

USING GIS TO INCORPORATE POPULATION
CHARACTERISTICS IN EXPLORATION OF
POTENTIAL RADIOACTIVE WASTE ROUTES
IN OKLAHOMA

By

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CHAPTER I

INTRODUCTION

Scientific research, national defense, and commercial development have all increased use of radioactive materials since the 1940's. Overtime, as these areas of nuclear technology have evolved, the volume of by-product waste has also grown. Many Americans are unaware of radioactive waste materials being transported by truck, train, or barge through their own cities. But knowledge of proximity to radioactive materials instills a strong personal reaction of apprehension in the general population (Sjoberg 2002).

In developing strategies to deal with radioactive waste routes, research has considered the potentials for risk consequence and probabilities of public harm should an accident occur. Preferred waste routes have been recommended using least-cost travel time or travel distance as the primary criteria. There has been limited progress in efforts to explicitly include population characteristics in the research process of route selection. Much of this is due to limitations in the way computers interact with large amounts of complex data in a routing problem, as is discussed in the Literature Review portion of this study. While incidents involving radioactive materials have been rare, during the decision making process, policymakers attempt to balance routing considerations with

public safety concerns. Positive communication with the general public is fundamental to the process. Therefore, there exists a strong need to identify and effectively incorporate population characteristics into the decision making process of selecting radioactive waste routes.

Since both waste routing and the analysis of population characteristics rely on spatial information handling, geographic information systems (GIS), which is designed to efficiently process spatial data, has the capabilities to help in the development of this type of methodology. It would be beneficial in the decision making process to know not only how many people live along the least-cost routes, but also the demographic composition of the people that could potentially be impacted should an accident take place. This information could influence which routes pose the least potential health risk or support the development of emergency response procedures. Ultimately, the creation of a GIS based routing methodology which attempts to balance population characteristics with the minimization of travel time offers decision makers a better understanding of their options in the route selection process. This study will attempt to support this effort in the state of Oklahoma by using GIS to incorporate population characteristics in exploration of potential radioactive waste routes.

Research Problem

Because of its geographical location, Oklahoma is potentially situated on national transportation routes for all types of radioactive waste shipped from points-of-origin to designated waste repositories. These routes transect Oklahoma's small rural communities and heavily populated urban areas. But to date, no state designated, preferred radioactive

waste routes have been established in Oklahoma. As the national transportation of nuclear waste grows, the need for selecting routes which allow waste to move through the state in the least amount of time balanced against concern for population characteristics will become even more critical to Oklahoma. To meet these goals, policymakers would have to adhere to the following federal regulations.

In 1992, the U.S. Department of Transportation (U.S. DOT) established the Guidelines for Selecting Preferred Highway Routes for Highway Controlled Quantity Shipments of Radioactive Materials. The Guidelines advocate shortest-distance or least-transit-time path in an area as the main criteria for route selection, balanced against least total population within a route corridor. Identification of population characteristics is not a first-tier priority of this route selection process. Emergency response capabilities are considered a secondary factor. The U.S.DOT contends in this routing procedure, that due to the nature of the cargo, transporting the materials quickly through an area lessens the overall probability of risk for the general population.

The other consideration policymakers must take into account is the necessity of ensuring nondiscrimination under Title VI of the Civil Rights Act of 1964, and meeting the requirements of Executive Order 12898 on Environmental Justice. This Executive Order was established in 1994 and the U.S. DOT implemented its final order to comply in 1997. To meet Environmental Justice mandates, in the transportation decision-making process, one must “avoid, minimize, or mitigate disproportionately high and adverse human health and environmental effects, including social and economic effects, on minority populations and low-income populations” (U.S. Department of Transportation 2000). Population characteristics must be identified.

Because of less expensive housing stocks, the elderly, along with low income and minority neighborhoods, are often located in proximity to the nation's major transportation routes (Margai 2001). Radioactive waste shortest distance and least-transit-time routes will most likely pass through these neighborhoods. The populations living in these communities are generally considered the most vulnerable in public safety situations. Environmental Justice mandates that the identified populations be informed and provided the opportunity to become a part of the decision making process. As the amount of radioactive waste grows and the need to transport the materials cross-country increases, identifying population groups with the intent of bringing them into the decision making process will become even more important.

Objectives

For state policymakers, it is critical that they adopt effective analysis procedures and understand how to apply these regulations. By including GIS processes, planners can offer with greater certainty, more informed options for consideration in the safe routing of waste through vulnerable populations.

The goal of this research is to create routing techniques and report on a methodology that identifies and incorporates population demographics directly into the creation of potential radioactive waste routes. In previous studies, computer software programs have been used to run least-cost routes, shortest path based on distance and least-transit-time, but the demographic makeup of the reported population was of secondary consideration and incidental to route locations. In this study, GIS techniques will be identified that incorporate explicit consideration of population demographics into

the routing model and provide a basis for analyzing the routing outcome. GIS software has evolved in the past 10 years and also become increasingly available to planners and analysts for this type of desktop research. GIS not only has mapping and visualizing capabilities but also, more importantly, it supports spatial analysis. By evaluating the effectiveness of the various least-cost routing criteria in this study, hopefully future planners can take this information and analyze with greater certainty possible routing scenarios which incorporate least-cost principals and population characteristics.

Study Area

This study examines several waste routes based on differing least-cost criteria and their effectiveness in identifying the demographics of the population living along the routes. The study area is defined by Oklahoma's location relative to national nuclear reactor sites and potential waste repositories. Three measurements for least-cost routing will be explored for Oklahoma. After investigating how national shortest path routes based on distance and least-transit-time interact with Oklahoma's population, least population routing criteria based on Oklahoma population demographics will be developed. This least-cost routing procedure takes into consideration the smallest number of population living in proximity to potential routes, and the development of a comparative index where Oklahoma's population characteristics establish the potential route. Using Oklahoma's population as the basis for comparison provides a controlled location to test least-cost routing scenarios and evaluate the effectiveness of potential GIS processes.

Significance of Research

Public policy is driven by public perception. Routing radioactive waste through populated communities is a somewhat controversial public policy. GIS and its analysis capabilities provide the means to identify potentially vulnerable groups in the general population. With this knowledge, policy makers can more effectively communicate to the community that their needs have been taken into consideration, and a public policy is well considered.

In 2005, Hurricane Katrina was a national “wakeup call” regarding vulnerable populations unable to remove themselves from harms way. When implementing potentially divisive laws and regulations, particularly where modern technologies aid society but have potentially negative side affects, it is vital that policy makers be as well informed as possible. Knowing how to effectively use the functionality of GIS as a tool for spatial inquiry can provide the means of gaining important knowledge in this undertaking. The GIS procedures developed in this least-cost routing study can help policy decision makers acknowledge that these populations exist and assist in routing hazardous waste in the safest possible manner.

The next chapter provides a historical overview of the treatment of radioactive waste materials in the United States. It also describes various research philosophies of waste routing and efforts in the analysis of populations living in association with hazardous materials. Finally, a review of GIS methods that have previously been incorporated into hazardous waste routing research will be described.

CHAPTER II

LITERATURE REVIEW

Introduction

It is important to understand the historical basis for the current status of routing radioactive waste in the United States and how efforts to identify population demography have evolved. The literature in this review summarizes current policies and introduces research philosophies that drive the discussion of safe handling of hazardous waste. This includes the evaluation of potential risk to the population and the weighing of accident probabilities, as opposed to consideration of accident consequence for the public. As noted earlier, the U.S. DOT Guidelines (1992) emphasize moving radioactive materials quickly through an area as a key factor in the routing decision process. Details of how the Guidelines should be implemented will be explained. Another aspect of the research debate considers population characteristics in hazardous waste research and how examines how those efforts have been studied. The final section of the Literature Review focuses on the incorporation of GIS techniques into hazardous waste routing

Treatment of Radioactive Waste in the U.S.

Since the 1950's, the United States government has attempted to deal with the transportation and long-term storage of low and high-level radioactive waste materials. Before permanent repositories were sited, most waste materials were typically stored or buried onsite at commercial and government facilities. It was also disposed of offshore in the oceans (The U.S. White House 1993).

Government, commercial and educational facilities use complex combinations of radioactive materials to achieve their various objectives. The by-product radioactive waste is categorized as low-level, high-level, and transuranic. These designations also have sub-categories. Category designations are based upon the makeup of the waste material (radioactive elements) and the level of radiation energy emitted. The category of waste determines which laws regulate the materials. It also determines the destination it will ultimately be routed to for long-term disposal.

One of the early Federal laws enacted to deal with the permanent disposal of radioactive waste disposal is the Low-Level Radioactive Waste Policy Act of 1980. The purpose of this Act is to turn over disposal responsibility of non-government, low-level waste generated in a state from the Federal government to that particular state. The states can also form alliances known as compacts (General Accounting Office 2004). The Act requires individual states or compact groups ultimately build their own waste repositories. Correspondingly, transportation of the waste would remain within the state or compact group boundaries.

The Nuclear Waste Policy Act of 1982 is one of the first laws to address primary responsibility for the storage of high-level waste (National Safety Council Environmental

Health Center 2001). With this Act, the Federal government took responsibility for finding one national, long-term burial site to store spent nuclear fuel rods produced at commercial nuclear power plants and Department of Energy (DOE) facilities. Currently, a site known as Yucca Mountain located in Nevada, approximately 100 miles northwest of Las Vegas, has been designated for this purpose.

Transuranic is another category of waste which also emits high-levels of radiation. It is a byproduct of nuclear weapons research development, production, and cleanup. The DOE National Security and Military Applications of Nuclear Energy Authorization Act of 1980 authorizes disposal of this waste category (Department of Energy Carlsbad Area Office 2000).

