Chapter V

TRANSPORTATION
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CHAPTER V

Conceptual Service Options

INTRODUCTION

The basis for any transit plan is the careful consideration of the realistic service types. The purpose of Chapter V is to develop a basic level of understanding of the different types of transit service that could be implemented. This chapter reviews the way that various transit services function and presents several different service concepts for Dubuque. Additionally, as a basis for discussion, a brief analysis of alternative fuels is presented.

TYPES OF TRANSIT SERVICE

The term "transit service" encompasses a wide range of alternatives. Traditionally, people think of transit service as buses operating on a strict schedule. A number of other transit service alternatives exist, such as demand-response service and commuter transportation.

Fixed-Route Service

Fixed-route transit service fits the popular description of a bus system—transit vehicles operating on specified routes and following set schedules. Specific bus stops are typically identified for the locations where passengers will be picked up and dropped off. Routes are usually laid out in either a radial or grid pattern.

Fixed-Route Service

In a radial route structure, all of the routes originate from a common point and extend to the outlying areas. The central location serves as a transfer point and is frequently located at a destination with high transit activity. In many communities, this is the central business district or downtown area, such as in Dubuque.

In a grid route structure, all of the routes function along a two-way direction (either north/south or east/west). The routes are normally spaced equidistantly if the roadway structure permits. This structure has no center transfer location. Instead, the transfers are conducted at intersections of the routes. This type of service is mainly used in urban areas where the population density is greater and equally distributed across the area. In rural areas, fixed-route service may be provided between major communities with connections to local services that operate within the communities.

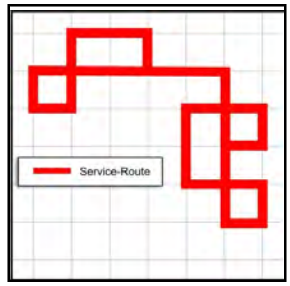
Fixed-route service is particularly convenient for passengers without disabilities. Research has shown that fixed-route passengers are willing to walk up to one-quarter mile to reach a bus stop. Therefore, a fixed-route service pattern may be efficiently laid out with routes having one-half-mile spacing. However, individuals with mobility impairments may have difficulty accessing the fixed-route system.

The advantages of fixed-route service are that it can be provided at a relatively low cost on a per passenger-trip basis, schedule reliability is high since buses do not deviate from their routes, service does not require advance reservations, and service is easy to understand.

Fixed-route transit service is seldom attractive for people with automobiles in smaller communities and rural areas. A private automobile offers flexibility compared to the rigid schedule of a fixed-route system. The need to walk even a few hundred feet to a bus stop, wait for the vehicle, and the comparatively slow travel time make the option of a private automobile an easy choice. Where there are significant congestion issues or limited parking availability, fixed-route transit service becomes a more attractive alternative. The low cost of transit as compared to owning and operating a private automobile can also be attractive, especially to young working couples who may be able to use the bus rather than own two vehicles.

The Americans With Disabilities Act requires that communities with fixed-route transit service also provide complementary paratransit service that operates, at a minimum, in a three-quarter-mile radius of each fixed route. Paratransit service is typically much more costly to operate than fixed-route service because of the characteristics of the service. Fixed routes are established to meet the highest demand travel patterns, while paratransit service must serve many origins and destinations in a dispersed pattern. Fixed-route operations lack the flexibility to meet the needs of passengers with any special requirements in low density areas.

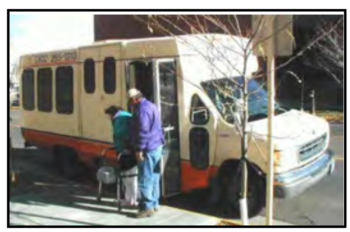
Service Routes



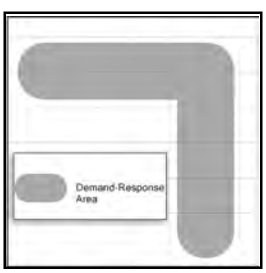
One concept that is being implemented in some communities as an alternative to traditional fixed-route or demand-response service is the service route. A service route is essentially a fixed route specifically designed to serve the elderly and disabled. Typically, a service route winds through residential neighborhoods with high concentrations of elderly and disabled persons in a pattern that passes within a block or two of all houses. It also directly serves important destinations, such as senior centers and commercial areas. The service provides a higher in-vehicle travel time and a longer wait for the bus than would normally be acceptable to the general public. The Bus (operating in Butte, Montana) and MET (in Billings, Montana) provide successful service routes to their local residents.

Demand-Response Service

Demand-response transit service, frequently termed dial-a-ride, is characterized as door-to-door transit service scheduled by a dispatcher. With demand-response service, advance reservations are typically required, although some immediate requests may be filled if time permits and if the service is particularly needed.



Demand-Response Service in Small Communities



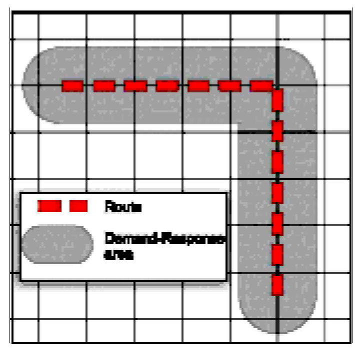
Demand-Response Service

The concept of demand-response service was originally developed in the early 1970s as an alternate form of public transportation for the general public. The original efforts proved to be more expensive than envisioned and did not attract the ridership that was forecast. As a result, demand-response transit has been used almost exclusively in this country for elderly and disabled passengers. However, many communities are beginning to recognize the advantages of demand-response service for low-density areas with low levels of transit demand. Improved technology has led to improvements in dispatching and scheduling, which has increased the efficiency of demand-response service and allows for real-time dispatching.

Flexible Routes

Another alternative is flexible routes, such as route-deviation or checkpoint service. With flexible routes, vehicle dispatching and scheduling must be done carefully to ensure that vehicles are available to serve the designated stops at the scheduled times. To provide a reasonable amount of flexibility, a lenient definition of on-time performance is typically used. A reasonable policy for route-deviation or checkpoint service within the Dubuque area is a 15-minute window at each designated stop.

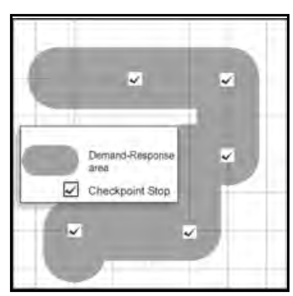
Route Deviation



Route-Deviation Service

With route deviation, transit vehicles follow a specific route, but leave the route to serve demand-response origins and destinations. The vehicles are required to return to the designated route within one block of the point of deviation to ensure that all intersections along the route are served. The passengers on the bus may have a longer travel time than for fixed-route service and the service reliability is lower. However, the ADA-mandated complementary paratransit service is therefore not necessary since the bus can deviate from the route to pick up disabled passengers.

