth of Texas

Final Report

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16. Abstract
This project developed a GIS-based Spatial Decision Support System to help local, metropolitan, and state jurisdictions and authorities in Texas understand the implications of transportation planning and investment decisions, and plan appropriately for the future. It provides an easily accessible, graphically represented, interactive database on infrastructural, demographic, environmental, agricultural, economic, hazard, and land use factors that affect transportation corridor location decisions. Specifically, the project team created an Internet-based spatial decision support system that will allow users to identify and visualize geographically those critical issues related to locating single mode or multi-modal surface transportation corridors for freight and passengers. Decision makers will be able to test multiple attributes in the decision making model to compare multiple transportation corridor scenarios for optimal mobility based on the decision parameters developed in the model. Jurisdictions and transportation authorities will use this tool to guide future decisions on transportation and its impacts on urban growth in a sustainable manner so that the need for economic development is balanced with environmental protection and human health, safety, and welfare. The system also helps address important research questions related to where future growth will occur in the Texas Urban Triangle, and at what scale, densities, and uses and to study selected impacts of this growth. Finally, the SDSS demonstrates the usefulness of WebGIS in facilitating sustainable transportation planning, policy making and investment decisions.

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Texas Urban Triangle:
Creating a Spatial Decision Support System (SDSS) for Mobility Policy and Investments that Shape the Sustainable Growth of Texas

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EXECUTIVE SUMMARY

The Texas Urban Triangle—comprised of the metropolises of Dallas-Fort Worth, Houston, San Antonio, and Austin—contains over 17 million people, almost 70% of the state's population. Projections indicate that over the next 20 years, population in the area will account for over 80% of the state's total. This makes Texas an urban state, despite its cowboy and open plains image. Moreover, the most rapid urban growth and land consumption in the state is in the Triangle cities' fringes. Not surprisingly then, most pollution and other environmental problems, along with unemployment and other social inequities, are generated in these metropolises, and therefore, in the Triangle itself.

The Texas Urban Triangle is a singular, new, complex, and important urban phenomenon. The Texas Urban Triangle, with official projections to over 23 million by 2030 (25 million by 2025, per the Governor's Business Council 2006 report on Shaping Texas's Metropolitan Regions) covering more than 60,000 square miles, is the economic motor of Texas and hub of the national transportation network operating in a global economy. The Triangle accounts for 70% of the state's population, 80% of the state's employment, and 85% of its wages. The Triangle is emerging as a new urban mega-region in its own right, competing with Los Angeles and New York, by virtue of its extensive internal connections and activities.

The results of this project provide the most comprehensive dataset available to form the basis for such discussions and research. The basic research questions are spatial in nature, so accordingly, Geographic Information Systems (GIS) was the primary method of data analysis:

- Where should the growth go in the future?
- What are the impacts of that growth?
- Are those locations vulnerable to hazards both natural and human?
- What scale/type/location of infrastructures is necessary to support it?

The Texas Urban Triangle has been the fastest growing region of the state for decades, along with parts of the eastern Rio Grande Valley. How to handle this new growth will determine to a large degree whether Texas continues to prosper.

The initial analysis revealed that two issues will dominate the Texan landscape and imagination over the next decades: water and energy. Data, analysis, and findings, and policy and planning recommendations for water and energy are contained in the initial report, which can be found at http://texasurbantriangle.tamu.edu.

This project addresses sustainable transportation in the Texas Urban Triangle at the regional scale. Its aim is to determine the most suitable locations for new transport infrastructures by employing a Spatial Decision Support System (SDSS) that was developed in this project. The SDSS differs from existing transportation decision systems in that it focuses on selected *strategic driving forces* of growth of the region *as a* *functional unit*—transport infrastructure, available land, economic activity, water, and energy—and then identifies corresponding measures of sustainability for key transportation systems and corridors within the Texas Urban Triangle. For example, development patterns driven by transportation infrastructure impact surface and groundwater resources in terms of water quantity and quality. Conversely, considering water availability and waste assimilative capacity can be used as a driver of infrastructure planning decisions to achieve greater long-term sustainability. The SDSS supports policy making for a comprehensive "sustainable regionalism."

Another feature of the SDSS is that it considers explicitly the intermodal linkages that ensure greater intersystem operability, enhance travel connectivity, and therefore improve overall mobility. For example, for passengers, the decision model assesses and identifies suitable locations for linking intercity high speed rail and metropolitan public transit (rail and bus of all speeds and gauges) with other surface transportation in key metropolitan nodes such as city centers and international airports. The SDSS assesses and identifies suitable locations for interconnections among freight modes, especially links among air, sea, and land in Houston, Dallas-Fort Worth, and San Antonio. Additionally, SDSS outputs suggest strategic sites for Advanced Logistics Zones (ALZ) where both inter-modal transshipment of goods and adding value to goods between modes (assembly, packaging, etc.) occurs.

The SDSS developed in this project is being tested through its application to a prototype corridor parallel to Interstate 35 between San Antonio and Austin. The SDSS provides a composite foundation for enhanced regional mobility, and using it in policy analysis and investment decisions can strengthen the Texas Urban Triangle as a hub in national transportation networks that can be emulated in urban regions world-wide.

In addition to assessing and evaluating locations for transportation rights of way, the SDSS can be adapted to assess locations for other surface infrastructure networks that are configured by linear corridors in large networks, such as electric power and water supply. Decision criteria in the model identify opportunities for shared rights of way among infrastructure types, further saving capital and land acquisition costs, lessening environmental impacts and habitat fragmentation, etc. The SDSS model has been designed so that it accounts for parameters and factors that exist outside of Texas and the United States, thus broadening its applications geographically. These research results can be used by state and federal transportation, utility, environmental, and urban/land development agencies; by Metropolitan Planning Organizations, Councils of Governments, and Regional Mobility Authorities; counties and municipalities, industry, citizen groups, professional and interest groups.

PROJECT PLAN

The project developed a GIS-based SDSS that is designed to help local, metropolitan, and state jurisdictions and authorities in Texas and elsewhere understand the implications of transportation planning and investment decisions, and plan appropriately for the future. Using the model, decision makers are able to assess multiple corridor location options and to determine, using a multi-attribute decision model, the *Suitability of Locations for Regional and Metropolitan Transportation Corridors to the Year 2030*. It provides an easily accessible, graphically represented, interactive, *multi-attribute* database that considers the following factors: infrastructural, demographic, environmental, agricultural, economic, hazard, and land use. These spatial factors are selected because of their strategic importance as drivers shaping growth and development, and corresponding transportation corridor and hub location decisions that reinforce both individual metro areas and the entire Texas Urban Triangle as a single functioning unit. One immediate application of the model is to the location of possible high-speed rail corridors in the Texas Urban Triangle.

STRATEGIC DRIVERS OF THE SDSS

Strategic drivers that have been incorporated into the SDSS include those factors that are foreseen to most likely shape growth patterns and resulting transportation demands/needs over the next 50 years: demographic and labor force changes, economic activity, land availability, environmental suitability, natural resources such as water, oil, and gas, utilities such as electric power and other infrastructures, accessibility and mobility of people and goods, producer services and secondary services availability, housing affordability, and the security and reliability of the transportation networks and other critical infrastructures. As strategic drivers, they are intimately connected to the surface transportation networks and therefore are to be accounted for in the SDSS.