To ensure public safety, policy makers have enacted government regulations to dispose of radioactive waste. Federal and state government agencies share in the responsibility of oversight and execution of these regulations and statutes. The safe disposal of radioactive waste is controlled through a complex interaction of Federal and state agencies. Along with the U.S. DOT and DOE, the Nuclear Regulatory Commission (NRC) and Environmental Protection Agency (EPA) are also involved. Various sub-organizations and offices within these Federal departments administer regulations.

States have their own counterpart agencies which offer local oversight. Oklahoma's Department of Transportation (ODOT), Department of Public Safety (ODPS), and Department of Environmental Quality (ODEQ) are three such agencies. Oklahoma is a member of the Central Interstate Low-level Radioactive Waste Commission (CILLRWC). This is a state compact group with approval authority over the export for disposal of low-level radioactive waste produced in Oklahoma.

High-level waste almost exclusively consists of spent nuclear fuel rods. DOE research facilities and commercial nuclear power plants are the sources for this waste. Currently, high-level waste is stored on site or transported between facilities owned or managed by the same entities. A Federal repository at Yucca Mountain is the proposed long-term radioactive waste storage site. The EPA anticipates the earliest Yucca Mountain could begin accepting waste is 2017. Waste from "77 locations in 35 states, including 72 commercial nuclear power plants and 5 DOE facilities" is targeted for shipment to Yucca Mountain (EPA 2005, 1). Federal Authorities project the facility will operate for 33 years. It is expected to hold 70,000 metric tons of waste (National Safety Council Environmental Health Center 2001).

DOE research and the Navy, via the Department of Defense, are responsible for the production of transuranic waste. The DOE indicates the waste is "not spent fuel rods but consists primarily of protective clothing, tools, glassware, equipment, soils, and sludge" (National Safety Council Environmental Health Center 2002, 10). Transuranic waste is transported from 10 national DOE sites to the Waste Isolation Pilot Plant (WIPP) outside of Carlsbad, New Mexico. The WIPP internet site states that Carlsbad began to receive shipments in 1999. The site indicates as of 2006, WIPP will have received 5,090 shipments. The disposal process is expected to continue for 35 years.

The NRC licenses commercial use of radiation. Along with DOE research, low-level waste is generated at civilian nuclear power stations and for industrial, agricultural, food, and medical purposes. Educational facilities, such as Oklahoma State University, also incorporate the use of radioactive materials in academic research. The NRC divides by-product, low-level wastes into categories by increasing levels of radiation emission

potential. The lowest is Class A, followed by B and C. Low-level waste can consist of rags, glass, soil, and even metal components from nuclear power plant containment vessels. Large volumes of materials containing radioactive elements may be routed to a disposal site, but they may emit small amounts of radiation. The DOE Manifest Information Management System (MIMS) tracks the amount of low-level waste shipped nationally. The MIMS on-line database indicates that in 2004, Arkansas low-level licensees routed for disposal 3,935.79 cubic feet of waste with a Curie activity level of 223.06. In the same year, MIMS shows Oklahoma routed 296,050.21 cubic feet of waste with a Curie activity level of 0.23 (U.S. Department of Transportation 2006).

Because of Federal mandates, low-level commercial users are obligated to transport their waste to state disposal sites. Louisiana, Kansas, Arkansas, and Oklahoma are members of the same compact. Since the 1980 Low-Level Radioactive Waste Act, no individual state or compact has successfully located a new low-level radioactive waste repository in its midst. Therefore, 36 states (including Oklahoma) have no designated disposal sites within their compact. They send their commercial waste materials to the two unaffiliated low-level disposal facilities in the nation. These are located in Barnwell, South Carolina, and Envirocare, situated in Toole County outside of Salt Lake City, Utah. While users have worked to reduce the amount of low-level waste produced, it is not foreseen that the commercial need for disposal will end.

The DOE has designated six of its facilities across the nation for low-level disposal sites. The agency also uses commercial facilities for storage of some of its waste. Hanford, Washington and the Nevada Test Site receive low and mixed-level waste materials from other DOE facilities (National Safety Council Environmental

Health Center 2002). Mixed-level waste can contain components of high, transuranic, and low-level waste. The DOE expects to dispose of 35 million cubic meters of low and mixed-level materials and contaminated soils (National Safety Council Environmental Health Center 2002). It anticipates this management practice will continue through 2070.

United States modes of transport in the shipment of hazardous radioactive waste from point-of-origin to disposal sites include airplane, truck, train, and ship or barge. Oklahoma's interstates, highways, municipal roads, along with commercial rail, have been integrated into this transportation network.

The DOE and NRC licensees are required to monitor the location and condition of their radioactive materials at all times. The amount of radioactive materials in the national transportation network fluctuates from day to day. Transportation of waste materials is contracted to brokers who specialize in disposal and packaging. They too may store materials until enough is ready for shipment to a repository. Should an emergency incident take place, liability is held by the waste generator and extends throughout the disposal process (Central Interstate Low-Level Radioactive Waste Commission 2006).

The contracted carrier notifies its dispatch office and local authorities should an incident take place involving radioactive materials (National Safety Council Environmental Health Center 2002). Low-level waste is subject to Oklahoma's motor carrier inspection system (State of Oklahoma 1995). Oklahoma's Department of Public Safety is notified when high-level waste is shipped through the state (Conference of Radiation Control Program Directors 2000). The DOE has developed a satellite tracking system to monitor high-level and transuranic shipments to their particular destinations.

This system is called Transportation Tracking and Communication (TRANSCOM) (DOE 2006).

The Federal government recognizes that transportation of these various radioactive materials can pose a potential health risk for the public. The Hazardous Materials Transportation Act of 1975 describes routing and transportation responsibilities (National Safety Council Environmental Health Center 2002). The NRC and the U.S. DOT cooperate regarding packaging waste for transport, appropriate motor carrier education, notification of transit to appropriate agencies, cargo inspection, truck signage, and waste labeling. Both Federal and state DOT agencies have responsibilities in safe routing of radioactive waste across the U.S. Carriers of low-level radioactive waste may designate their own routes, but these must be shown to minimize risk. The U.S. DOT's Code of Regulation (2005) attempts to minimize overall risk to the public during the transportation of high-level waste by weighing several factors against one another. This includes consideration of overall transit times, population density and activity, accident rates, time of day, and day of the week. The nation's Interstate System is the federal DOT preferred route when trucks are utilized for cross-country transport of hazardous materials. Each state DOT may designate preferred alternative routes to an interstate, when this option reflects the safest route through a particular local. A by-pass opportunity in a metropolitan area is an example of a preferred route.

According to the National Hazardous Materials Route Registry, Oklahoma submitted its restrictions for hazardous material routes in 1997. It suggests transportation through large metropolitan urban areas be restricted for all hazardous materials during times of day when congestion is expected. Carriers should also contact ODOT for road

construction activity and possible closures. ODOT has assigned restricted hazardous material routes which bypass downtown Tulsa and Oklahoma City. But the interstate system is the federal DOT preferred route for radioactive waste in Oklahoma.

Risk Analysis in the Establishment of Potential Routes

A variety of studies exist which deal with radioactive materials and proximity to populations. Some of these focus on analyzing risk to populations living in association with transportation routes and fixed hazardous facility sites. These studies focus on population reaction or fear of risk consequence. Others focus on routing and probability risk as it pertains to the transportation of high-level radioactive waste. Most of the latter concentrate on the potential for conflict which exists in carrying out the U.S. DOT's routing considerations outlined in the Code of Regulations (Department of Transportation 2005). It requires limiting radioactive materials transit times and at the same time consideration of population density and population activities in the selection of preferred routes (Department of Transportation 2005). But, achieving limited shipment transit time can be at odds with limiting potential radiation exposure in densely populated urban areas. This is why many studies analyze probabilities of accidents, comparing urban or non urban areas. They also consider the overall ratio of route length to population totals.

Less of the research includes activities or the characteristics of the exposed population in their methodology for choosing routes. Rather, they study characteristics of population to determine methods for emergency planning. Or, they research how proximity to hazardous materials impact individuals views of their own neighborhoods and potential loss of property value. Enforcement of environmental justice mandates

requires the identification of the potential impacted communities, so they can become informed and participate in the decision making process.

As a methodology resource for state routing agencies, in 1992 the U.S. DOT created The Guidelines for Selecting Preferred Highway Routes for Highway Route Controlled Quantity Shipments of Radioactive Materials. When considering overall public risk, state routing agencies are instructed by the Federal Code to use this guide or an equivalent routing analysis. Consultation with local jurisdictions must take place before routes are designated as preferred (Department of Transportation 2005). The Guide lists primary factors it considers important for route analysis and consideration of adjacent population. These include components of Normal Radiation Exposure, Public Health Risks from Accidents, and Economic Risks from Accidents (Department of Transportation 1992). Each of these factors incorporates a comparative risk index figure in its methodology for the evaluation of routes. These index figures are representative, "computed by simplifying certain factors that are not route-specific" (Department of Transportation 1992, 3). The Guide points this out because much of the research literature developed from DOE laboratories and other researchers utilize technical computer modeling and site-specific information. This could include a specific radiation count for a particular waste material, amount of waste released, wind dispersion on a specific location, seriousness of accident, fire, etc. The U.S. DOT perceives this methodology as "far beyond the capacity and resources available to a State routing agency" (Department of Transportation 1992, 3). The U.S. DOT Guide does offer a methodology for comparing routes based on population count. For long distances, a ten and 20 mile wide buffer is situated along a route segment. The population count within

the buffer is then multiplied by a general (versus site-specific) Accident Release Consequence index the Guide provides. The results are then divided by the length of the route segment. The ideal route is chosen by comparing calculations. The U.S. DOT Accident Release Consequence index is derived from atmospheric dispersion calculations. The population within the ten mile buffer is potentially exposed to a higher radiation dose rate, and therefore, their Accident Release Consequence index is set at a higher percentage.