Checkpoint Service



Checkpoint Service

Under checkpoint service, vehicles make periodic scheduled stops at centers of activity (such as program sites, shopping areas, or residential communities). The specific routes are not established between checkpoints, allowing the vehicles to provide demand-response service, and again alleviating the need for the ADA-mandated complementary paratransit service. Riders are picked up, typically at a reduced fare, at the checkpoints and taken either to another checkpoint or to a demand-response specific destination. Service between the checkpoints does not require advance reservations. However, service from any other location on a demand-response basis requires an advance reservation so that the vehicles can be scheduled for pick up and drop-off.

Checkpoint service offers an advantage over route deviation because there is no specified route for the vehicles to use. Checkpoint service requires only that the vehicle arrive at the next checkpoint within the designated time window.

Commuter or Express Service

With commuter and express service, the route is primarily designed to link different parts of the community together for employment purposes instead of linking all areas adjacent to the route. These destinations may be within the same geographic area. This type of service is commonly known as an express or limited express service. This type of service can range from long-distance medical trips to commuter trips between different geographical areas in the Dubuque area. There may be potential for express or limited stop service between major destination areas, such as from Downtown to Kennedy Mall.

FIXED-ROUTE ISSUES

Topography/Geography

One of the major hurdles to the design of the KeyLine routes is the natural topography and geography of the city. The bluffs and hills of Dubuque create a street and development pattern that deviates from traditional design. Because of the topography, many streets are designed along the natural elevation curves. Additionally, many neighborhoods are separated or have limited access points. With regard to the geography of the area, downtown is located in a non-central location.

Timed Transfers

The KeyLine system currently operates three separate transfer points. These transfer locations are located downtown and in the Westend neighborhood. The location of these centers means that there are limited opportunities for individuals to transfer, depending on what route they are on. The Orange route only accesses the downtown transfer point. On some occasions, individuals may have to wait long periods of time to transfer to their needed route because of the route timing. There is the potential to rework the transfer points and/or the timing of buses so that connections and timings may run smoother. In addition, the transfer center could use upgraded facilities, including bus pullouts, restrooms, and better shelter to enhance the experience of riders.

The main issue is the pulsing of the routes. Pulsing refers to routes meeting at designated locations at the same time. Table V-1 shows the location of the routes at the transfer centers by time. Some problems can arise from routes that pulse poorly, especially in a system that only allows riders to transfer buses at three locations. For example, both Red routes pull into the Delhi station at 30 minutes past the hour. These buses are usually the only ones at Delhi at this time, meaning that a user wishing to transfer from red to green, has a 30-minute wait. Improving these timings will help users complete their trips in a more timely manner.

Route Duplication

Many of the routes in Dubuque have a lot of overlap and duplication of services. There are areas of routes that either run on parallel streets or the same streets for a large portion of the run. Limiting the duplication of service will allow for a greater service area to be covered, creating a more efficient route structure. Many of the routes loop throughout the service area and crisscross other routes. This is an inefficient design of services.

Table V-1
Timed Pulse

Time	Downtown	Delhi	Kennedy Circle
6:15 AM			
6:30 AM			
6:40 AM			
6:45 AM			
7:00 AM			
7:15 AM			
7:30 AM			
7:45 AM			
8:00 AM			
8:15 AM			
8:30 AM			
8:45 AM			
9:00 AM			
9:15 AM			
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6:15 PM			

Source: KeyLine 2009

Legend
- Westbound
- Eastbound
- Westbound
- Eastbound
- Westbound
- Eastbound
- Southbound
- Northbound

West End Demand

Demand on the west end of Dubuque is geographically dispersed. Many of the important destinations, mostly shopping and medical facilities, are separated from each other and from downtown. This creates challenges in route development and timing. Many of the locations that need to be reached are 30 to 45 minutes of travel time by bus from the downtown area.

Route Segment Boardings

Large stretches of some routes showed very limited or no boardings during the three days of count data. It may be possible to realign segments of these routes to serve more people or to alter the type of service in some areas of the community.

CONCEPTUAL SERVICE IN DUBUQUE

At this point in the project the LSC Team is providing the City with conceptual service options that may be appropriate for use in the community. After reviewing all information to-date, on-site field notes, an awareness of the political nature of transit, public comment, and experience; the following section provides an overview of the types of service design that may be investigated in subsequent tasks. Limited detail is presented at this point in the project as this information is provided as a basis for discussion and response.

Funding Alternatives

Scenarios for future development obviously depend upon funding and sustainability of service and ridership. From a funding standpoint, the LSC Team is looking at scenarios such as the following:

- Services under the existing budget
- Optimal services with no funding restrictions
- Preferred services that meet both service needs and budget constraints

These scenarios will each include several options for services. Again, detailed evaluation of various options will be provided in Technical Memorandum #3.

Service Concepts

There are several concepts that may provide a basis for future route design alternatives. These concepts are presented in the following text and graphics as a means of discussion. Each has advantages and disadvantages, however each may prove advantageous over the existing service design.

Maintain Core Transfer Points

One option is to continue to maintain the existing three-transfer-point system. This type of system has inherent problems associated with route transfers and timings. As it is today, there are limited opportunities to transfer between buses and hence there are routes that have large loops to cover a greater geographic area of the City. Maintaining the three-transfer-point system is something that may require change in the future.

Move Main Transfer Point from Downtown

As mentioned previously, the main transfer point in the downtown area is geographically and topologically isolated from the majority of destinations to the west. One concept would be to move the main transfer point to a more central location, such as in the area of Mercy Hospital/Delhi Transfer Point. This would allow routes to be operated on an effective timed pulse system and allow for shorter routes. Interlining, the strategy of using buses on multiple routes (such as operating both red and green), can create a system where users do not require a transfer from bus to bus for some trips.

General Public Dial-a-Ride

There has been discussion regarding general public dial-a-ride service for residents of the area. This is not a realistic or feasible alternative. Fixed-route service is more efficient than dial-a-ride service. It is also capable of producing more one-way trips than dial-a-ride service. There may be areas where a dial-a-ride service area may make sense, however as an answer to fixed-route service, this is not a viable option.

Additional Hours of Service

Certainly without increased funding, the level of service for KeyLine will remain unchanged. Additional hours of service are warranted for both the morning and afternoon. At this point, it is nearly impossible to reach downtown for a workday start of 8:00 a.m. and it is difficult to catch the outbound bus from downtown. Increasing the number of service hours per day would improve service immensely. Additionally, there may be times during the day when service could be reduced or increased during the peak hours to increase frequency.

Paratransit Services

There are certainly ways to coordinate paratransit services between KeyLine and the RTA. The RTA is considerably less expensive to operate than KeyLine. The RTA buses sit idle much of the day and could be used to provide services for KeyLine. Historically, paratransit services have gone back and forth between the City and the RTA. Coordination between the two entities exists and could be further fostered. This is something that should be pursued through the City and RTA.

Service Design

Certainly the existing fixed routes present a host of challenges with the aforementioned issues. LSC has prepared a set of conceptual service options that will be explored in more detail in Technical Memorandum #3. Figure V-1 through V-6 present six concepts of operation which can aid in addressing some of the deficiencies as mentioned. Please note that these maps represent broader concepts and do not abide by existing street grid patterns. The routes on the conceptual maps should be thought of more as corridors of service rather than definitive routes.