SPATIAL DECISION SUPPORT SYSTEM DEVELOPMENT PROCESS

To develop the SDSS itself, the researchers have taken the following steps:

1. Identify factors to be included in the SDSS analytical model.
2. Identify factor specialists across the Texas A&M College Station campus and elsewhere to provide expert advice on the factors.
3. Select factors to be included in the SDSS model.
4. Identify data sources for the factors and collect data.
5. Determine weights for each factor.
6. Determine rankings" for each factor.

The factors in the SDSS refer to the individual criteria used in the model to assess the most suitable location for locating transportation corridors on the landscape. The research team member initially selected 83 factors that could have been included in the SDSS criteria organized in seven categories: Agriculture, Demographic, Engineering, Environmental, Hazard, Infrastructure, Land Use. After research and deliberation, the team identified 42 factors appropriate in Texas.

DETERMINE THE INTERNAL CLASSIFICATION FOR EACH FACTOR

Factor weights refer to the value, on a scale of 1 to 10, assigned to each of the factors (decision criteria) in the SDSS. A value or weight of 10 is the highest weight for each factor and reflects a negative value for locating a transportation corridor in that place—least suitable location. A value of zero is the lowest weight for each factor, and reflects a positive value for locating a transportation corridor—most suitable location.

For example, below are the weights for population density, in persons per square mile. Since there are 640 acres per square mile, a density of 2000 is less than 4 people per acre.

Population Density	**Scale**
0–999	10
1000–1999	5
2000 and up	1

DETERMINE FACTOR WEIGHTS

Factor weights refer to the relative value of factors compared to each other. Thus, for 42 factors, the most important factor to consider for locating High Speed Rail in the Texas Urban Triangle is weighted most, the second most important factor next, and so on. To determine appropriate factor weights, the research team used the Analytic Hierarchical Process (AHP), a widely accepted decision making strategy. For the pilot study, the relationships between eight pre-selected factors were tested: Population Density/Property Value/Road Types/Vertical Slope/Floodplain/Geology/Soli Types/Hydrology. The relationship between the factors and factor weights are crucial part of the entire SDSS process.

	POP. Density	Vertical Slope	Road Type	Hydrology	Parcel Value	Floodplain	Geology	Soil Type	**Eigen Vector & In Percentage**	
POP. Density	0.30	0.40	0.31	0.24	0.33	0.20	0.16	0.20	**0.2674**	**26.74%**
Vertical Slope	0.15	0.20	0.31	0.24	0.22	0.16	0.16	0.20	**0.2051**	**20.51%**
Road Type	0.15	0.10	0.16	0.24	0.22	0.16	0.22	0.20	**0.1801**	**18.01%**
Hydrology	0.06	0.04	0.03	0.05	0.05	0.08	0.05	0.02	**0.0481**	**4.81%**
Parcel Value	0.10	0.10	0.08	0.10	0.11	0.20	0.27	0.20	**0.1439**	**14.39%**
Floodplain	0.06	0.05	0.04	0.02	0.02	0.04	0.05	0.05	**0.0423**	**4.23%**
Geology	0.10	0.07	0.04	0.05	0.02	0.04	0.05	0.10	**0.0586**	**5.86%**
Soil Type	0.08	0.05	0.04	0.05	0.03	0.12	0.03	0.05	**0.0545**	**5.45%**
SUM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**1.0000**	**100.00%**

Table 1. Factor Weight Matrix Using AHP and Reliability Test.

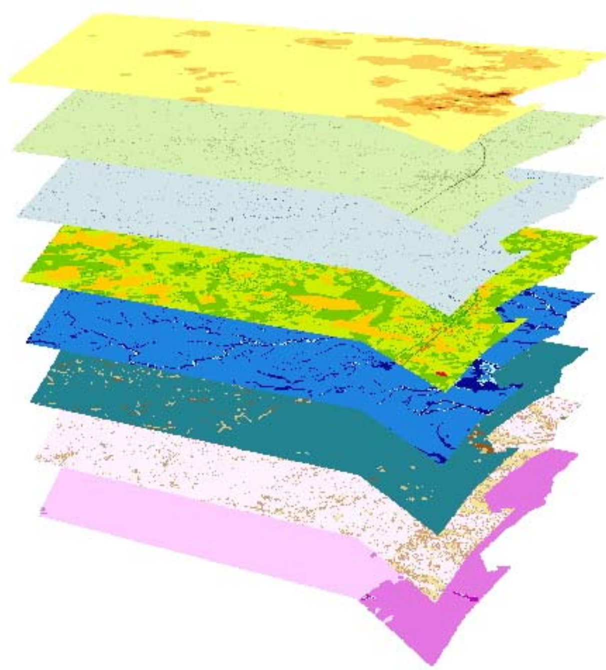
Based on the result, the map algebra could be written as follows,

$$Score_{total} = \Sigma\ a(S_{pop.density}) + b(S_{slope}) + c(S_{road\ type}) + d(S_{hydrology}) + e(S_{rparcel\ value}) + f(S_{rfloodplain}) + g(S_{rgeology}) + h(S_{soil\ type})$$

(a ~ g=factor weight for each factor/S=internal classification of each factor)

λ_{max} = 8.6328, Consistency Index (CI) = 0.0904, Random Index (RI) = 1.41 (n = 8)
Consistency Ratio (CR) = 0.0641 -> 6.41% < 10.0%
(CR less than 10% considered a consistent preference matrix)

The analysis tested the GIS-based SDSS on a specific corridor segment between San Antonio and Austin in Hays County. This pilot study/proof of concept in a focused geographic area used a single county for ease of data gathering. Over time, this study expects to apply the SDSS on an entire strategic transportation corridor that is now in play—the San Antonio-Austin-DFW corridor. The output of the model is displayed online using interactive, web-based GIS maps.



*Cost Surface = Σ (0.2674*Population Density) + (0.2051*Vertical Slope) + (0.1801*Road Type) + (0.0481*Hydrology) + (0.1439*Parcel Value) + (0.0423*Floodplain) + (0.0586*Geology) + (0.0545*Soil Type)*

Figure 2. Cost Surface Maps for Eight Factors.

Finally, research team searched for an optimal route that would require the least cost and most sustainable way to locate the high speed railway within Hays County. This process was done with the function called “Least Path” in ArcGIS.

THE PROBLEM AND BACKGROUND

THE TEXAS URBAN TRIANGLE: FRAMEWORK FOR FUTURE GROWTH

The Texas Urban Triangle—comprised of the metropolises of Dallas-Fort Worth, Houston, San Antonio, and Austin—contains over 17 million people, almost 70% of the state's population. Projections indicate that over the next 20 years, population in the area will account for over 80% of the state's total. This makes Texas an urban state, despite its cowboy and open plains image. Moreover, the most rapid urban growth and land consumption in the state is in the Triangle cities' fringes. Not surprisingly then, most pollution and other environmental problems, along with unemployment and other social inequities, are generated in these metropolises, and therefore, in the Triangle itself.

The Texas Urban Triangle is a singular, new, complex, and important urban phenomenon. The results of this project provide the most comprehensive data set available to form the basis for such discussions and research. The basic research questions asked are spatial in nature, so accordingly, GIS will be the primary method of data analysis:

- Where should the growth go in the future?
- What are the impacts of that growth?
- Are those locations vulnerable to hazards both natural and human?
- What scale/type/location of infrastructures is necessary to support it?

The Texas Urban Triangle is a new urban phenomenon in North America, if not the globe, in two significant ways. First, it is distinguished among megalopolises because it is not linear, but rather triangular. Second, the urban development between its metropolises is not physically contiguous. The axis from San Antonio to Dallas is on its way to becoming fully urbanized due to the proximity of the string of cities along Interstate 35: New Braunfels, San Marcos, Austin, Georgetown, Temple, Killeen, and Waco. In contrast, along Interstate 45 between Dallas and Houston, and Interstate 10 between Houston and San Antonio, there are only small villages and towns along these arteries.