Mills and Neuhauser's research (1998) on urban risks of truck transport was produced after the U.S. DOT Guide but before Environmental Justice mandates were adopted. It is sponsored by Sandia Laboratory. It illustrates the degree of technical information necessary to run a more complex routing model. The research compares the relative risk for a population when routes completely by-pass urban areas, versus the use of interstates through urban areas. The goal was to find the shortest-path distance measurement for each routing scenario, and compare risk for populations. The researchers relied on a RADTRAN4 programming code to assess the transportation risks. A cross-country preferred route was chosen, based on it having been studied previously as an end location for a possible waste repository. A road atlas was used to visually locate the comparison alternate route. By-pass and interstate route link-lengths were input in the program and calculated estimates of total population density were compared. Researchers concluded in their study results that interstate routing has less risk for populations than secondary road systems. Although population totals were higher along urban areas, interstates shortened the distance and lessened the probability for accidents. They also point out that their calculations do not eliminate accident consequence in urban

areas amongst large populations. While the research methodology was interesting and had useful examples, the degree of complexity substantiates the U.S. DOT's view that it would be difficult to replicate this study without RADTRAN.

With approval from Sandia National Laboratory, the RADTRAN/RadCat risk package software is now available for download. The User's Guide (Sandia Laboratory 2006) is technical but well written regarding software functionality. However, the software requires input of technical information specific to radioactive materials proposed for transport. A strong familiarity in physics and medical effects of radiation exposure are necessary to successfully run the program. Because of its emphasis on the nuclear aspect of routing versus expertise in road systems and populations, a state transportation agency would find it difficult to run the program.

Two other routing studies offered interesting alternatives in their approach to applying risk. Because the U.S. DOT rules allow for viable alternative routing options, these were reviewed for this project.

The equitable spread of risk is one way of looking at the problem (Gopalan et al. 1990). The objective is to determine a set of routes that will minimize the total risk of travel and spread the risk equitably among the zones of a geographical region in which the transportation network is embedded. Zones may be interpreted as a township or municipality. Various shipments would be rotated to the various zones. The risk estimate equation the authors support is based on multiplying the probability of an accident with estimated consequence to evaluate expected damage.

Erkut and Verter's (1998) study on risk and transportation modeling is one of the more comprehensive in how specific weights are applied to shortest path algorithms.

Several ways of defining the modeling problem are discussed. The first is unit road segment risk. This establishes the risk of transporting hazardous materials B over unit road segment A. A probability is multiplied by population density on a road segment length. The second definition deals with edge risk. A long stretch of highway which runs through a series of population centers and farmland should not be represented as a single edge, but a series of edges. These edges would carry different weights and totaled for the distance. Comparison of routes would rely on shortest path modeling.

While informative, the U.S. DOT may not deem the equitable model as viable for establishing preferred routes. A state agency would find it difficult to consult with all public parties in the various jurisdictions and not have strong disagreements ensue regarding equity of exposure to risk. The models used by Erkut and Verter (1998) would be more practical to apply. Unfortunately both studies rely on material specific probabilities, dispersion models, and health considerations for weight calculations. It would be difficult to generalize the necessary data, particularly health considerations specific to a radioactive isotope.

Population Characteristics Analysis in Hazardous Routing

An element of emotional detachment seems to run through the literature discussion of probabilities of incidents involving hazardous waste routing and health risks to the population. Most look at probabilities and the minimization of consequence without addressing specifics of population.

One exception where population characteristics were included is Margai's (2001) research on health risk and environmental inequity during hazardous materials release.

Previous research indicated that as of 2001 "one in six Americans" live in high-risk zones where they are vulnerable to exposure from a hazardous waste spill (Margai 2001, 423). The author researched location patterns of actual hazardous material releases in two New York counties in 1997. These accidents were associated with fixed facilities and transportation routes. Because of the counties location in the state, both large urban and more remote rural populations were included along the routes. Population characteristics were analyzed at the 1990 census tract level. Both counties were representative of various industries who utilize and transport hazardous waste materials. The study researched race and ethnic composition, education levels, housing value, median rent, and proportion of vulnerable residents (Margai 2001). The EPA Emergency Response and Notification System provided hazardous spills accident details, including deaths, and type and amount of materials spilled (Margai 2001). Research revealed that a high proportion of Hispanics and low-income individuals live in zones associated with potential hazards release. The author notes that knowledge of these kinds of demographics should be used by government officials and emergency response planners in route consideration.

Many of the researchers note public concern of an accident taking place during the transportation of hazardous waste as one reason for their research on the subject. Sjoberg (2002) conducts research on experts' perception of risk. He concludes that their perception is not so much different from the general public, but driven by different values. One significant difference, "experts pay more attention to probability, the public to consequence" (Sjoberg 2002, 447). Experience with an issue dictates perception. Likewise, so does vested interest of all concerned, the experts and general population.

Public policy makers attempt to support the needs of society by utilizing technologies. The public is uneasy about living in the midst of hazardous waste materials produced through these technologies. Because of public vested interest and perception, no new commercial nuclear power plant or radioactive waste repository has been built since the 1980s.

Riddel et al. (2003) focused on household behavior and residential decisions to either stay or relocate once a neighborhood becomes associated with a hazardous waste materials site or transportation route. With the proposed repository at Yucca Mountain, truck routes will likely pass through several Las Vegas neighborhoods. Train routing will also impact neighborhoods. The "public's perception of the health and safety risk will determine the final economic impact of the facility" (Riddel et al. 2003, 436).

Researchers used surveys measuring individuals' subjective attitude to risk and levels of ambiguity. Researchers asked participants to compare risk exposure and at what compensation levels would they willingly stay in their houses or relocate. The researchers theorize that "compensation offsets the cost of additional risk" (Riddel et al. 2003, 436). The researchers conclude "for a given level of risk, healthier respondents are more likely to relocate than their less healthy counterparts" (Riddel et al. 2003, 450).

Researchers believe that intangibles, such as the inconvenience of relocation affect perceptions of risk. Along with the less healthy, retirees were more likely to stay. Where risk was considered low, homeowners were more likely to stay than renters. Where risk was considered higher, homeowners fear loss of property value. If the housing market supports the decision, they would choose to leave. Researchers conclude that participants "average subjective risk is much higher than that reported by the DOE" (Riddel et al.

2003, 456). They conclude a better educational program would be necessary to alter these perceptions.

U.S. DOT Environmental Justice regulations require the identification of low-income and minority populations. According to the U.S. DOT (2000), disproportionately high and adverse effects, not size, are the basis for Environmental Justice. A very small minority or low-income population in the project, study, or planning area does not eliminate the possibility of a disproportionately high and adverse effect on these populations. In the process of identifying characteristics of the population, the U.S. DOT suggests local policymakers consider comparative effects on these populations, in relation to either non-minority or the general population in the study area. Upon identification, these groups are brought into the process through special meetings and involvement in advisory committees. No independent research identifying the success or failure of the U.S. DOT efforts to carry out Environmental Justice initiatives for transporting radioactive waste was identified for this study.

Incorporation of GIS in Routing Decisions

Through the principals of Environmental Justice, the U.S. DOT seeks out the identification of minorities and low-income populations in an effort to bring them into the decision making process. Available U.S. DOT case studies had not dealt directly with identifying populations in the establishment of hazardous waste routes. Although case study goals vary, common to all is the use of GIS in the identification of populations within a defined area.

Margai (2001) researched populations at the 1990 census tract level. The author accomplished her goals by mapping previous accident impact zones. Next, the 1997 accident sites were geocoded and merged with demographic data. Buffers were established around the accident sites. Finally, population data within the buffers was statistically analyzed.

Miller and Shaw (2001) focus on the usefulness of incorporating GIS techniques as a tool in analyzing hazardous materials routing. Cartographic mapping visually displays routes and provides a framework to help identify site-specific features of research interest. With this information, establishing simple buffers along possible routes sets the parameters for qualitative and quantitative analysis with selected attributes. The text also outlines the use of networks and linear referencing and dynamic segmentation. This establishes the variations inherent to a road network. The authors argue that routing models should not be single-objective. Versus using either economic or population risk as a deciding factor regarding an appropriate hazardous materials route, a tradeoff or compromise is necessary in locating an optimal path.

TRAGIS is a web-based mapping software package developed at Oak Ridge National Laboratories. It incorporates many of the GIS technologies Miller and Shaw describe in their text. This includes road network data and the ability to set spatial buffers along possible routes. With permission, the software can be downloaded to a personal computer. The server at Oak Ridge retains the data to execute the routing scenarios. The software incorporates GIS technologies in establishing viable radioactive waste routes. The user interface is based on Environmental Systems Research Institute, Inc. (ESRI) map objects programming. Resulting routes can in turn be incorporated with

RADTRAN/RadCat risk package software to establish probabilities. This is clearly the most advanced software package for establishing potential radiation waste routes. There are drawbacks though with using the system. The software and available data is still undergoing modification. TRAGIS is attempting to incorporate U.S. Census population density and count information. This has only been achieved for the Oak Ridge area in Tennessee. The TRAGIS User's Manual indicates it is unknown when population density data for the nation will be incorporated into the software (Oak Ridge National Laboratories 2003). Also, TRAGIS provides a preset list of origination and destination nodes. This information is located on the server end and cannot be modified.