Option 1

Figure V-1 shows one of the first conceptual options that has been developed. This option maintains the three current transfer points and only slightly modifies service. This option shows similar corridors as the existing service, with streamlined routes.

Option 2

This option depicts a fairly standard hub and spoke system, as seen in Figure V-2. All of the routes have one transfer point. With the exception of the Red route on the map, they all start and end at this point. The advantage of this type of system is that the routes all pulse at the same time, allowing users to easily transfer. The transfer point was chosen near the current Delhi transfer center because of the centralized location.

Option 3

This option uses two transfer points—downtown and at the mall. Figure V-3 depicts the route options. There are two routes that serve the northeast portion of the city. Three routes are crosstown routes that connect the two transfer points and serve various neighborhoods in between. The Blue route is a shopping circulator that is aimed at serving the mall and various other shopping plazas in the region.

Option 4

This option also features two transfer points—one near Delhi and one downtown. The Red and Black routes connect the two transfer points. The other routes all stem from one of these two transfer centers. Figure V-4 shows this option in more detail.

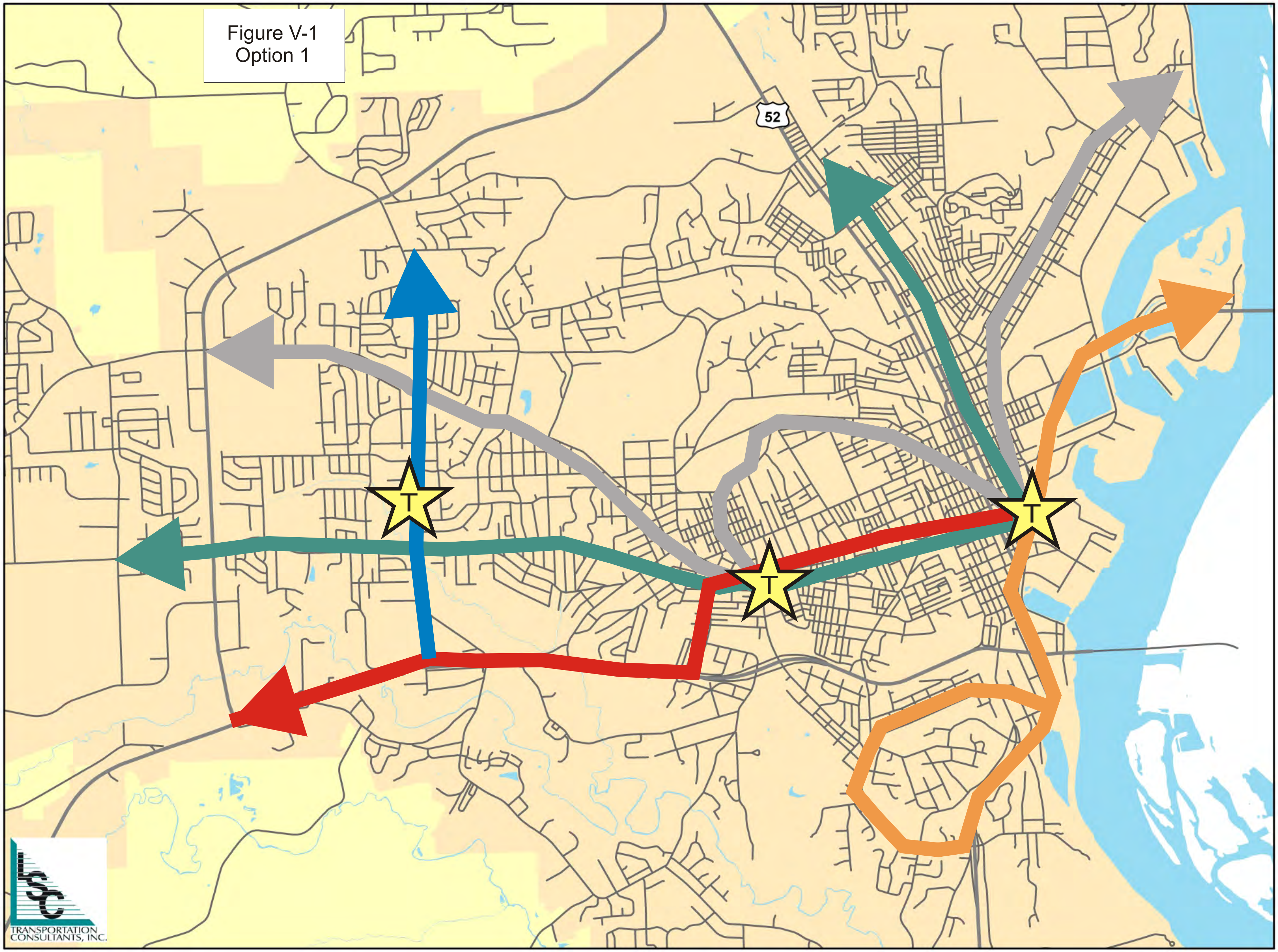
Option 5

This option has a major and minor transfer point. The major transfer point is near Delhi, with the minor transfer point near the mall. This option combines a hub-and-spoke design with two circulators. The two circulators are for the mall and local university and school-age students. Figure V-5 shows this option in further detail.

Option 6

This option, shown in Figure V-6, is the largest departure from the current service. While it has a basic hub-and-spoke structure with the transfer center being near Delhi, it also incorporates demand-response service. These larger demand-response zones operate similarly to paratransit, with the exception being that they are open to everyone within the zone. They also do not generally act as door-to-door services, but rather connect people to the existing route structure. Scheduling would be real-time rather than with advance reservations. Demand-response zones help to serve areas that have limited ridership but still have a need for transit.