So on the one hand, the Texas Urban Triangle's characteristics corroborate findings of prior work on multiple-metropolis mega cities in the United States that regional growth is polycentric, as it has been for individual metropolises. On the other hand, unlike megalopolises in the past, much of the Texas Urban Triangle's urban development is not continuous or contiguous, suggesting that connections among the metropolises that make it up take advantage of telecommunications and transportation infrastructure networks to make the links, indicating a new socio-spatial order, the networked region.

The Texas Urban Triangle has been the fastest growing region of the state for decades, along with parts of the eastern Rio Grande Valley. In the year 2030, population for the counties that make up the Triangle is projected to be 23,067,000, compared to 31,831,000 for the entire state, according to our calculations derived from scenario .5 of the State Demographer. In other words, the 2030 population of the Triangle alone is projected to exceed the 2000 population of the entire state by over two million persons.

Texas is projected to continue to grow steadily, and population in the Triangle is projected to increase 57% between 2000 and 2030. This compares to 53% growth for the entire state. The Texas Urban Triangle is projected to account for 8,407,000 of the state's 10,979,000 new inhabitants in that period, or 77% of all Texas's growth. The attendant impacts of growth—new homes, new jobs and businesses, new transportation and infrastructure networks, less farm and ranch lands, and more pollution—are easy to predict based on past experience. How to handle this new growth will determine to a large degree whether Texas continues to prosper and enjoy a high quality of life.

Our initial analysis revealed that two issues will dominate the Texan landscape and imagination over the next decades: water and energy. Data, analysis, and findings, and policy and planning recommendations for water and energy are contained in the initial report, which can be found at http://texasurbantriangle.tamu.edu.

These findings provide a baseline foundation for policy guidance to decision makers at all levels of government—especially state and federal—and the private sector. Unlike most sector-specific studies, it took a broad and synthetic view of the key factors that drive regional growth so that in the future it can be accommodated in a more sustainable regional design. They also inform and extend the debate about the future of the city region (Neuman and Hull, 2009). These findings also provide a baseline for the current project, developing a Spatial Decision Support System (SDSS) for *Mobility Policy and Investments that Shape the Sustainable Growth of Texas*.

PROJECT SIGNIFICANCE

The Texas Urban Triangle, now approaching 17 million inhabitants with official projections to over 23 million by 2030 (25 million by 2025, per the Governor's Business Council 2006 report on Shaping Texas's Metropolitan Regions) covering more than 60,000 square miles, is the economic motor of Texas and hub of the national transportation network operating in a global economy. The Triangle accounts for 70% of the state's population, 80% of the state's employment, and 85% of its wages. The Triangle is emerging as a new urban mega-region in its own right, competing with Los Angeles and New York, by virtue of its extensive internal connections and activities. The volume of movements within the Triangle, especially among its metropolises, exceeds the volume with places outside the Triangle, pointing to its increasing functionality as a single unit. This is true despite the key international sea, air, and land ports, especially those in Dallas-Fort Worth (DFW), Houston, and the emerging inland "Port San Antonio"; the first two themselves being factors that contributed to shaping the Triangle as it now exists. Accordingly, freight and passenger mobility within and among the Triangle's metro areas, as well as outward across the continent, is critical to economic and social development and to the preservation of its natural assets.

Given that transportation infrastructure shapes and supports that growth, that $58 billion of $72 billion identified State of Texas transportation infrastructure needs over the next 25 years are in the Texas Urban Triangle (Governor's Business Council, 2006),[1] and that transportation in all modes consumes over 28% of all U.S. energy (mostly oil-based) (EIA, 2008); a new set of policy priorities for energy independence and renewable energy is emerging. These policies are interdependent and cut across many realms: national security, climate crises, economic competitiveness, air and noise pollution, congestion due to the Vehicle Miles Travelled, and land use. Moreover, existing highway-dominated surface transport systems are exceeding design capacity and increasingly costly to expand and maintain. Accordingly, there is an urgent need for policy and investment decisions that are based on a new and wider set of criteria that account for new conditions and considerations. A new form of decision making based on emerging realities could pave the way for a wider range of options for transportation that are *sustainable.*

This project addresses sustainable transportation in the Texas Urban Triangle at the regional scale. Its aim is to determine the most suitable locations for new transport infrastructures by employing an SDSS that will be developed in this project. The SDSS differs from existing transportation decision systems in that it focuses on selected *strategic driving forces* of growth of the region *as a functional unit*—transport infrastructure, available land, economic activity, water, and energy—and then identifies corresponding measures of sustainability for key transportation systems and corridors within the Texas Urban Triangle. For example, development patterns driven by transportation infrastructure in turn create impacts on surface and groundwater resources in terms of water quantity and quality. Conversely, considering water availability and waste assimilative capacity can be used as a driver of infrastructure planning decisions to achieve greater long-term sustainability. The SDSS supports policy making for a comprehensive "sustainable regionalism."

Another feature of the SDSS is that it considers explicitly the intermodal linkages that ensure greater intersystem operability, enhance travel connectivity, and therefore improve overall mobility. For example, for passengers, the decision model assesses and identifies suitable locations for linking intercity high speed rail and metropolitan public transit (rail and bus of all speeds and gauges) with other surface transportation in key metropolitan nodes such as city centers and international airports. The SDSS assesses and identifies suitable locations for interconnections among freight modes, especially links among air, sea, and land in Houston, Dallas-Fort Worth, and San Antonio. Additionally, SDSS outputs suggest strategic sites for Advanced Logistics Zones (ALZ) where both inter-modal transshipment of goods and adding value to goods between modes (assembly, packaging, etc.) occurs. ALZs are new strategic projects areas in their metropolises, further enhancing economic growth and competitiveness.

[1] Unofficial, unreleased, preliminary data as of late 2008 suggests that actual needs will be $120 billion through 2030 to keep congestion from getting worse, and $150 billion to eliminate serious congestion in four Texas Urban Triangle metros: DFW, Houston, S.A. and Austin (TTI researcher personal communication). Regardless of the actual figures, transport infrastructure needs are extremely large, and sound decision methods are urgently critical.

The SDSS developed in this project is being tested through its application to a prototype corridor parallel to Interstate 35 between San Antonio and Austin. The SDSS provides a composite foundation for enhanced regional mobility, and using it in policy analysis and investment decisions can strengthen the Texas Urban Triangle as a hub in national transportation networks that can be emulated in urban regions world-wide.

In addition to assessing and evaluating locations for transportation rights of way, the SDSS can be adapted to assess locations for other surface infrastructure networks that are configured by linear corridors in large networks, such as electric power and water supply. Decision criteria in the model identify opportunities for shared rights of way among infrastructure types, further saving capital and land acquisition costs, lessening environmental impacts and habitat fragmentation, etc. The SDSS model has been designed so that it accounts for parameters and factors that exist outside of Texas and the United States, thus broadening its applications geographically.

These research results can be used by state and federal transportation, utility, environmental, and urban/land development agencies; by Metropolitan Planning Organizations, Councils of Governments, and Regional Mobility Authorities; counties and municipalities, industry, citizen groups, professional and interest groups. This project builds on the research project "Texas Urban Triangle: Framework for Future Growth" funded by SWUTC. See http://sustainableurbanism.tamu.edu, and click on projects, or see http://texasurbantriangle.tamu.edu.