TRAGIS (Oak Ridge National Laboratory National Transportation Research Center 2003) population data relies on the U.S. Census Bureau and 2000 block tract information for population density and count. This data was incorporated into an Oak Ridge database which also considered night time population, topography, and land cover. Oak Ridge's goal was to approximate the population as it exists in the Tennessee landscape. What is interesting about the Oak Ridge model is in how the population density is depicted with grids based on the size of the block tract. It also differentiates between commercial and residential zones. TRAGIS will continue future research on American cities and incorporate census data at the block level. The following figure is an example of the Oak Ridge population density model:

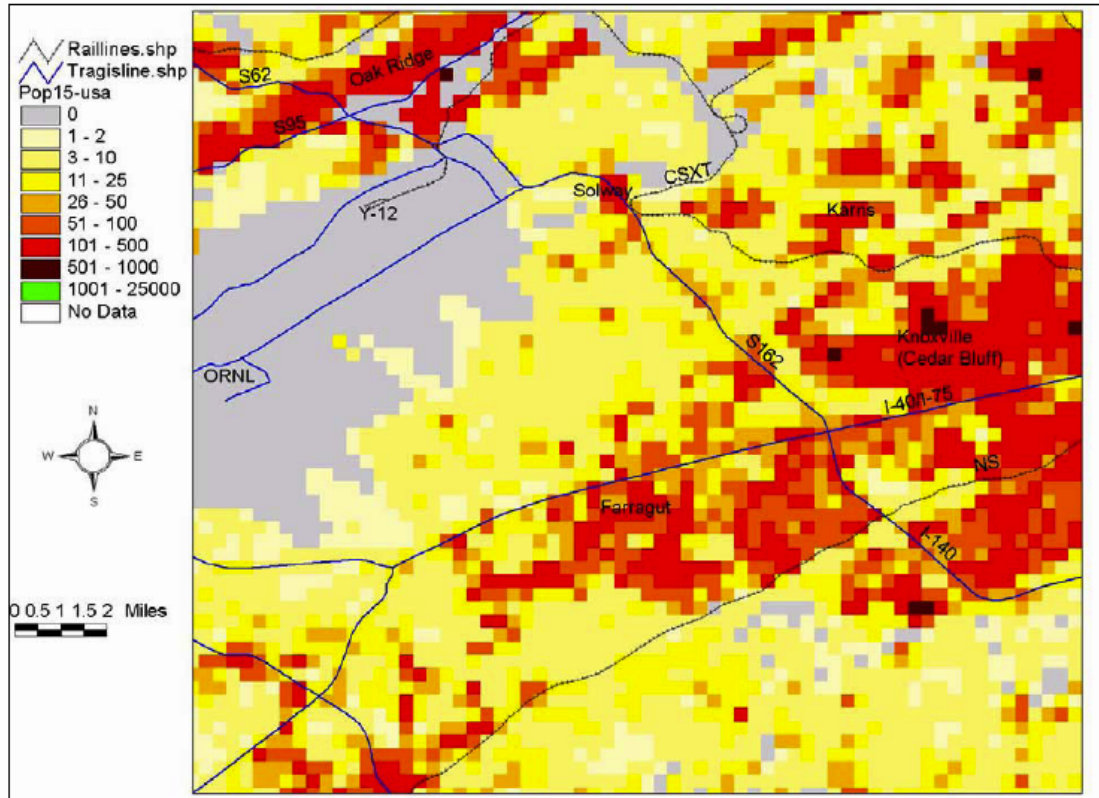


FIGURE 1. Knoxville, Tennessee, TRAGIS grid cell population data.

Based on 2000 Census block tract and transportation networks (Oak Ridge National Laboratory National Transportation Research Center 2003, 14).

In summary, various aspects of the research concepts outlined in the reviewed materials are valid for carrying out a study based on routing radioactive waste through Oklahoma. But what also became evident in the review is that there is no “cookie cutter fit” methodology for individual states to use to establish preferred routes. No one existing research application can be applied to fit individual state waste routing situations without major modifications. As the U.S. DOT outlines in their guidelines, it is up to state policymakers to designate their own preferred routes.

TRAGIS software is still in the research phase and not available for this study. Nor does it focus on population demographics or have the ability to be modified by a

state to fit its own needs. To date, the entire population data for the nation has not been included in its data sets. But aspects of TRAGIS methodology can be adapted to analyze population characteristics in Oklahoma, i.e. shortest path, setting buffers, and counting total population.

Those authors who focused on risk probabilities and consequence use shortest-path concepts and offer techniques for weighing risk by breaking routes into segments and measuring population density. Mills and Neuhauser (1998, 784) conclude after comparing all "accident severity levels" along their routes, major consequential accidents should not be the primary focus for establishing risk corridors or buffers. But understanding population characteristics along potential routes was never the intent of this study or others whose focus was probabilities and consequence. Neither did researchers focus on GIS software capabilities in their analysis.

Research involving population characteristics indicates the necessity of incorporating demographics in the route decision process. As states proceed to set their own preferred routes they must know the public they will be dealing with.

To establish a GIS methodology that would establish least-cost preferred routes through Oklahoma and incorporate population demographics to analyze potential impacts, the U.S. DOT model seems the most viable approach. U.S. DOT guidelines allows for modifications in how the research is undertaken. Mills and Neuhauser (1998), TRAGIS (2003), and Margai (2001), all include aspects of a routing methodology which could reasonably be modified to ascertain population characteristics.

CHAPTER III

METHODOLOGY

Introduction

This study will focus on developing GIS procedures which could support the decision making process and selection of viable preferred radioactive waste routes in Oklahoma. The procedures has a basis in the U.S. DOT routing guidelines, but focus on developing GIS techniques and a criteria where population characteristics are explicitly considered.

To accomplish building a waste routing methodology, a number of steps in specific order need to be completed using GIS software. First, based on established methods, least-cost routes founded on shortest-distance or least-transit-time is created. The demographic characteristics of the population living in proximity to the routes are derived using GIS analysis functions. Second, a least-cost route is derived using population counts as the weights assigned to the road network. This route will have the smallest number of people living within proximity to the potential waste corridor, based on a 10-mile buffer. Ultimately, this route can be used as a benchmark to evaluate the efficiency of other routes in terms of minimizing population's influence. The final route based on smallest population tests the efficiency of using a derived population index to establish a least-cost population route.

The following chapter sections include a description of Oklahoma as the study area for the population analysis, the required datasets used in the routing analysis (population, road network, etc.), and details of implementing in GIS the shortest-distance and least-transit-time routing scenarios, along with the smallest-population routing approach.

Study Area and Data Selection

Creating a GIS methodology where Oklahoma population demographics are explicitly considered in a least-cost routing scenario is the main focus of this study. But GIS is a tool in the process and the selection of appropriate data is equally important as the basis for analysis.

There are no nuclear power plants within the state's borders. It is not necessarily self-evident where waste routes enter and exit the state. It is necessary to create a national routing scenario to understand how least-cost routing can actually interact with the state's population. For this routing problem, various nuclear power reactors in the southeast United States will act as points of origin in establishing where routes enter Oklahoma's borders. The proposed waste repository at Yucca Mountain, Nevada will act as the routing end point, and establish where routes leave the state (see Figure 2). The national routing outcome will also test how the selected transportation network datasets function within the GIS software framework, and that the routes follow a reasonable course across the United States. The International Atomic Energy Agency is the source of location data on U.S. nuclear reactors.

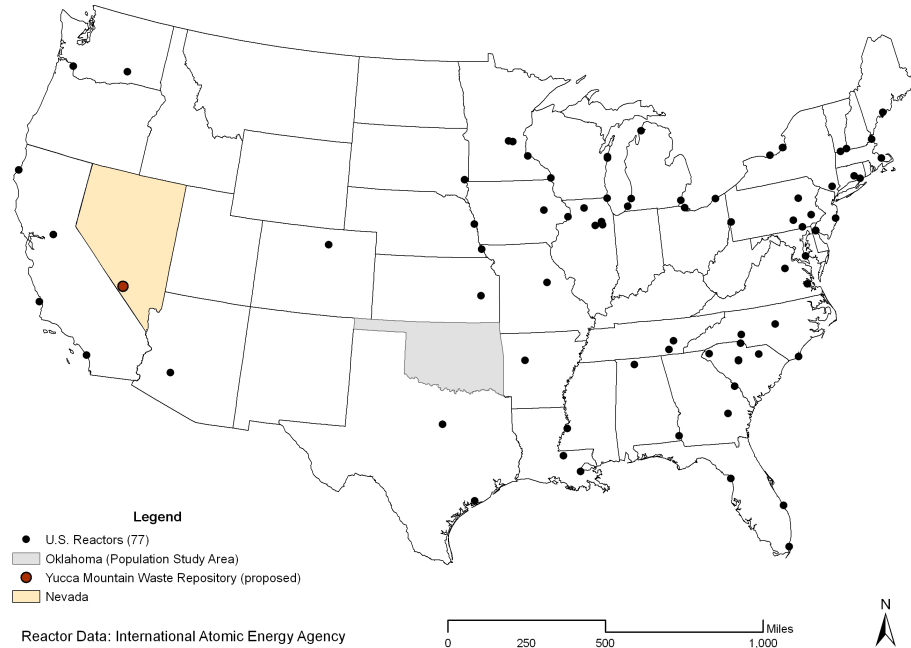


FIGURE 2. Oklahoma’s location relative to U.S. Reactors and Yucca Mountain.