Figure V-1
Option 1



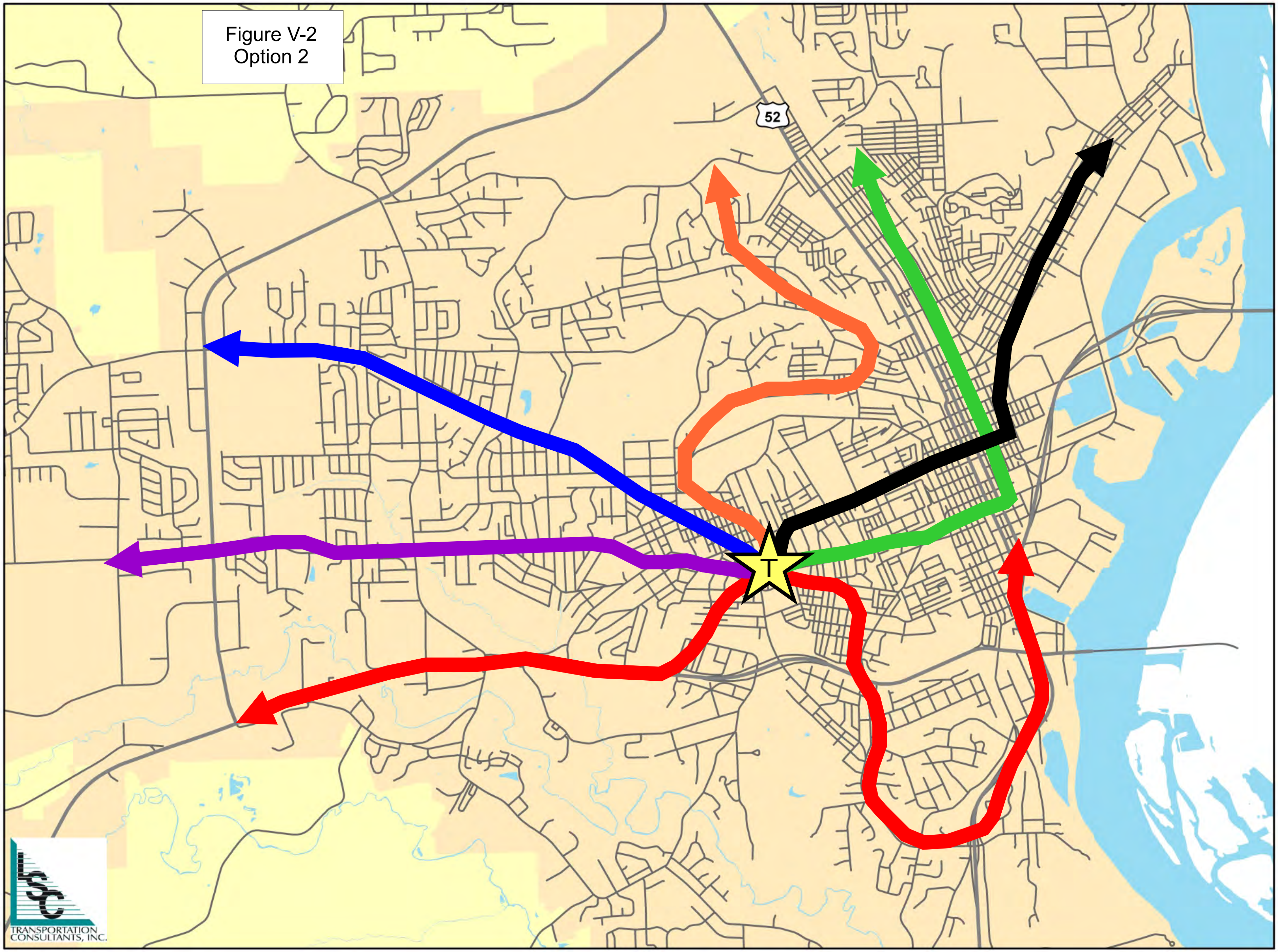


Figure V-2
Option 2
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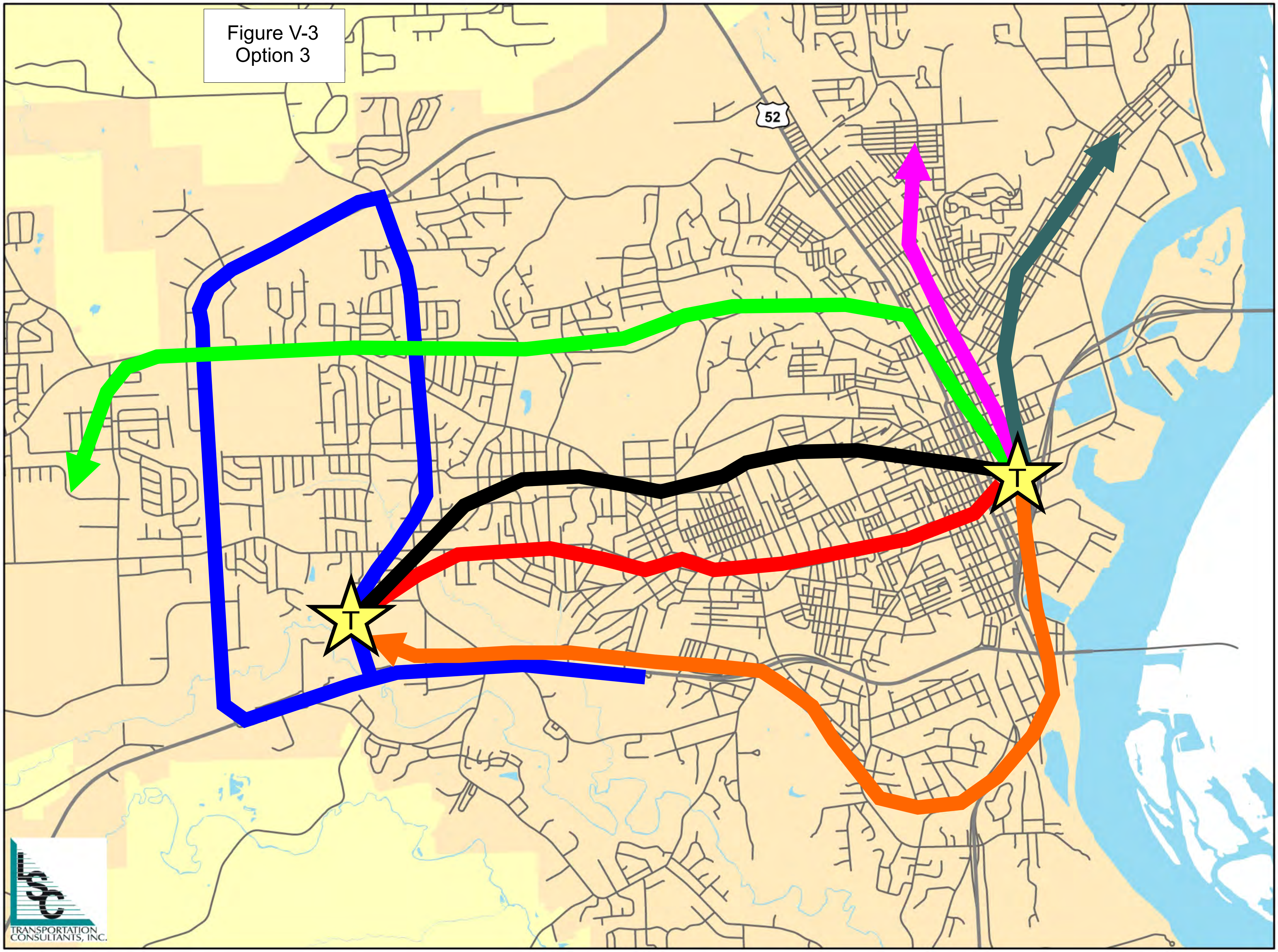