APPROACH

PROJECT PLAN

The project developed a GIS-based SDSS that is designed to help local, metropolitan, and state jurisdictions and authorities in Texas and elsewhere understand the implications of transportation planning and investment decisions, and plan appropriately for the future. Using the model, decision makers are able to assess multiple corridor location options and to determine, using a multi-attribute decision model, the Suitability of Locations for Regional and Metropolitan Transportation Corridors to the Year 2030. It provides an easily accessible, graphically represented, interactive, *multi-attribute* database that considers the following factors: infrastructural, demographic, environmental, agricultural, economic, hazard, and land use. These spatial factors are selected because of their strategic importance as drivers shaping growth and development, and corresponding transportation corridor and hub location decisions that reinforce both individual metro areas and the entire Texas Urban Triangle as a single functioning unit. One immediate application of the model is to the location of possible high speed rail corridors in the Texas Urban Triangle.

The Spatial Decision Support System can be modified by users to support location decisions regarding local and state transportation corridors, in addition to metropolitan and regional scale corridors. Moreover, it can be used to evaluate other types of infrastructure corridors that can be placed in shared rights-of-way within or alongside transportation corridors. In this sense the SDSS is a *multi-scalar* in addition to multi-attribute, and should represent an advance in DSS model development, building on existing transportation (TTI's TransDec 2.0) and planning decision support systems (Zhang and Wang 1998).

STRATEGIC DRIVERS OF THE SDSS

The vastly changed transportation investment decision panorama in Texas and the U.S. implies a new type of decision making that considers more than just capital costs and environmental constraints. It needs to consider the life cycle of the systems, and the economic, demographic, social, ecological, infrastructural, and fiscal parameters influencing decisions. Today, wildly erratic fuel prices, climate crises, CO_2 emissions, and having reached or exceeded highway and freight rail capacities on several corridors, plus the spiraling costs of expanding highways in urbanized areas seriously complicate decisions that in the past were conditioned by population, demographic, immigration, and economic development factors; along with EPA air and water pollution restrictions.

Strategic drivers that have been incorporated into the SDSS include those factors that are foreseen to most likely shape growth patterns and resulting transportation demands/needs over the next 50 years: demographic and labor force changes, economic activity, land availability, environmental suitability, natural resources such as water, oil, and gas, utilities such as electric power and other infrastructures, accessibility and mobility of people and goods, producer services and secondary services availability, housing affordability, and the security and reliability of the transportation networks and other critical infrastructures. As strategic drivers, they are intimately connected to the surface transportation networks and therefore are be accounted for in the SDSS.

BACKGROUND/PRIOR RESEARCH

Several studies have examined the need to link more closely the major urban cities of the Texas Triangle with high-speed rail service. Roco and Olson of TTI in a Southwest University Transportation Center report from 2004, *Policy and Financial Analysis of High-Speed Rail Ventures in the State of Texas* outline several of these:

- Texas Rail System Evaluation (1976–1977) – The Texas legislature funded a comprehensive study of Texas intercity travel and passenger rail needs, which looked at the history of passenger rail and evaluated projected needs into the 1990s. The results of this study found that highways and air travel capacity provided by the newly completed interstate highway system and planned airport construction in the major urban areas would meet intercity travel needs through the mid-1990s.

- The German High Speed Consortium Study (1985) – This privately funded study evaluated High Speed Rail (HSR) service between Houston and Dallas-Fort Worth using existing rail right of way. The study indicated with speeds exceeding 185 mph riders could travel between downtown Houston and downtown Dallas in

100 minutes, with capital costs between $1.4 billion to $4.4 billion, depending on the configuration (Roco, 2004).

- Texas Turnpike Authority Study (1988) – The Texas Triangle High Speed Rail Study was publicly funded and concluded that a high speed rail service on all legs of the Texas Triangle were feasible. Built in a dedicated right of way, it was proposed to operate at high speed (125–200 mph) at a total cost of $4.4 billion (Roco, 2004).

- Texas FasTrac Study (1991) – This study was submitted as part of a franchise application to the Texas High Speed Rail Authority (THSRA) and proposed the use of German high speed rail technology. The proposed system would link a line between Houston to Waco through Bryan-College Station to a line between Dallas-Fort Worth and San Antonio. The anticipated capital cost was $5.22 billion. The system also proposed a Houston to Austin line to be constructed at a later date (Roco, 2004).

- Texas TGV Study (1991) – This study was submitted as part of a franchise application to the THSRA and proposed the use of French high speed rail technology. This proposed system included three phases of system construction that consisted of three legs connecting Houston to Dallas-Fort Worth, Dallas to San Antonio, and Houston to Austin. The total estimated capital cost was $5.8 billion (Roco, 2004).

All of these studies for this *single mode* of travel linking the Triangle's metros would have benefited greatly from the ability to use an SDSS such as proposed by this project to evaluate differing corridor configurations, travel modes, emerging project cost escalations, and the effect of dynamic development patterns not anticipated in the past. The SDSS allows future transportation planners and other infrastructure and land-use planners to evaluate their decisions both *intermodally* and *interactively*—taking into account both sustainability criteria and changing demographics.

SPATIAL DECISION SUPPORT SYSTEM DEVELOPMENT PROCESS

To develop the SDSS itself, the researchers have taken the following steps:

1. Identify factors to be included in the SDSS analytical model.
2. Identify factor specialists across the Texas A&M College Station campus and elsewhere to provide expert advice on the factors.
3. Select factors to be included in the SDSS model.
4. Identify data sources for the factors and collect data.
5. Determine weights for each factor.
6. Determine rankings for each factor.

1. Identify Factors to be Included in the SDSS

Factors in the SDSS refer to the individual criteria used in the model to assess the most suitable location for locating transportation corridors on the landscape. The research team member initially selected 83 factors that could have been included in the SDSS criteria organized in seven categories:

1. Agriculture.
2. Demographic.
3. Engineering.
4. Environmental.
5. Hazard.
6. Infrastructure.
7. Land use.

After research and deliberation, the team identified 42 factors appropriate for a transportation corridor location-determining SDSS in the State of Texas. Not all of these factors will be used in the pilot study of the SDSS in Hays County.

For each factor, the researchers determined the criteria or indicators that are employed in the model. In some cases it is a simple binary, such as Yes or No, meaning does or does not exist/should or should not exist within the transportation corridor, in this case a High Speed Rail Right of Way. In other cases the factors are quantitative, and in still other cases the factors are qualitative. In some cases the factors mark a gradient or a range, within which there are acceptable/suitable or non-acceptable/non-suitable values.

2. Identify Factor Specialists

For each of the SDSS factors, the researchers identified factor specialists/experts, mostly located on the Texas A&M campus, to assist you in understanding the factor fully, vis-à-vis high speed rail. The research team worked closely with these persons, as necessary, to determine the extent to which the factor is critical, what its dimensions are, and how it may be applied specifically in this SDSS in Texas. Factor specialists were asked if there are related factors not on our list that are pertinent to the SDSS. Researchers also worked with the factor specialists to obtain data to test the SDSS model. Appendix 3 lists these factor specialists.

3. Select Factors to be Included in the SDSS

The research team met numerous times throughout the year to review the factors and select the ones used in the SDSS model. The analysis started with over 80 factors and narrowed the number down to 42 by the end of the model development stage. See Appendix 4, SDSS Model Factors.

4. Identify Data Sources and Collect Data

Databases and datasets accompanying each factor were identified and gathered by the research team. Many of the sources are online databases.