The state of Oklahoma is the main area of focus in the development of this GIS routing methodology. Although national rail and water transportation systems are used to ship radioactive waste in the U.S., these routing methods do not apply to a study where Oklahoma is the focus. National barge capability and rail systems originating at reactor sites and Yucca Mountain currently do not exist. The national highway system is the transport mechanism that will be used to establish routes in this procedure. The U.S. DOT Federal Highway Administration, National Highway Planning Network (NHPN) 2005 dataset has highway functional class designations which can be applied to solving routing problems for this study, including major highways, and urban and rural arterials.

It also has the continuous connectivity necessary to create a GIS compatible network dataset and process national routing scenarios.

U.S. Census 2000 block group data is the source of population characteristics for this analysis and can be obtained from the Census Bureau's web site. Census block groups for the entire state of Oklahoma and block groups from six adjacent states located within 10 miles of the Oklahoma border will be included. Selected population information will include those groups of people who may be more vulnerable should an incident involving the transport of radioactive waste take place. For policy makers, knowing if people living along potential routes are elderly or people with physical disability, who generally have low mobility and need extra care in the case of an emergency, may be an important factor in the decision making process. The data groups selected will include total population, age 65 and up, population with disabilities, and minority information including: White, Black, American Indian, Asian, Hawaiian, Others, Two or More Races and Hispanic population. Figure 3 shows the Oklahoma study area with a dot density map for population distribution at the census block group level overlain with NHPN transportation data.

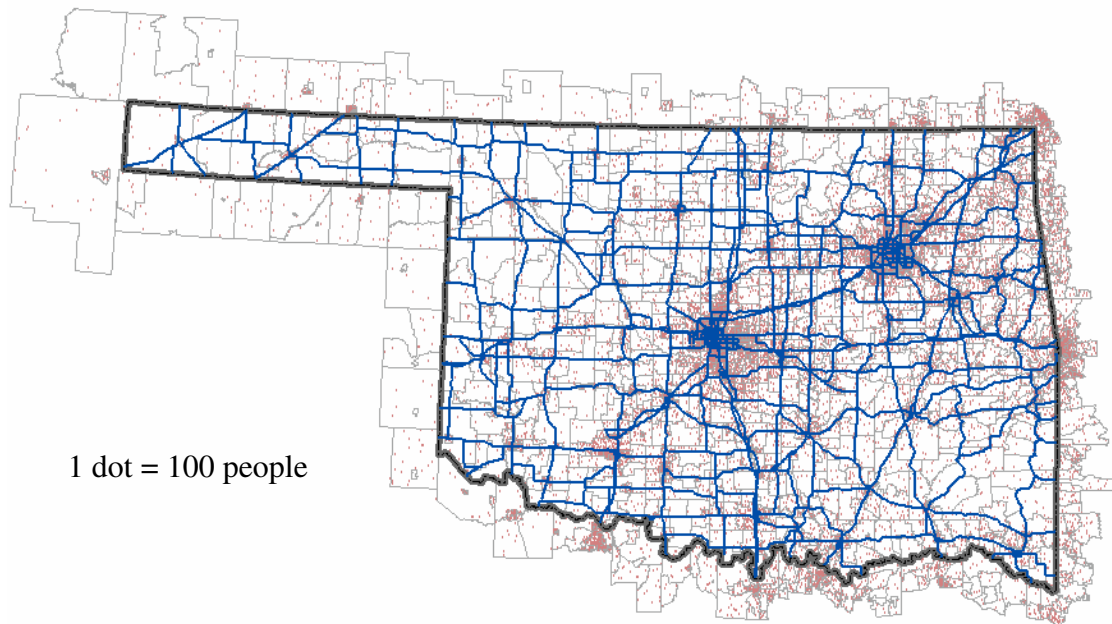


FIGURE 3 Population distribution (at census block group level) and major highways in Oklahoma.

Least-Cost Routing Models – Shortest-Distance, Least-Transit-Time, and Smallest-Population

The goal of this study is to incorporate population characteristics into the creation of a viable GIS waste routing methodology. Traditional least-cost routing models based on distance and time will first be tested with Oklahoma's population. Potential shortest-distance and least-transit-time routes will be calculated and the population characteristics along the routes (5 and 10 mile buffer zones based on the center line) will be reported, with emphasis on minority composition. This will be followed up with smallest-population routing scenarios, where the routes will be derived based on the fewest people living along the corridors (within 5 miles on each side of the center line). This will be

accomplished by incorporating population variables as the weight which defines the routes.

Shortest-Path Radioactive Waste Routes

The U.S. DOT (1992) guidelines allows for an arbitrary choice of least-cost routing for comparison in establishing routes. This portion of the routing methodology is based on an origination point and destination site assigned at nuclear reactor locations in the southeast U.S. and Yucca Mountain. Using these points will establish where routes enter and leave the state of Oklahoma. This study will incorporate GIS technologies to establish two possible radioactive waste routes for least-cost comparison, based on the following standard considerations:

- Shortest path based on distance
- Shortest path based on least-transit-time

For shortest path based on distance, each segment length will be calculated and added to a total for the route. Shortest total distance between designated origination and end points establishes the most viable route based on distance.

To establish shortest path based on least-transit-time, the appropriate miles-per-hour designation will be applied to each segment based on the NHPN functional class designation. For comparison sake, the same origination point and end point will be utilized (as used for the shortest distance routing) for each routing test. Least-transit-time expended on a route will establish the most viable route based on time.

Identification of Population Characteristics along Route Corridors

After the potential shortest path routes are established based on each criterion consideration, research will commence on establishing population characteristics within

the state of Oklahoma. To compare route populations, the U.S. DOT recommends creating a 10 and 20 mile buffer zone straddling the proposed route. Using GIS to establish a route overlay based on the road centerline, the population falling inside the buffer will provide the total route population count.

The U.S. Census Bureau 2000 Summary Level 3 (SF3) census block group data will be accessed for population and demographics information. Total population within a buffer zone and population characteristics for individuals within the buffer will also be defined. In this study, the following demographic variables associated with each census block group are included - total general population, population age 65 and above, population with disability, and race or minority composition.

Identifying the Least-Cost Route Based on Population Count

A second objective of this study which has not been investigated to date for radioactive waste routes is to explore how consideration of population characteristics can be incorporated into routing radioactive waste within the state of Oklahoma. The purpose of finding such a route is to define a population benchmark which can be used to evaluate other routes in terms of their potential influence on population. The entrance and exit locations established in the aforementioned shortest path models will act as the origination and destination points in this routing problem. Two types of routing paths will be created by running the least-cost route analysis using certain derived population counts or an index as the weight of the arcs in the road network. The first is based on the fewest number of the general population living in association with the Oklahoma road network. The second is a compiled population index applied to the general population total. In this study, as a way of demonstrating how the compiled population index works,

two of the census population groups are selected and identified as vulnerable should an incident take place, and will be included in the total population of the first route and the compiled index route. One of the assigned population variables is age 65 and older; another will be assigned to the population group with disabilities. An index ratio is defined based on the derived population count assigned to a single road segment, the segment length, and time expenditure assigned to the segment. The smallest number of population over the road network weighted by derived total population or least-population index will establish the route that avoids general population.

The following chapter will describe GIS procedures and data preparation necessary to create the routing networks, and the outcome of incorporating the described GIS techniques into the proposed routing criterion. An evaluation of routing results will follow. One of the principal evaluations will discuss whether including a population index was successful in creating a viable routing procedure that explicitly includes populations in finding a least cost route. Finally, the derived demographic composition of the populations living in association with each of the four routes will be compared and discussed, as this relates to how policymakers can utilize this information in their discussion of choosing preferred waste routes.

CHAPTER IV

GIS PROCEDURE RESULTS AND ANALYSIS DISCUSSION

Introduction

The goal of this study is the creation of a methodology using modern GIS techniques to explore ways of incorporating population characteristics in the routing decision process to facilitate the selection of Oklahoma radioactive waste routes. To achieve this, the first step is the establishment of conventional shortest path routing options, based on potential national points of origin and an end point. This GIS procedure will help establish where probable waste routes will enter and leave the state. It will also produce a summary of the travel time commitment that can be expected from the shortest path routes based on distance and the routes based on time expenditure.

The second step in the process is identifying population characteristics of the Oklahomans living in association with the potential routes that cross the state. This would provide policymakers the necessary knowledge regarding who in the state could potentially be impacted should an incident take place while waste is en route.

Upon locating where routes might enter and leave the state and potentially affect populations, the third step in the process is the establishment of alternative routing possibilities within Oklahoma. These are based on population demographics and a

derived index which integrates a combination of considerations, including population, distance, and transit time. The purpose of the index is to incorporate consideration of population characteristics of the people living in the state and the need to move radioactive waste through the state in the least amount of time possible. The population index is assigned to the entire Oklahoma road network, and then routes are analyzed that move the waste through the state with the least impact to the population.

Ultimately, routing guidelines stipulate that potentially impacted populations should be informed and involved in the decision making process. Policymakers' ability to understand the parameters of the problem and offer well-considered decisions in the selection of preferred waste routes is enhanced by the knowledge of the population they are dealing with. With this information, policymakers can make better informed decision regarding balancing transit time and the population they must take into consideration.

GIS Software Applications and Data Preparation

The following data preparation using GIS mapping software is necessary before the GIS routing process can be undertaken for least-cost routing based on shortest distance or least-travel-time. Various aspects of the data preparation are also necessary to ensure proper routing where a population index is created and incorporated into the routing model.

ArcGIS 9

ArcGIS 9 is mapping software created and developed by Environmental Systems Research Institute (ESRI). It includes three application modules: ArcMap, ArcCatalog, and ArcToolbox. Each of these modules is necessary to this process of creating a

transportation routing methodology and defining population locations. ArcGIS has developed the Network Analyst extension that will be used to run the least-cost path analysis in this study.