Figure V-3
Option 3

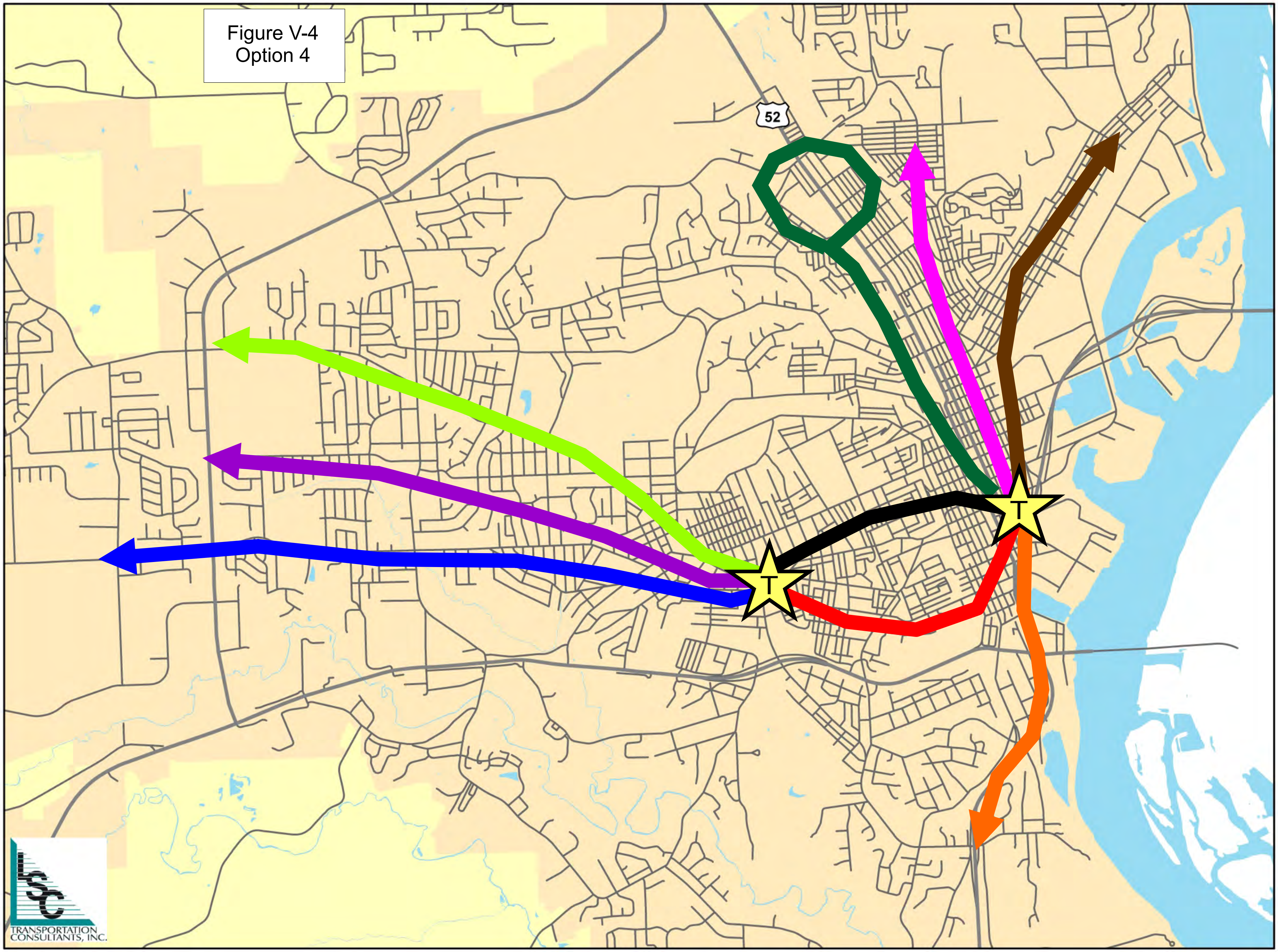

Figure V-4
Option 4

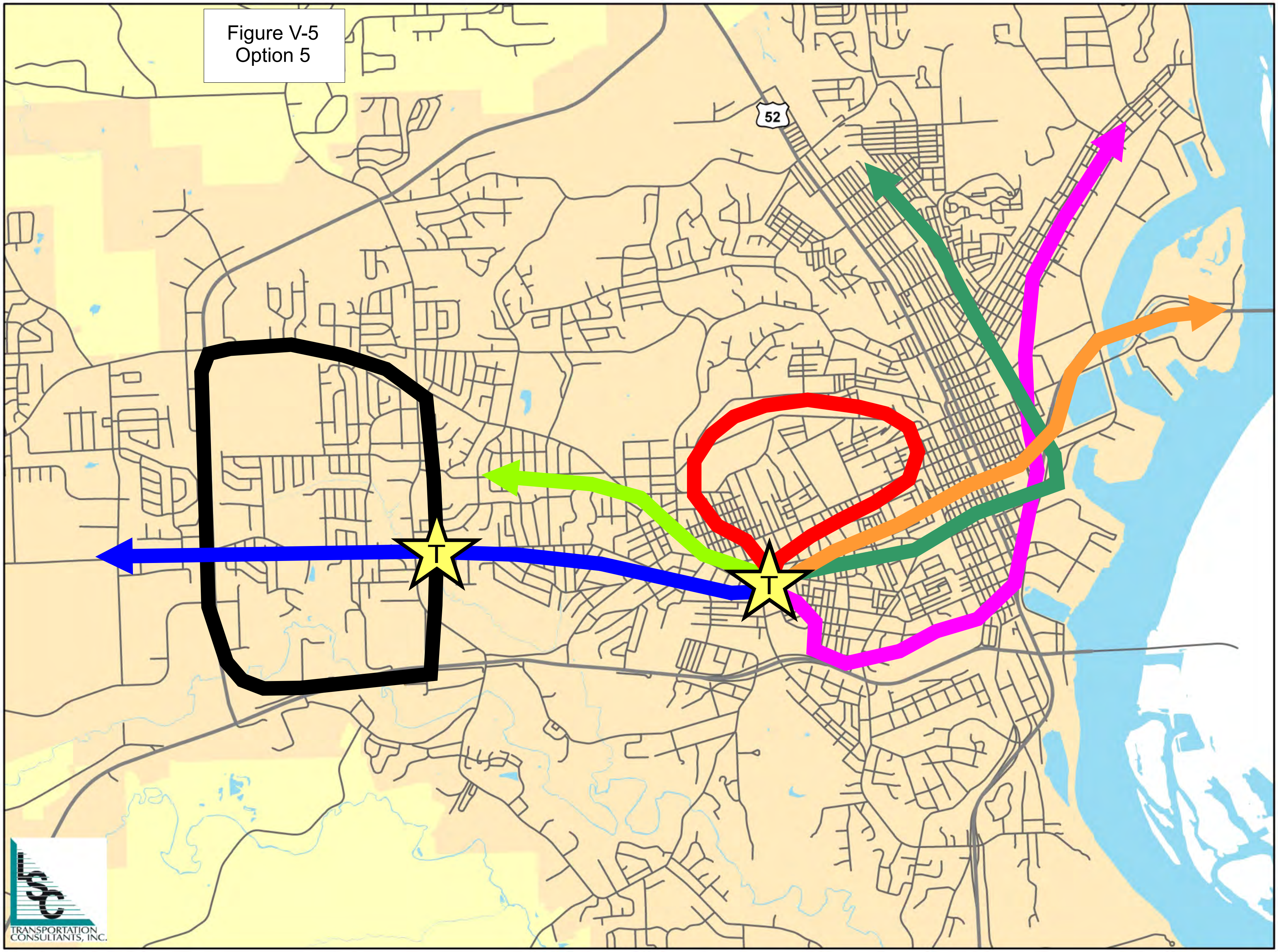

Figure V-5
Option 5

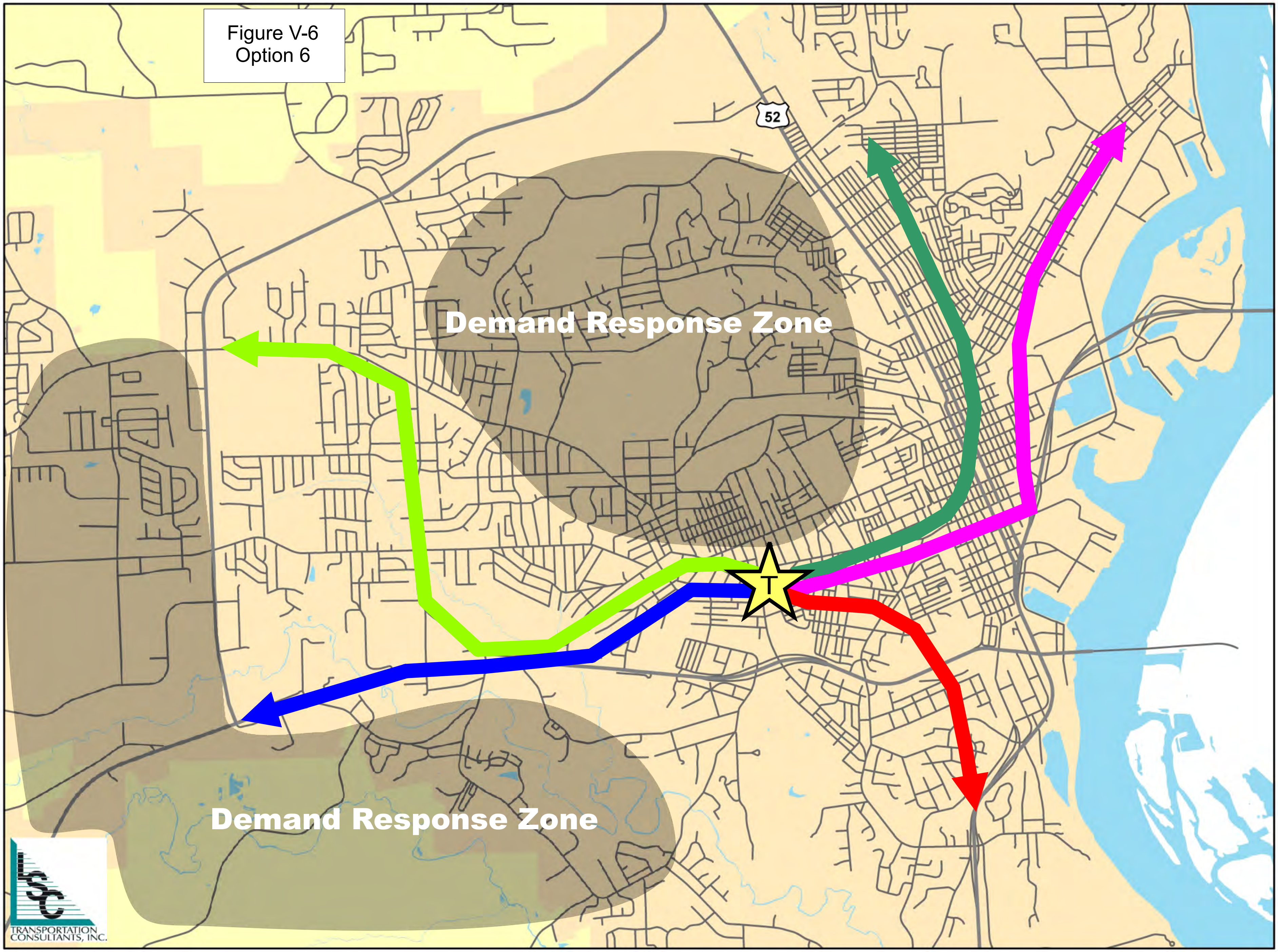
Figure V-6
Option 6
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Demand Response Zone
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ALTERNATIVE FUELS

To reduce pollution from mobile sources, the national Clean Air Act Amendments of 1990 encouraged the use of clean fuels such as methanol, ethanol, and natural gas derivatives (including compressed natural gas, liquefied natural gas, and liquefied petroleum gas). In order to develop a working concept of the different alternative fuels, their advantages and disadvantages, and their potential application for the area, the following review of relatively common alternative fuels has been prepared.

The purpose of this report is to analyze the effectiveness of alternative-fuel buses as compared to the operational effectiveness of the traditional diesel-powered bus. This report evaluates existing studies on Hydrogen Fuel Cell, Compressed Natural Gas (CNG), Liquified Natural Gas (LNG), and Hybrid Diesel-Electric powered buses. There is also some discussion of Ultra Low Sulfur Diesel (ULSD) powered buses. This report presents the highlights of each study and charts that compare each of the above-mentioned fuels in areas of cost and reliability.

Compressed Natural Gas (CNG)