5. Determine Weights for Each Factor

Factor weights refer to the value, on a scale of 1 to 10, assigned to each of the factors (decision criteria) in the SDSS. A value or weight of 10 is the highest weight for each factor and reflects a negative value for locating a transportation corridor in that place—least suitable location. A value of zero is the lowest weight for each factor and reflects a positive value for locating the most suitable location of the transportation corridor—.

For example, here are the weights for population density and improved property value. Population density is in the units of persons per square mile. Since there are 640 acres per square mile, a density of 2000 is less than 4 people per acre, or one to two households per acre, which is a low figure. Improved property value units are in dollars per parcel.

Population Density	**Scale**
0–999	10
1000–1999	5
2000 and up	1

Improved Property Value	**Scale**
$0–99K	1
$100–199K	2
$200–299K	3
$300–399K	4
$400–499K	5
$500K and up	10

6. Determine Rankings for Each Factor

Factor weights refer to the relative value of factors compared to each other. Thus, for 42 factors, the most important factor to consider for locating HSR in the Texas Urban Triangle is weighted most, the second most important factor next, and so on, until the least important factor. In order to determine appropriate factor weights, the research team implemented the Analytic Hierarchical Process (AHP). AHP is a widely accepted decision making strategy especially when dealing with various datasets with multiple criteria. For the pilot study, the relationships between eight pre-selected factors were tested: Population Density/Property Value/Road Types/Vertical Slope/Floodplain/Geology/Soli Types/Hydrology. It found that the relationship between the factors and factor weights are crucial part of the entire SDSS process. The way to determine factor weights might yield significantly different result, and this is the reason why a pilot study was performed first.

	POP. Density	Vertical Slope	Road Type	Hydrology	Parcel Value	Floodplain	Geology	Soil Type	Eigen Vector & In Percentage	
POP. Density	0.30	0.40	0.31	0.24	0.33	0.20	0.16	0.20	**0.2674**	**26.74%**
Vertical Slope	0.15	0.20	0.31	0.24	0.22	0.16	0.16	0.20	**0.2051**	**20.51%**
Road Type	0.15	0.10	0.16	0.24	0.22	0.16	0.22	0.20	**0.1801**	**18.01%**
Hydrology	0.06	0.04	0.03	0.05	0.05	0.08	0.05	0.02	**0.0481**	**4.81%**
Parcel Value	0.10	0.10	0.08	0.10	0.11	0.20	0.27	0.20	**0.1439**	**14.39%**
Floodplain	0.06	0.05	0.04	0.02	0.02	0.04	0.05	0.05	**0.0423**	**4.23%**
Geology	0.10	0.07	0.04	0.05	0.02	0.04	0.05	0.10	**0.0586**	**5.86%**
Soil Type	0.08	0.05	0.04	0.05	0.03	0.12	0.03	0.05	**0.0545**	**5.45%**
SUM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**1.0000**	**100.00%**

λ_{max} = 8.6328, Consistency Index (CI) = 0.0904, Random Index (RI) = 1.41 (n = 8)
Consistency Ratio (CR) = 0.0641 -> 6.41% < 10.0%
(CR less than 10% considered a consistent preference matrix)

Based on the result, the map algebra could be written as follows,

$$Score_{total} = \Sigma\, a(S_{pop.density}) + b(S_{slope}) + c(S_{road\ type}) + d(S_{hydrology}) + e(S_{rparcel\ value}) + f(S_{rfloodplain}) + g(S_{rgeology}) + h(S_{soil\ type})$$

(a ~ g=factor weight for each factor/S=internal classification of each factor)

Cost Surface = Σ (0.2674*Population Density) + (0.2051*Vertical Slope) + (0.1801*Road Type) + (0.0481*Hydrology) + (0.1439*Parcel Value) + (0.0423*Floodplain) + (0.0586*Geology) + (0.0545*Soil Type)

THE SPATIAL DECISION SUPPORT SYSTEM

Specifically, the project created an Internet-based spatial decision support system that allows users to identify and visualize geographically those critical issues related to locating single mode or multi-modal surface transportation corridors for freight and passengers. This entailed incorporating indicators that address both the strategic drivers listed above, and sustainability (environment-economy-equity) parameters. The SDSS coupled these indicators/decision criteria to a land suitability analysis model (McHarg

1995), employing GIS to map strategic social, economic, and environmental characteristics, and overlay them to assess which locations are most and least suitable for regional transportation networks and urban scale growth. This built on the preliminary suitability analysis for the non-urbanized areas of the Texas Urban Triangle conducted by Co-PI Professor Elise Bright and her Master of Urban Planning students in 2006. This SDSS, a composite of traditional DSS and multi-criteria land suitability analysis, differs markedly from standard environmental assessments employed in infrastructure network planning decisions in that it analyzes the finite and sustainable carrying capacity of the land in regard to existing and projected urban and infrastructural development (see our brief review of some DSS in Appendix 1). The SDSS includes four general categories of decision attributes: infrastructural, environmental, social, and economic. It evaluated these data and then mapped them to show suitable geographic locations.

Specific attributes include: the capacities and locations and other attributes of transportation corridors (e.g., grade and curvature requirements for rail) of transportation, water, wastewater, power, and telecommunications infrastructure networks and facilities, and utilities; the capacities and locations of hydrogeologic, soil, climate, water, flood plains, aquifer recharge areas, slope, vegetation, species, elevation, natural hazards, ecosystems, and habitats; population, density, income, education, ethnicity, migration, and changes of these characteristics over time (e.g., growth rates, income inequalities); job locations and density, available land, productive agricultural land, and housing availability/affordability. In the application of the model the research team's plan is to work over the long term with the metropolitan area Councils of Government / Metropolitan Planning Organizations, to identify decision criteria and attributes. Their metropolitan analyses will inform the mega-regional analysis intended to be conducted in the future as an extension of this research.

TESTING THE SDSS

The team tested the GIS-based SDSS on a specific corridor segment between San Antonio and Austin in Hays County. This pilot study/proof of concept in a focused geographic area selected a single county for ease of data gathering. Over time, the team expects to apply the SDSS on an entire strategic transportation corridor that is now in play—the San Antonio-Austin-DFW corridor. The output of the model is displayed online using interactive, web-based GIS maps. Researchers Warner and Wunneburger, experts in GIS, specializing in passenger systems and freight operations, and urban, regional, and environmental planning, respectively, have led and collaborated with a team of researchers to develop the web-based GIS component of the SDSS.

FINDINGS

First, the research team searched for appropriate literatures that could be implemented when defining the internal classification of each factor. Accordingly, each factor was classified to a proper scale, ranging in most cases from 1 to 10, as described above. For example, high-speed rail literature routinely describes the vertical slope or gradient for the track for high-speed rail should be less than 2%. Given this accepted norm, the team established a scale for Vertical Slope that has five for the ground with slope more than

2%, and one for the track with less than 1% of slope. Designation of the remaining factors' internal classification is as follows.