Nuclear Power Sites of the World Database and Yucca Mountain

Created by the International Atomic Energy (2000) from sources that include the Nuclear Regulatory Committee, this .E00 database file consists of world-wide and U.S. nuclear reactor locations in decimal degree format. The E00 information file was originally created in ArcGIS./ArcINFO. It is necessary that the data be converted to a coverage file in ArcCatalog for this study. After the area of interest, national nuclear reactor locations, is identified and the mapping extent established, the coverage was exported as a shapefile. The proposed Yucca Mountain point location was accessed through the Department of Energy (2007). The location point was converted from latitude and longitude to decimal degrees. As an *x and y* data point, the location was ultimately added to the U.S. reactor shapefile.

National Highway Planning Network (NHPN)

The ArcGIS Network Analyst extension has the capabilities for creating a routing road network based on the NHPN data set. The metadata for the NHPN road network indicates that the line segments for each state have been edge matched at the state boundary (NHPN, 2005). This provides a national network where no breaks in the route will occur during the execution of the shortest path routing problem between national reactors and Yucca Mountain. NHPN road segments are measured in both kilometers and miles. Comparison of shortest-path based on distance, least-travel-time, and smallest population route lengths is determined from totaling the *Miles* field for each route.

The NHPN has a *Functional Classification* field where each road segment has an assigned functional value, i.e. Value 1 = Rural Interstate or Value 14 = Urban Principal Arterial. The 2002 Highway Performance Monitoring System (HPMS) is the source of functional classification designations for this field. The U.S. DOT Routing Guidelines (1992) does not designate one road classification over another road classification for selecting preferred routes, i.e. *functional class* field versus *Strahnet* field. U.S. nuclear reactor sites are not necessarily located on *Strahnet* designated roadways. The Guidelines focus on the road network which leads to least amount of time routing through an area.

To establish the least-travel-time path, miles-per-hour have been assigned to the functional classification field designations. This new field was assigned the name *Travel Speed*. Then the travel time on each arc in the road network was calculated according to the travel speed assigned to the arc. The travel time values were used in the shortest path analysis to derive the least-transit-time route. The following miles-per-hour speed assignments were applied to the NHPN road network for this shortest path study:

HPMS Functional Class	Road Type	Miles-Per- Hour (MPH) Assignment
1	Rural Interstate	65
2	Rural Principal Arterial	55
6	Rural Minor Arterial	55
7	Rural Major Collector	25
8	Rural Minor Collector	25
9	Rural Local	25
11	Urban Interstate	65
12	Urban Freeway or Expressway	55
14	Urban Principal Arterial	40
16	Urban Minor Arterial	40
17	Urban Collector	25
MPH based on Kentucky Transportation Cabinet (2003) speed study estimates and identification of Oklahoma roads.		

TABLE 1. NHPN applied miles-per-hour.

Preparing ArcGIS 9 Network Analyst datasets in ArcCatalog is the final step in creating the necessary road networks used in this methodology to test shortest path routing based on distance and least-travel-time. The routes produced from these network dataset will be known as the preferred waste routes used for population counts. With the NHPN road set, dataset preparation includes choosing the appropriate line segment connectivity, i.e. end (node) points or any vertex of geometric coincidence. With NHPN segments, designated freeways, arterials and collectors can all be connected at any vertex. Edge connectivity and any vertex were selected in the creation of these shortest path data sets. Global turns were allowed versus turn restrictions. The attributes minutes and miles

were used as route evaluators in the initial dataset created for shortest path routing analysis. The attributes total population count and population index were applied in the second least-cost population model dataset where routes were created based explicitly on population demographics.

U.S. Census Bureau Population Data and Tiger/Line files

It is necessary to acquire base census population data representative of the geographic area of interest and prepare the data for compatibility with mapping analysis in ArcGIS 9. For this study, acquisition of a US Census Bureau Summary File 3 (SF3) population data at the block group level for the state of Oklahoma is necessary. Block groups from six adjacent states of Oklahoma and located within 10 miles of the border of Oklahoma are also included in the population data set to prevent potential edge effect when deriving the least-cost route based on population count or compiled population index.

To complete the mapping process, US Census Tiger/Line data files with the appropriate census block group geometry are also required. Both the population data and Tiger/Line data have a corresponding unique identifier field called the FIPS code on which to perform a table join in ArcMap. Joining population data to the Tiger/Line geometry offers an opportunity to perform geographical analysis and visually identify the spatial relationships associated with each of the data variables and their location in the state of Oklahoma.

To acquire Census Bureau SF3 population data tables for an entire state and for particular population variables, such as age, disabilities, and racial composition, the census population data must undergo an extraction process. This is also the case for

creating the appropriate Tiger/Line mapping data for state-wide block group geographies. The U.S. Census Bureau offers data extraction methodology based on 1997 Microsoft Access software applications. The Tennessee Electronic Atlas, sponsored by the Geography Department at the University of Tennessee, is another resource that offers census data extraction software. This extraction software offers greater ease of use than the Census Bureau method. The Tennessee method was used in this study.

Inherent with Census Bureau Tiger/Line geometry is the duplication of data. Other states data may mistakenly be included with your particular state's line geometry. These additions can be identified by their unique state FIPS code. Duplicate Tiger/Line polygons may also be present within a state table and appear as a sliver polygon. To identify duplicate attribute files in the data tables, Microsoft Access has a Find Duplicate Query search feature. It is important that the data .dbf file not be altered or saved in Access after the duplicates are found. Appropriate corrections to the dataset should be made in ArcMap. The search for duplicate data should take place before joining the SF3 population data to the Tiger/Line data. If not, an inflated population number may be introduced into the study.

Map Projection and Geodatabase

A crucial step necessary in the data preparation process includes setting the mapping extent in ArcMap for the area of interest and projecting the same coordinate system for all of data layer shapefiles. Correctly projecting the individual map layers ensures the data will maintain a proper association with each other and that any calculated distances are consistent. Albers Equal Area Conic USGS is the projection coordinate system chosen for the data layers. This coordinate system is designed to

represent a large multi-state area represented by the census block group data and the national road network. To complete the process, a personal geodatabase is created in ArcCatalog, along with a feature data set to contain the various data layers as feature classes. In the process, the Tiger/Line feature class block group polygons will acquire a field which will contain the area totals represented in each polygon.

GIS Procedures – Derive Demographic Composition of Waste Routes

The following description and GIS procedural process, depicted in Figure 4, illustrates the steps necessary to derive the demographic composition of people living within the proximity of radioactive waste routes based on least-cost shortest path routing.

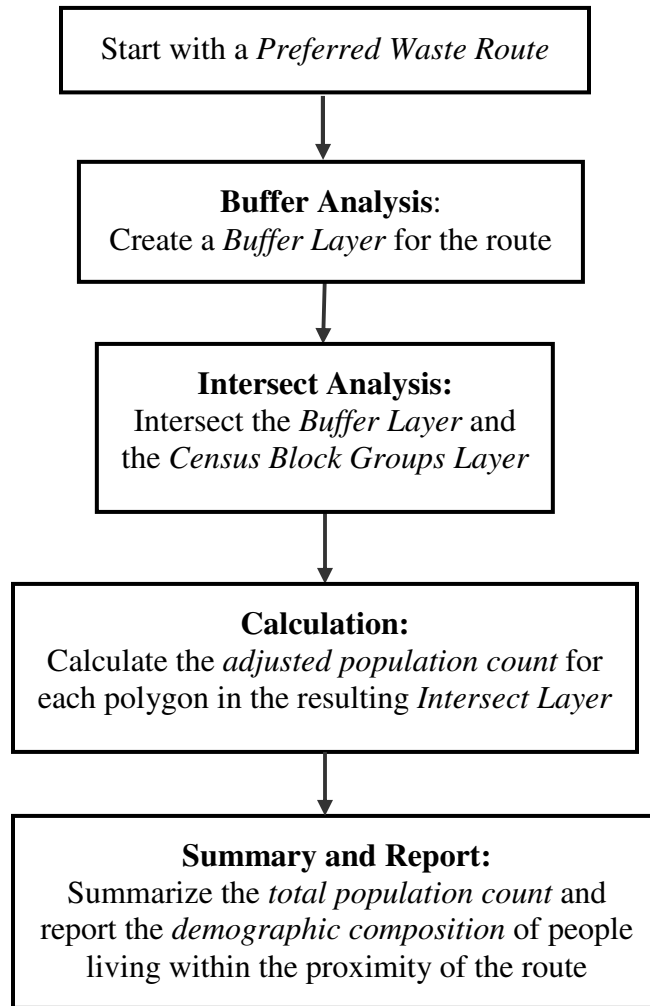


FIGURE 4 GIS procedure to derive demographic composition of a waste route.

Using ArcGIS software network analysis functions, a user can generate a preferred radioactive waste route, by either manually picking a route, or as described in the NHPN data preparation description, by using the routing function to derive a least-cost route based on distance or travel time. A buffer analysis (5 and 10 mile based on the center line) is created using the ArcToolbox Analysis buffer tool applied to the preferred route. The resulting buffer map layer represents the route's proximity area, where

populations can receive significant exposure in the case of an accidental radiation release. The derived buffer layer and the census block group layer (which includes the selected population characteristics) are used as the input layers for an intersect analysis, which is also available in ArcToolbox. The resulting intersect layer includes all census block groups and portions of census block groups that fall within the buffer zone of the route. Block groups that did not intersect the buffer are no longer necessary to this portion of the study and are omitted. Assuming an even population distribution within each census block group, the population from each block group that falls in the buffer zone can be adjusted according to the areal ratio (new area divided by old area) of the block group geometry that falls inside the buffer zone. For example, if a block group with a population of 500 has only 20 percent of its area falling inside the buffer zone, only 100 people (i.e. 20 percent of 500) from that block group will be counted. Finally, the adjusted population counts of all block groups are summed up and a total population count for each interested demographic group is then reported to the user. This procedure can be applied to multiple routes and a comparison of the results is then available to assess alternative routes' impacts on the population.