Transit agencies have been using CNG- or LNG-fueled buses since approximately 1991, which makes these two fuels the oldest technology available for alternative fuel use. In 1991, the State of Texas enacted House Bill 734 (Senate Bill 200) which required all centrally fueled fleets of 15 or more vehicles to convert 90 percent of their vehicles to alternative fuels by 1998. The non-funded mandate law encouraged the use of natural gas, which is produced in Texas, in either the form of CNG or LNG. For this analysis, three research documents were reviewed—a case study developed by the US Department of Energy on the use of CNG and LNG buses at Sun Metro Transit of El Paso, Texas; *A Comparative Analysis of the Feasibility and Cost of Compliance with Potential Future Emission Standards for Heavy-Duty Vehicles Using Diesel or Natural Gas* prepared by Sierra Research of Sacramento, California for Californians for a Sound Fuel Strategy; and statistical data comparing natural gas performance to diesel fuel obtained from the Clean Air Initiative website.

LNG is natural gas that has been condensed to a liquid, typically by cryogenically cooling the natural gas to -250 degrees Fahrenheit. CNG is natural gas that has been compressed to a pressure of 2,400 to 3,600 pounds per square inch (psi). LNG provides a greater driving range than CNG. It is also denser than CNG and fewer tanks are needed to hold the same amount of fuel, which means less weight added to the bus. A CNG bus weighs about 1,900 pounds more than a similar diesel bus, but a LNG bus is only 600 pounds heavier. Having fewer fuel tanks also decreases the cost of an LNG bus. On average, an LNG bus costs approximately $20,000 less than a similar CNG bus and approximately $50,000 more than a similar diesel bus.