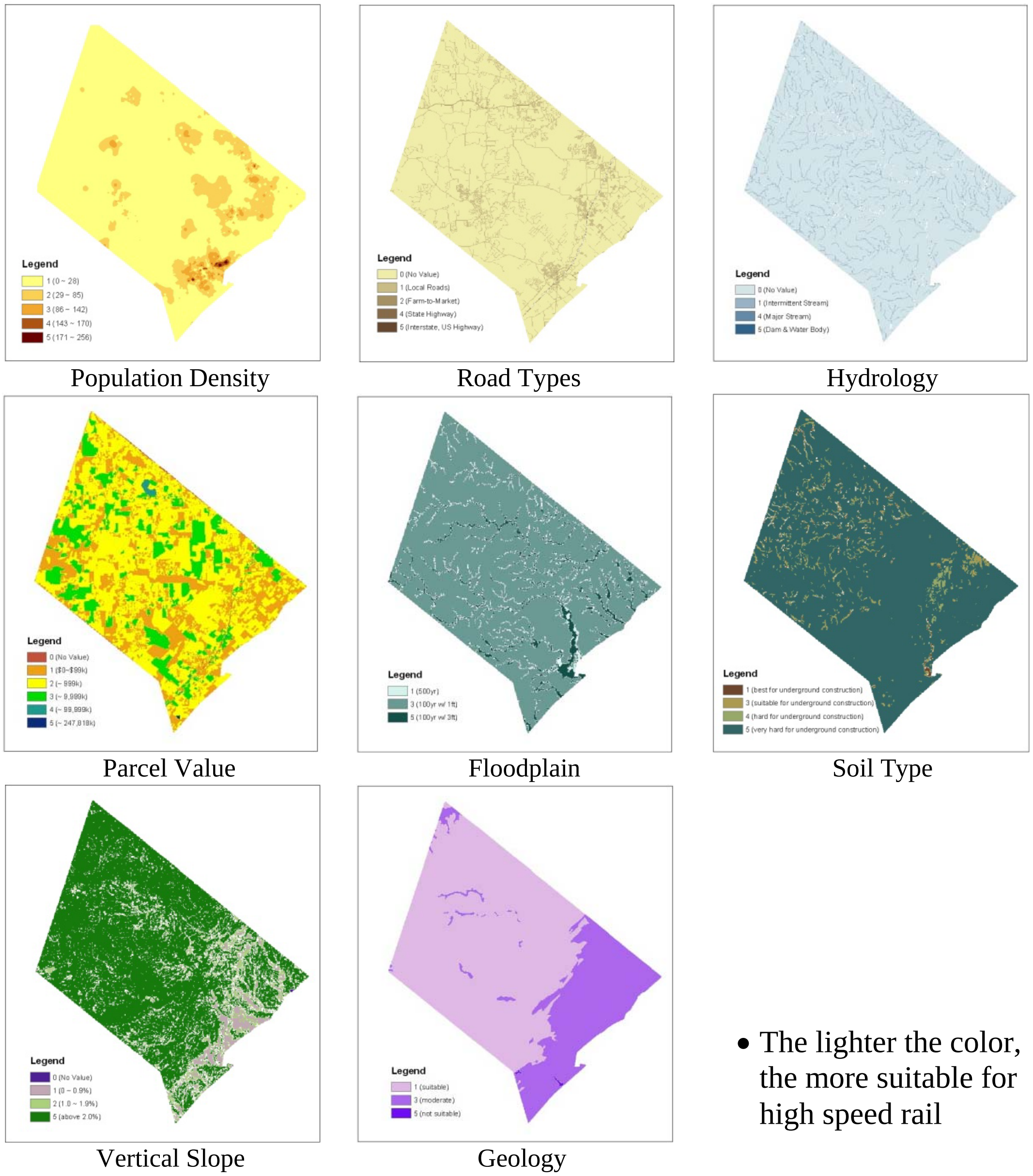
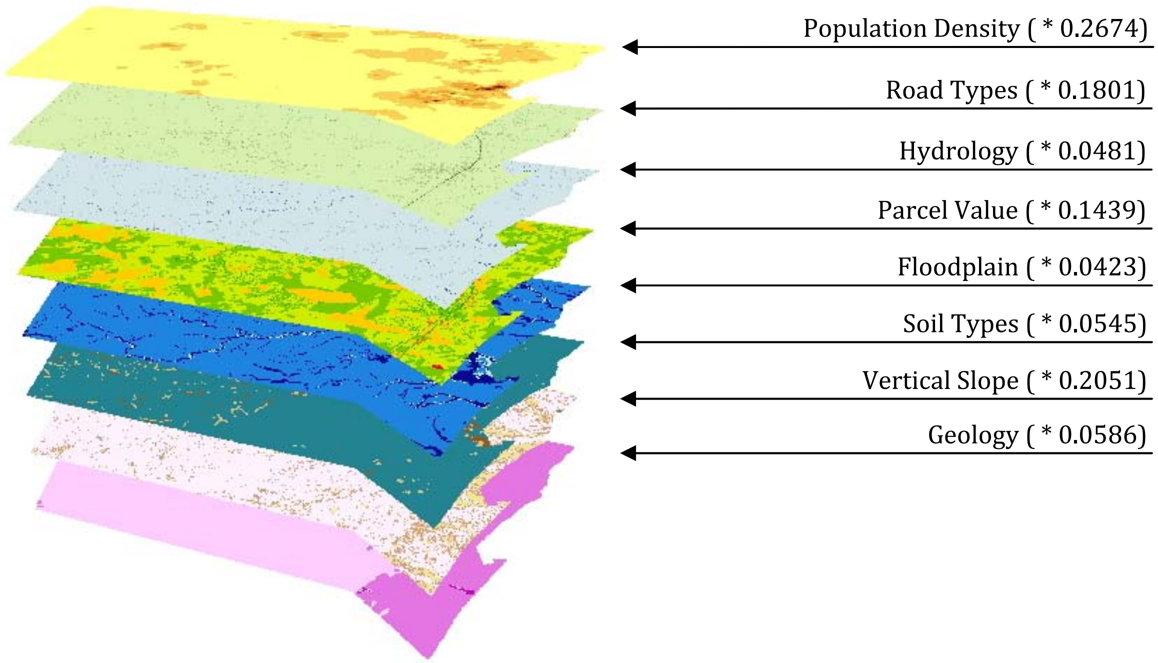


Figure 1. Factor Maps for Eight Factors.

After this internal classification process, research team created a cost surface map using the previously defined map algebra.



$$\textit{Cost Surface} = \Sigma\ (0.2674*\textit{Population Density}) + (0.2051*\textit{Vertical Slope}) + (0.1801*\textit{Road Type}) + (0.0481*\textit{Hydrology}) + (0.1439*\textit{Parcel Value}) + (0.0423*\textit{Floodplain}) + (0.0586*\textit{Geology}) + (0.0545*\textit{Soil Type})$$

Figure 2. Cost Surface Maps for Eight Factors.

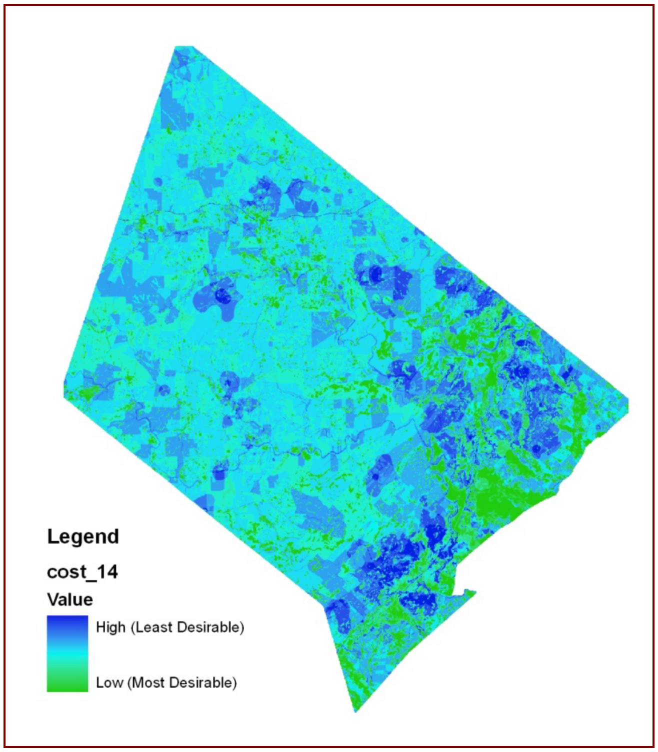


Figure 3. Finalized Cost-Surface Map.