GIS Procedures – Calculating Waste Route Using Population Count as the Weight

Preferred radioactive waste routes are generally derived from the least-cost methodology based on either distance or transit time. However, these routes will most likely pass through densely populated areas. In this portion of the study, the goal is to create a methodology to find a route that has the fewest people along its proximity. Figure 5 illustrates a procedure to derive a least-cost route based on population count.

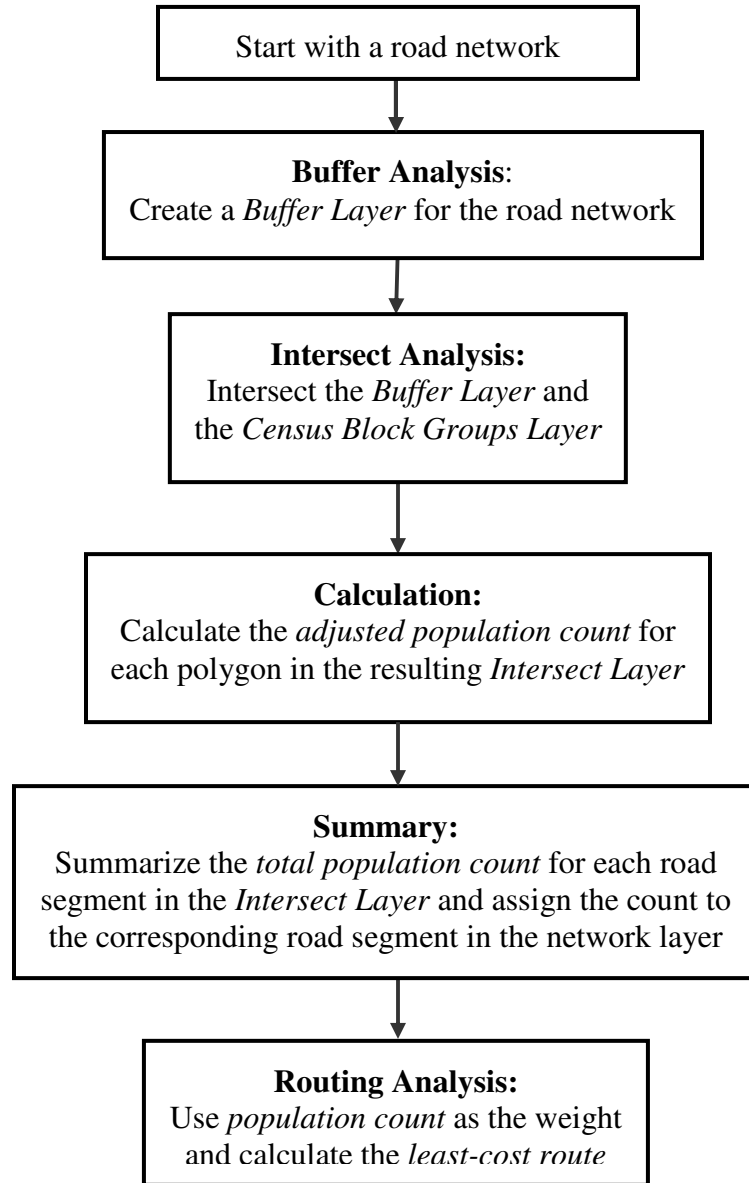


FIGURE 5 GIS Procedure to calculate a waste route using population as the weight.



FIGURE 6 Flat-end buffer vs. round-end buffer

Data preparation for establishing routes based on a population characteristics index must take place after Census Bureau SF3 block group population data is acquired from the Census Bureau and prepared as described above. The NHPN data set is utilized in this routing procedure as the road network. Because this portion of the study is based on Oklahoma's population, for comparison sake, the same Oklahoma entrance and exit points established in the national shortest path routing analysis based on distance and least-travel-time routes are used as the origination and destination points.

In order to use population count as the weight for routing, it is necessary that the number of people residing in the proximity of each road segment in the network be defined. Different from distance and travel time which are intrinsic attributes of a road segment, population count has to be retrieved from a different source. This task requires a series of GIS analyses techniques applied to the road network layer and the census block group layer. A buffer analysis is first applied to the road network layer. One buffer zone is generated for each road segment in the network to define its proximity. A flat-end buffer (FIGURE 6), instead of a round-end buffer, is adopted in this study to help reduce the unnecessary overlap between the buffer zones of connected line segments. An intersect analysis is then applied to the buffer layer and the census block groups layer. In the resulting intersect layer, block groups and/or portions of block groups that fall within the buffer zone of a specific road segment can be identified. Adjusted population count for a portion of a block group can be derived using the same approach described in the previous section. Adjusted population counts of block groups and/or portions of block groups that fall inside the same buffer zone of a road segment then are summed up to a total population count. Later, the total population count is applied to the corresponding

road segment in the network layer. Using the derived population count (total population, age 65 and older, and population with disabilities totaled) as the weight associated to each road segment, an ArcGIS 9 Network Analyst dataset is created (described in the NHPN dataset preparation portion of this chapter). A least-cost route can be calculated with a given pair of origin and destination points. The resulting route has the fewest people residing in the proximity of the route, which means a minimum number of people are under the potential exposure to the radioactive waste. Summary analysis of the total population, along with population variables age 65 and older and population with disabilities is undertaken by counting the population that falls within the 10 and 20 mile buffer overlay. Block groups which intersect and are split by the buffer layer are again areal weighted to derive a correct population count. Since this route has the fewest people impacted, it provides a useful benchmark for evaluating other routes' performance on reducing the number of people under potential for exposure.

This process is repeated in the study for the final routing procedure, but now an index is created, which combines both population count and travel time. An index is calculated for each road segment in the NHPN layers based on the following formula:

$$index_value = \frac{Pop}{l} * t$$

where *Pop* is the population count (total population, age 65 and older, and population with disabilities totaled) associated with one road segment, *l* is the length of the segment, and *t* is the travel time on the segment. This total population count index is assigned to the corresponding road segment in the network layer. Using the derived population count as the weight associated to each road segment, a least-cost route can be calculated with a given pair of origin and destination points. This population index is multiplied against

the combined total population and the results applied to the Network Analyst created network dataset and used as the evaluator during this final smallest population routing scenario. The population along this routing outcome will be summarized using the buffer/intersect block group areal weighting procedure described previously.

Least-Cost Routes based on Distance and Transit-Time

In this least-cost routing scenario based on distance or time, it is not self-evident where cross-country routes will enter and leave the state of Oklahoma. To identify potential routes, a road network dataset is created via the ArcGIS Network Analyst extension. As described previously, each NHPN road network segment has a field representing length which is called *Miles*. A field (*Travel Speed*) with miles-per-hour has also been assigned to each segment based on the HPMS functional class assigned to the road segment. The attribute fields *Miles* and *Travel Speed* are assigned to the road network dataset and each in turn act as the evaluator in the establishment of parameters for the potential routes.

Figure 2 depicts the latitude of national reactor locations relative to Yucca Mountain, Nevada and the state of Oklahoma. Finding a route based on a network dataset is accomplished through the ArcMap Network Analyst extension, and through the process of elimination. Understanding which reactor waste shipments are likely to pass through Oklahoma on the way to Yucca Mountain is based on testing various potential origination sites and the analysis of subsequent routing paths.

Upon choosing origination reactor locations east of Oklahoma, it becomes apparent that the Shearon Harris reactor located in central North Carolina is the northern

most origination point where shortest path routes traverse Oklahoma on their way to Yucca Mountain. From this origination point, both of the routing scenarios, shortest path based on distance and least-travel-time would potentially route through Oklahoma. The Hatch reactors in Georgia are the southern-most based reactor site which potentially would route through Oklahoma in a least-cost shortest-path scenario. In this case, the least-transit-time route travels through Oklahoma, but the shortest path based on distance route travel south of Oklahoma through northern Texas. Both Shearon Harris and Hatch potential routes are depicted below in Figure 7. In this route testing scenario, 14 reactor locations east of Oklahoma can potentially route waste through the state to Yucca Mountain in Nevada.

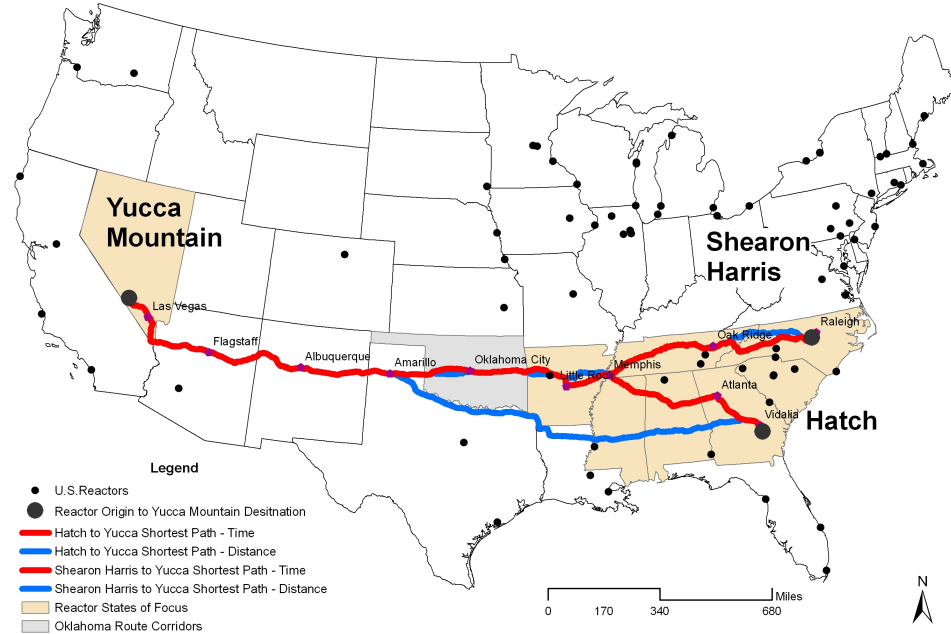


FIGURE 7. Potential cross-country shortest path routing through Oklahoma.