There have been various studies conducted on the environmental impacts of natural gas-fueled buses that have found that the CNG-powered buses pollute more than a diesel bus equipped with after-treatment devices (such as a catalytic converter) and using ultra low sulfur diesel fuel (ULSD). The Sierra Research study stated the following:

> *By using after-treatment devices to reach the 0.01 g/bhp-hr level for Particulate Matter (PM) emissions, diesel PM emissions will be the equivalent to PM emissions from natural gas engines, eliminating most if not all of the health concerns related to operation of diesel-fueled vehicles.*

The study went on to say that modifications to diesel engines, including the use of after-treatment devices, are much more cost-effective for reducing oxides of nitrogen (Nox) and PM emissions than is the substitution of natural gas engines for diesel engines.

The strength of compressed natural gas (CNG) as an alternative fuel for transit buses is that it is generally less expensive per unit of energy than gasoline or diesel fuels. CNG fuel also has the potential to reduce the oxides of nitrogen emissions, reactive organic hydrocarbons, particulate matter concentrations, and carbon monoxide concentrations. The advantages of a CNG bus include no visible pollution and quieter operation. Over the last several years, CNG has become one of the alternative fuels of choice for transit systems in the United States.

Historically, the weakness of CNG fuel is its difficult and large storage requirements. CNG is typically stored in high-pressure cylinders under maximum pressure. The high weight, volume, and cost of the storage tanks have been a barrier to its commercialization as an alternative fuel. The recent development of lighter aluminum tanks, however, has reduced this disadvantage to some degree.

The main problem with CNG is primarily associated with the moisture in the compressed fuel freezing during the fueling process, since the approximate time to fill a bus may be three hours. Other problems that have been encountered nationally include the quality of local CNG supplies, limited testing of altitude effects on CNG, low power for climbing steep grades, and limited CNG testing in extreme temperatures.

According to TCRP Report #38, modifications from diesel to CNG are observed to result in reductions in fuel economy of between 20 and 40 percent in transit service when natural gas engines are used in place of similar diesel engines in similar service. As a rule of thumb, manufacturers price heavy-duty natural gas engines at nearly twice that of counterpart diesels.

Methanol

Most of the methanol used commercially within the United States is manufactured from natural gas, making it economical to use. The tailpipe emissions of methanol are generally considered to be about half as reactive as an equal mass of emissions from gasoline or diesel fuel, promoting its use to reduce ozone in urban areas (such as Los Angeles). By volume, methanol has slightly more than half the energy content of diesel fuel and slightly more than half the energy content of gasoline. Due to the above characteristics, a methanol engine will consume slightly more than twice the volume of fuel per mile of service as compared to a diesel engine. Due to cost, methanol is unlikely to be an alternative of choice for the transit industry.

Ethanol

While not as corrosive as methanol, the major use of ethanol is currently limited as an octane additive and oxygenate for gasoline. The cost of ethanol is almost twice as much as that of methanol, making its use limited as a motor vehicle fuel. Aside from the fuel's economic drawbacks, ethanol has many benefits. Ethanol produces lower carbon monoxide emission rates than gasoline, has a higher energy density than methanol, and has a lower toxicity than either methanol or gasoline.

Diesel Fuel

Diesel-fueled engines have traditionally dominated the transit vehicle marketplace due to diesel fuel's efficiency and durability, making up nearly 90 percent of the existing fuel for existing transit agencies. From an air quality perspective, diesel engines have very low tailpipe emissions of carbon monoxide and other organic gases. The concern from an air quality perspective, however, has been the diesel emission rates of the oxides of nitrogen (Nox) emissions and particulate matter. Due to increasing environmental pressure to reduce the above emissions, the Environmental Protection Agency and American Public Transit Association have developed stringent regulations. The Clean Air Act Amendments (CAAA) permit the use of clean diesel in urban buses provided that the clean diesel engines meet the particulate matter standards imposed by the CAAA. According to the Transit Cooperative Research Report #38, in the past few years emission rates from new automotive diesel engines have decreased significantly, mainly in response to legislated emission standards. Additionally, TCRP Report #38 reports that fuel is a major contributor to the cost of operating a bus and obtaining accurate fuel cost comparisons against diesel engines is an important element of any evaluation of alternative-fuel options. Fuel consumption can vary widely depending on several factors, one being road grade. It is difficult at this time to determine fuel consumption without first determining the service and vehicles to be used.

Biodiesel

Biodiesel is a clean-burning alternative fuel made from the domestic renewable resources of vegetable oil and animal fat. Biofuel consists of the mono-alkyl esters that are derived from vegetable oils or animal fats which conform to the ASTM-D-6751 specifications for use in diesel engines. This fuel is then mixed with diesel to reduce the amount of pollution that the vehicle normally produces.

One advantage of biodiesel is that the fuel can be used in existing diesel bus engines with a small amount of engine adjustment at a low cost. There are several grant sources through the FTA and the Department of Agriculture to aid in funding biodiesel conversions, such as the Clean Fuel Program and Congestion Mitigation Air Quality Program.

One small rural provider in Vermont recently started a program making their own biodiesel. This program successfully makes a small quantity of fuel and is looking to expand. The costs per gallon are substantially lower than diesel costs.

Hydrogen Fuel Technology

Hydrogen fuel cell-powered buses use a new technology still in the prototype phase of development. The National Renewable Energy Laboratory, which is an agency within the United States Department of Energy (DOE), has prepared three analytical studies on this new technology. Three transit agencies—AC Transit of Oakland, California; Santa Clara County Transportation Authority (VTA) in San Jose, California; and SunLine Transit in Palm Springs, California—that use hydrogen technology are presented in the following sections.

AC Transit

AC Transit partnered with Chevron Technology Ventures to construct a hydrogen energy fueling station. AC Transit chose to modify an existing facility and spent $1.5 million on modifications to the facility. The hydrogen fuel cell buses are 40-foot heavy-duty transit buses that cost $3.2 million each.

AC Transit ran a reliability test comparing the three fuel cell buses with three traditional diesel-powered buses. During the test period, April through November 2006, the fuel cell buses were available for service only 77 percent of the time. The diesel buses were available for service 85 percent of the time. Maintenance cost per mile for the fuel cell buses was $1.45, whereas the diesel buses had a cost per mile of only $0.58.

Due to the high volatility of hydrogen gas, AC Transit had to renovate a vehicle maintenance bay at a cost of $1.5 million. A firewall designed to withstand a fire for two hours was constructed between the hydrogen bus bay and the other mechanical bay. Also needed was:

- Hydrogen leak and fire detection thermal systems
- Ignition for free space heating system
- Antistatic ground floor covering
- High-speed roll-up doors
- Magnetic door releases
- Audiovisual strobe alarms
- A three-fan ventilation system capable of providing four to six air exchanges per hour
- Class one division two electrical classifications

Even with all this safety equipment, mechanics had to depressurize each bus to 600 pounds of hydrogen per square inch before the bus could enter the bay. This was done to save on modification costs; however, it forced the mechanics to push the bus into the bay. The study did not state what amount of cost savings was derived from this procedure.