Finally, research team searched for an optimal route that would require the least cost and most sustainable way to locate the high speed railway within Hays County. This process was done with the function called "Least Path" in ArcGIS. Further, the starting and ending point for the route were determined based on the straight path from the Austin-Bergstrom Airport to San Antonio International Airport.

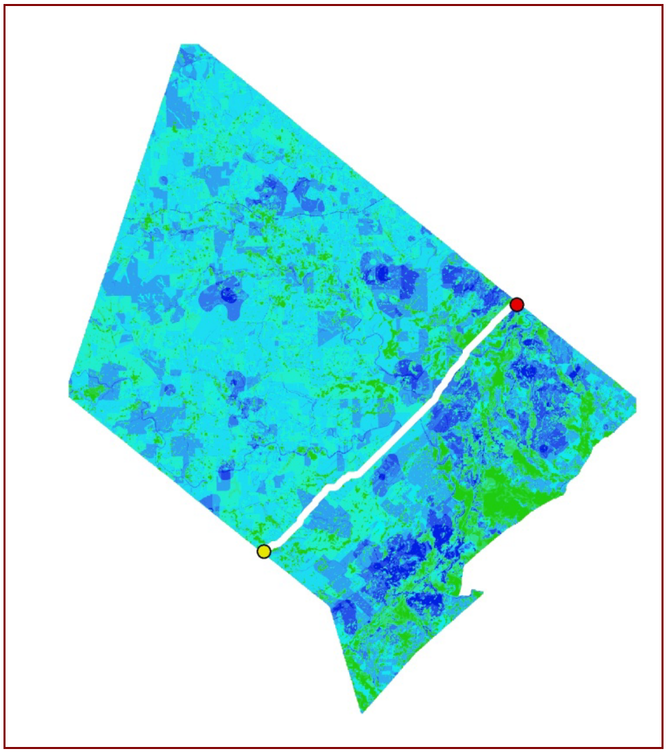


Figure 4. Finalized Cost-Surface Map with the Least-Cost Path.

CONCLUSIONS

For the effective application of the SDSS in the Texas Urban Triangle, two important criteria are the clarity of the methodology used to develop the SDSS model, and the rigor of the theory underlying it.

This SDSS is robust, meaning: supported by valid theory, developed using a sound methodology, and based on reliable and accurate data. This robust quality, coupled with the wide range (42) of factors (variables) in the SDSS model, enable it to be adapted to a wide range of geographic and technological circumstances, depending on the intended use. By wide range of geographic conditions is meant two things: places throughout the United States and the world, not just Texas; and a range of scales from the municipality to the multi-state region. By wide range of technological circumstances, is meant any type of ground transportation technology or mode, whether rail, road, or multi-modal.

Furthermore, the adaptability/flexibility of the model is afforded by the ability of any user to tailor the 42 factors to suit the scale and territory to which it is applied. For example, if a region is heavily forested and topographically rugged, those two environmental characteristics can be bolstered with additional factors, and those two factors themselves can be adjusted to suit the specific local conditions. Moreover, end users can adjust the internal weights within each factor, and the external rankings among the factors as compared to the other factors selected.

The power of the SDSS thus resides in its wide-ranging capacity to incorporate a range of parameters (criteria/factors) related to transportation corridor decision making, its ability to display results graphically and geographically using GIS, and its ability to be adjusted and adapted to different places, different circumstances, and different infrastructure networks, merely by varying the factors/parameters chosen to be used in the model, and by varying the factor weights and factor rankings.

RECOMMENDATIONS

Several actions come to mind as a result of this research. The list below is not necessarily one of priority order.

1. Continue developing and testing the SDSS.

2. Apply the SDSS to actual decision making for transportation corridors in the Texas Urban Triangle in concert with key regional transportation entities, including but not limited to the four principal Metropolitan Planning Organizations and Councils of Government in the Triangle, as well as the Texas Department of Transportation.

3. Apply and/or modify the SDSS to address perceptions held by stakeholders. For example, additional factors may be beneficial for analyzing and mitigating adverse impacts of large ownerships by fragmentation.

4. Continue to establish the Texas Urban Triangle Research Consortium. See Appendix 5.

APPENDIX 1
LIST OF TRANSPORTATION DECISION SUPPORT SYSTEM MODELS REVIEWED IN SUPPORT OF THE DEVELOPMENT OF OUR MODEL

TransDec 2.0 Transportation Decision-Making Software: Developed by TTI under NCHRP 20-29 and 20-29 (2), TransDec is a multimodal investment model that takes into account many factors not easily measured in traditional benefit-cost assessments of project desirability, such as air quality considerations, gross mobility impacts, community livability factors, and aesthetic considerations. TransDec uses multi-criteria utility analysis methods to assess trade-offs between transportation modes, planning methods, and priorities set by project evaluators. TransDec software makes it possible to have a process that allows the decision-maker(s) to rotate the emphasis from one category of measures to the others to assess the resiliency of a given option across all of the selection criteria and choose those that perform well from all of the perspectives considered important.

"Low Cost" At-Grade Rail Crossing Warning Detection System Evaluation: NCHRP 3-76 (B) required TTI Multimodal personnel to use TransDec 2.0 software to make a comparative evaluation of two proposed lower cost at-grade rail crossing warning detection systems. An audible and a radar based system were compared against the performance of one another and traditional track-based detection systems. Cost, functionality, placement ease, and maintainability were among the factors that were compared.

Development of Intercity Passenger Network in Texas TxDOT 0-5930: This on-going project has developed a state-wide network to move people between the urban regions by either passenger rail or intercity bus services. For each intercity corridor a set of criteria was developed to compare the suitability of each corridor against the others. Criteria utilized for this project include population along each corridor, population density, projected population growth, total employees, number of public or private universities, air passenger travel between corridor airports, vehicular traffic, percent trucks, and average number of corridor flights per day. The outcome of this evaluation will be the recommendation of which corridors are most likely to support an intercity transit system and whether bus or rail is most suitable.

Evaluation of Locations for Idle-Reduction Technology (EPA): This project used GIS to identify the most appropriate location for truck stop locations with idling emissions-reduction technology. The research team developed a set of criteria to directly compare roadway segments throughout the entire U.S. that are best suited to accommodate a new truck stop containing the plug-in external power idle-reduction technology features. Criteria included roadway segment characteristics, such as truck volumes, criteria related to non-attainment areas, number of existing facilities, annual winter and summer temperatures, and proximity to major highway intersections.

MicroBENCOST Model: MicroBENCOST software was developed by TTI researchers in the mid-1990s. It provides a planning-level economic analysis tool that can be used to analyze a variety of transportation projects.

Kendig Keast Collaborative: Kendig Keast Collaborative is a U.S. planning consulting firm that indicates an interest to "design with nature." According to their website (www.kendigkeast.com) they perform comprehensive plans, land use and design, and 3D modeling. They appear to be very visual in their planning techniques. Two software offerings are identified on their website: ScenarioPlus and BufferBuilder. The software of interest for the UTCM TUT project appears to be the ScenarioPlus package. They describe ScenarioPlus as "future land use modeling software that allows for the preparation of multiple development scenarios and an instantaneous quantification of their impacts." The stated focus of ScenarioPlus is the development impact analysis. Modeling in real-time, it shows the "impacts that a proposed scenario would have on population, housing requirements, school enrollment, sewer and water demand, employment, trip generation, and established levels of service." Additional, the website states the fiscal consequences of alternative futures can be evaluated. They indicate that the software package "scans the alternatives and feeds the land use plan into a sophisticated spreadsheet, which calculates the acreage of each proposed land use and performs detailed environmental, community, and/or fiscal impact analyses." Although, it does not appear to calculate the optimal alternative, it does calculate impacts of all the alternatives based on the model inputs.

Feasibility Evaluation of Freight Pipeline System in Texas: Developed by TTI researchers, this report applied multi-attribute value/utility methodology to evaluate several alternatives of freight pipeline alignments in Texas. The criteria considered and the methods for weighting and ranking can be used in Spatial Decision Support Systems.

UPlan: A Versatile Urban Growth Model for Transportation Planning: This is a GIS-based urban growth model that runs in the Windows version of ArcView on a personal computer. The model was designed by the research team to rely on a minimum amount of data, but allocates urban growth in several land use types for small (parcel-sized) grid cells. It is a scenario-testing model and rule-based, that is it is not strictly calibrated on historical data and uses no choice or other statistical models. The result-land use types can be applied to various urban impact models to forecast soil erosion, local service costs, and other impacts.

The "ALLOT" Model: A PC-Based Approach to Siting and Planning: This model is an early prototype of Spatial Decision Support System developed in 1992 in an attempt to provide governmental jurisdictions and private landowners with more economically efficient and environmentally sound land use and development patterns than usually occur. It employed GIS land suitability analysis model and multi-attribute value method that helped to determine the location of lands that are suitable for different land uses.

APPENDIX 2
SUPPORTING LITERATURE

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APPENDIX 3
FACTOR SPECIALIST LIST

	Expert	Email	Number
Historic Resources, National Properties	Dr. Fred Smines	f-smeins@tamu.edu	(979) 845-5573
Historic Resources, National Districts	Dr. Fred Smines	f-smeins@tamu.edu	(979) 845-5574
Historic Resources, State Historical Sites	Dr. Fred Smines	f-smeins@tamu.edu	(979) 845-5575
Historic Resources, State Historical Markers	Dr. Fred Smines	f-smeins@tamu.edu	(979) 845-5575
Archeological and paleontological resources	Dr. David Carlson	dcarlson@tamu.edu	(979) 847-9248
Parks and other sites (National)	Dr. Louise Hose	lhose@ag.tamu.edu	(979) 845-9787
State Parks and Wildlife Management Areas (Texas)			
American Indian sites	Dr. Angela Pulley Hudson	aphudson@tamu.edu	979-845-7164
Urban Area Buffers (2000)			
Economy and Jobs			
Existing Population			
Housing by Type	Dr. Van Zandt	svanzandt@tamu.edu	(979) 458-1223
Housing Vacancy Rates	Dr. Van Zandt	svanzandt@tamu.edu	(979) 458-1223
Infant Mortality			
Population Density Projection			
Population Density			
Station Locations			
Air Quality	Dr. Calvin Parnell	c-parnell@tamu.edu	(979) 845-3985

Energy			
Life cycle energy use			
Air Emissions (due to electric generation)	Dr. Calvin Parnell	c-parnell@tamu.edu	(979) 845-3985
Location of Power Generators			
Railroad Ownership			
Inactive Railroad Stations			
Highway ROW - Existing			
Railroad ROW - Existing			
Railroad ROW - Existing Inactive			
Brownfields and Superfund Sites	Dr. Fred Smines	f-smeins@tamu.edu	(979) 845-5576
Location of Hazardous Materials Facilities			
Solid waste disposal sites - landfills, etc			
Prime Farmlands			
Quality of Farmland			
Flood plain - outside of 500 year flood zone			
Aquifer Recharge Zones and water springs	Dr. Ronald Kaiser	rkaiser@tamu.edu	(979) 845-5303
Slope - topography	Dr. Robert Coulson	r-coulson@tamu.edu	(979) 845-9725
Geology	Richard Carlson	carlson@geo.tamu.edu	(979)845-1398
River Basins	Dr. Robert Knight	bob-knight@tamu.edu	(979) 845-5557
Salinity (? Is this factor necessary)			
Soil types	Dr. Tom Hallmark	hallmark@tamu.edu	(979) 845-4678
Surface Waters - Wetlands	Dr. Robert Knight	bob-knight@tamu.edu	(979) 845-5557

Empirical Data of Recent Floods - Flooding			
Land Subsidence			
Location of Coal Deposits	Bob Popp	popp@geo.tamu.edu	(979)845-639
Forestland	Dr. Mark G. Tjoelker	m-tjoelker@tamu.edu	(979) 845-8279
Forest Patches	Dr. Mark G. Tjoelker	m-tjoelker@tamu.edu	(979) 845-8279
Riparian Areas	R. Douglas Slack	d-slack@tamu.edu	(979) 845-5707
Threatened and Endangered Species	Dr. Michael L. Morrison	mlmorrison@tamu.edu	(979) 862-7667

APPENDIX 4
SDSS MODEL FACTORS

Criteria

Roadway ROW -Existing private, state, county roads*	**Urban Areas: present/not present**
Railroad ROW - Existing active	**Superfund Sites**
Bridges	**Location of Hazardous Material Facilities**
Slope/Maximum grade*	**Solid Waste disposal site**
width of ROW	**Subsidence**
Vertical clearance	**Coal Deposits**
Horizontal alignment	**Forestland & Forestland patches**
Option to enter and leave highway ROW	**Riparian Areas**
Air Quality	**Threatened & Endangered Species**
Control speeds on turns (turning radius < 2miles)	**Farmland**
Inactive railroad stations	**Floodplain***
Turnouts	**Aquifers**
Location of Power Generators	**Geology/Faults***
Station locations	**Surface Waters***
Historic Areas	**Soil Types***
Historic Sites	**Wetlands**
Historic Markers	**Property line divisions**
Cemeteries: existing/not existing	**Oil & gas pipelines**
Archeological/ Paleontological Resources	**Population Density***
Parks & Wildlife Areas	**Structure Value/Improvements (parcel value)***
American Indian Sites: present/not present	

* Factors applied in the 2010 version of the model

APPENDIX 5
TEXAS URBAN TRIANGLE RESEARCH CONSORTIUM

The research consortium composed of research universities in the Texas Urban Triangle, and other research institutes and organizations, organized by metropolitan area. Goal is to promote research and policy and investments into the Texas Urban Triangle and its sustainable development.

Metropolitan Areas	Institutions/Organizations	Contacts
Dallas – Fort Worth	University of Texas at Arlington	Barbara Becker Donald Gatzke
	University of Texas at Dallas	Brian Berry Timothy Bray
	North Central Texas Council of Government	Mike Eastland
	Federal Reserve Bank of Dallas	Bill Gilmer
Houston – Galveston	Texas Southern University	Carol Lewis
	Houston Tomorrow	David Crossley
	Houston Advanced Research Consortium	Bill Harriss
San Antonio	University of Texas at San Antonio	Roberto Rodriguez
Austin	University of Texas at Austin	Fritz Steiner Ming Zhang Kent Butler
Bryan – College Station	Texas A&M University	Elise Bright Eric Dumbaugh Daniel Sui Mark Fossett Joe Feagin Mark Burris Kelly Brumbelow Francisco Olivera
	Texas Transportation Institute	Tim Lomax David Ellis
	University Transportation Center for Mobility	Melissa Tooley

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