VTA Transit

For their demonstration project, VTA constructed a new maintenance facility and fueling station for their hydrogen fuel cell buses. This cost the agency $4.4 million. Three hydrogen-electric Gillig buses were purchased at a cost of $10.6 million (approximately $3.5 million each).

Specific information gathered from this study includes:

- Fuel cell buses are 6,800 pounds heavier and two feet taller than a standard diesel bus.
- The batteries on the fuel cell buses had frequent cell failures that caused shorting problems that significantly decreased voltage.
- The air conditioning system was modified to be driven by electric motors rather than mechanical belts. Initially there were many problems with the electric motors failing.
- The fuel cell power system cell stack assembly was decaying at a much higher rate than expected.

- Diesel bus availability during the testing period was 85 percent. Hydrogen bus availability was only 58 percent. This means that for a transit service operating 365 days a year, these hydrogen fuel cell buses would only be in service 212 days out of 365.
- The average maintenance cost per mile for the fuel cell buses was $3.55. The average maintenance cost per mile for the diesel buses was $0.54.
- The fuel cell buses averaged 898 miles between road calls; the diesel buses averaged 8,189 miles between road calls.

SunLine Transit

SunLine Transit has been using alternative fuel buses since 1994 when it purchased its first CNG-powered bus. All buses and support vehicles are powered by CNG. SunLine tested a hydrogen fuel cell bus identical to the fuel cell buses in the AC Transit and VTA Transit studies. The agency also tested a hydrogen hybrid internal combustion engine (HHICE) bus, which is a one-of-a-kind vehicle. The fuel cell bus cost $3.1 million. The HHICE bus cost $1.2 million. The engine was customized to operate on a CNG and hydrogen fuel blend.

These buses were tested against five new CNG-powered buses built by Orion Industries at a cost of $375,000 each. The test comparison lasted 11 months, from January through November 2006. Below are the results of this test:

- The fuel economy of the fuel cell bus was 149 percent higher than the CNG bus.
- The fuel economy of the hybrid bus was 46 percent higher than the CNG buses.
- The maintenance cost per mile for the hybrid bus was $0.55, $0.44 for the fuel cell bus, and $0.25 for the CNG bus.

The results of these three studies show that hydrogen fuel cell technology for heavy equipment is still in its infant stage and could take years before it can used in a commercial enterprise. The costs for the vehicles and supplemental equipment are staggering. The $3.5 million cost of one hydrogen fuel cell bus could purchase nine CNG buses at $375,000 each and 11 buses running on ultra-low-sulphur diesel fuel at $300,000 each. Also, the dangers of devastating explosions and fires associated with hydrogen gas demands tremendous expenditures of revenue to make transit facilities safe and able to maintain and fuel the hydrogen buses. All but one of the transit systems (SunLine) incurred millions of dollars in expenses for facility construction and remodeling. SunLine's expenses were lower mainly because it had experience in using alternative fuels and developing facilities for these vehicles. The desert climate in which SunLine operates also saved on construction of a facility that did not need to be protected from cold weather or heavy rainfall.

Hybrid Buses

Hybrid electric buses combine a traditional diesel engine with a parallel electric propulsion unit that blends both the diesel engine power and the electric motor power to provide propulsion power to move the bus. This hybrid propulsion system lowers the amount of diesel fuel needed to power the bus, which also lowers the amount of pollutants produced by diesel fuel. The parallel propulsion system has a drive unit that contains two motors and fits where a standard size transmission would normally be placed in a transit bus. The National Renewable Energy Laboratory, an agency within the United States Department of Energy (DOE), has prepared an analytical study on this new technology. The study was conducted at King County Metro, which replaced their old fleet of hybrid buses that ran on diesel and electricity provided by a cantilevered power wire with the hybrid electric buses described above.

King County Metro Transit Hybrid Articulated Buses

This evaluation focused on diesel and hybrid diesel bus comparative operational efficiencies. Ten hybrid buses were compared with 10 diesel buses over a 12-month evaluation period.

King County Metro operates public transit service for the City of Seattle and King County. Its fleet contains 1,400 standard and articulated buses, trolley buses, and streetcars. New Flyer is the manufacturer of the new hybrid electric buses used in this study. The vehicles are powered by a General Motors Allison E50 electric parallel hybrid propulsion system and a Caterpillar C9 diesel engine. Listed below are some pertinent findings from the study.

- The hybrid articulated bus is priced at $645,000, while the diesel articulated bus is priced at $445,000.
- The hybrid buses had, on average, 27 percent higher fuel economy than the diesel buses.
- The hybrid bus is approximately 1,000 pounds heavier than the diesel bus.
- The total maintenance cost per mile was practically identical, with the diesel buses averaging $0.46 and the hybrid buses averaging $0.44.
- The total operating cost per mile showed the hybrid buses cost less to operate than the diesel buses. Hybrid total operating cost per mile was $1.06. The diesel buses cost $1.25 per mile to operate.
- The hybrid buses ran cleaner than the diesel buses. The diesel buses used biodiesel at a ratio of five percent biodiesel and 95 percent ultra-low-sulfur diesel (ULSD). The hybrid used a 100 percent mixture of ULSD. The study showed that the hybrid bus produced 26.6 percent less nitrogen oxide (NOX), 97.1 percent less particulate matter (PM), 59.5 percent less carbon monoxide (CO), and 56.3 percent less total hydrocarbons than the bus using the five percent biodiesel with 95 percent ULSD fuel.

Diesel-electric hybrid bus technology is far more advanced than hydrogen fuel cell technology and has been in use commercially for over 10 years. The diesel-electric hybrid bus has been proven to operate almost as reliably as traditional diesel buses, uses less fuel, and produces far fewer pollutants. The only drawback, especially for small transit agencies, is the high cost of the vehicle when compared to the cost of a traditional diesel transit bus. Small transit agencies would also incur additional training costs associated with familiarizing its maintenance crew with the electric propulsion system. One advantage of this alternative fuel technology is that there is no need to develop a fueling station specifically for this alternative fuel since it runs on diesel fuel.

Tax Credits

On July 29, 2005, Congress passed the first comprehensive energy legislation, HR 6 (P.L. 109-58), which includes a number of provisions for alternative-fuel vehicles. The credit for purchasing a fuel cell vehicle is determined by a base credit amount that depends on the vehicle's weight. For fuel cell-powered vehicles weighing less than 8,500 pounds, the base credit will be $8,000, while heavier vehicles will get bigger credits.

Overall Conclusions

The overriding theme of this section of the document has been that technology exists that can fuel buses with fuels other than diesel. The major issue, however, is that this technology results in greater costs to a transit agency in terms of vehicle procurement, facility construction or improvements, and training costs. In terms of environmental improvements, only the diesel-electric hybrid shows significant environmental improvements over a diesel engine equipped with pollution control equipment and running on ULSD. However, with the continued escalation of diesel fuel costs and the geopolitical issues associated with the importation of oil, transit systems need to be aware of the possibility that alternative fuels may soon be mandated by the federal government. If this mandate extends to other types of transportation vehicles, the higher costs associated with alternative fuels may become nonexistent.