Upon examination of the NHPN road system, generally these southern shortest path routes may start on smaller two-lane and four-lane state highways, but gravitate to the national interstate systems as they travel west cross-country to Yucca Mountain. This includes I-40 across Arkansas, Tennessee, etc., and I-20 across Louisiana. The routes through Oklahoma all enter the state on I-40 at Fort Smith, Arkansas and exit the state at the Texas boundary, also using I-40.

Table 2 below compares the expenditure of time and distance involved in the routing scenarios for the Hatch and the Shearon Harris reactors. The distance expended on the Hatch cross country routes is comparable, with less than 50 miles difference in

total length for both Hatch distance and time routes. There is a difference in time expended on the routes and approximately three hours less time is expended on this cross-country route based on miles-per-hour, as compared to the Hatch route based on distance. The distance expended on the Shearon Harris cross-country routes also indicates less than 50 miles difference in total length for both Shearon Harris distance and time routes. The Shearon Harris route comparison indicates approximately three and one/quarter hours less time is expended using the miles-per-hour time route, as compared to the Shearon Harris route based on distance. Because Oklahoma’s population as it relates to the various routes is the focus of this analysis, population data for the other states located along these routes were not compared. The outcome in distance and time of this cross-country route comparison is so similar that it confirms the perception that including other factors, such as population characteristics, can provide additional necessary perspective in the process of route selection.

Route Length Least-Cost Distance/Time Comparison	Minutes	Miles
Hatch to Yucca Route, Least-Travel-Time Path	2219	2287
Hatch to Yucca Route, Shortest Path Distance	2397	2246
Shearon Harris to Yucca Route, Least-Travel-Time Path	2327	2444
Shearon Harris to Yucca Route, Shortest Path Distance	2522	2417

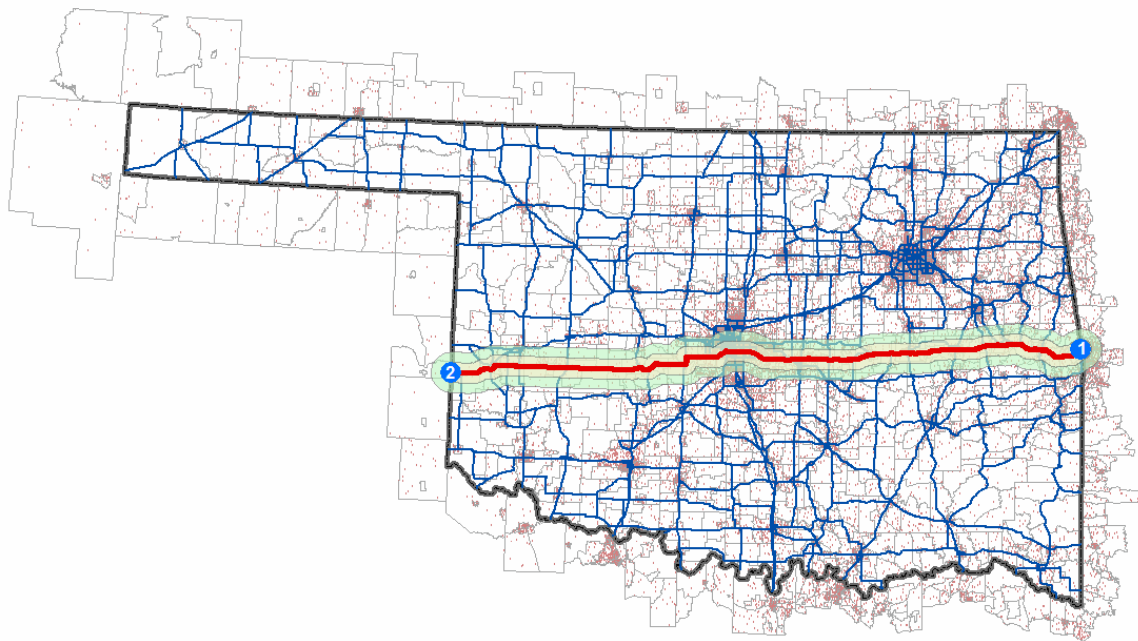
TABLE 2 Comparison cross-country shortest path routing.

To establish the distance and time expended on the Oklahoma portion of the routes, the shortest path routing scenarios were repeated, based on the intersections of I-40 and the state border with Arkansas and Texas acting as the origination and destination

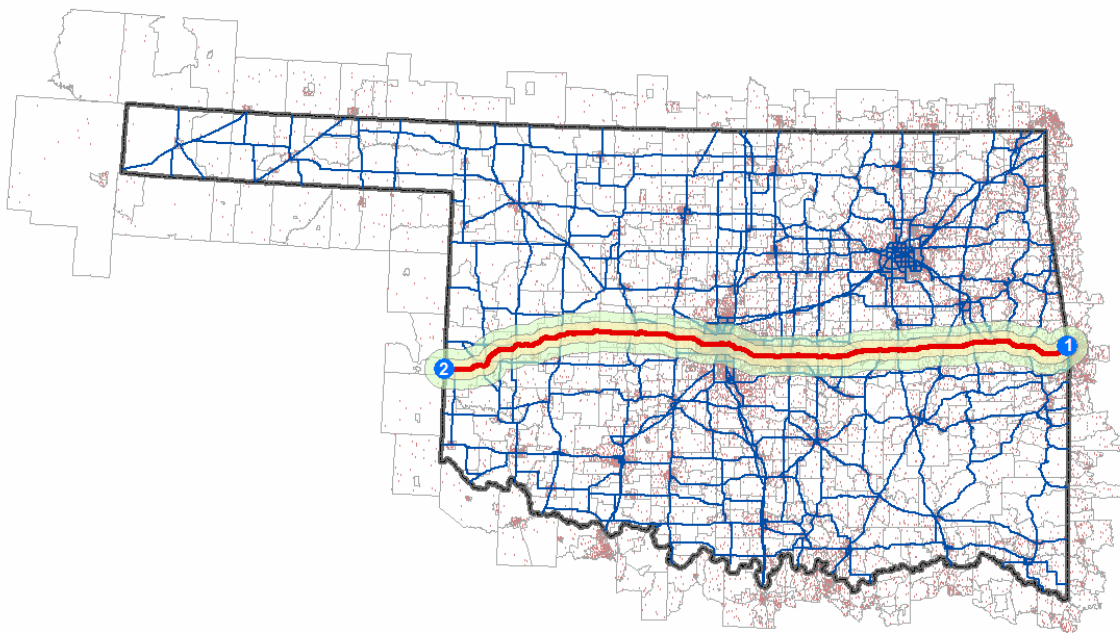
points. The shortest-distance route and the least-transit-time route are calculated on the NHPN road network in Oklahoma (Figure 8).and the process follows the proposed GIS procedure described previously. The results are compared with one-another to provide insights on how the routes interact with the highway system within the state. A comparison analysis of route distance and time expended in Oklahoma is described in Table 3.

As Figure 8 indicates, the two routes across Oklahoma are similar. Both routes follow I-40 from the origination point on the eastern border to the eastern edge of the Oklahoma City metropolitan area, at which point they deviate. The shortest-distance route travels along I-240 between Moore and Oklahoma City to highway OK-152, and west through the city of Mustang. While the least-transit-time route continues west on I-40 through Midwest City, the downtown area of Oklahoma City, El Reno, etc. The routes come back together east of the Oklahoma /Texas border at the town of Sayre, Oklahoma, where highway 152 meets I-40.

The Table 3 comparison shows the least-transit-time route along I-40 is nearly the same length as the shortest-distance route, approximately 0.68% longer, but it uses 20.5% less time to transport the waste out of Oklahoma.



a. Shortest-distance route



b. Least-transit-time route

FIGURE 8 Shortest-path – distance and least-transit-time routes.

Population Summaries of the Shortest-distance and the Least-Transit-Time Routes

According to the requirement in the Guidelines (Department of Transportation 1992), five-mile and ten-mile wide buffer zones are generated on each side of the route centerline for the purpose of comparing the population living along the two routes. Through a GIS intersection procedure, Census Bureau 2000 population block group data was merged with the buffer layers. As described in Chapter 3, the population count within the block group geometry that was intersected or split by the buffer areas was adjusted to correspond with the new areal unit. The population characteristics of people living along the two routes are reported in Table 3.

The least-transit-time route, (following I-40 through the center of Oklahoma City) has more people living within its buffer proximity. Specifically, within five-miles of the route centerline, 23.12% more elderly people live along the least-transit-time route than that of the shortest-distance route. Within the same buffer corridor, 16.37% more of the population with reported disabilities are located along the least-transit-time route versus the shortest-distance route. If the least-transit-time route is used, extra effort is needed to take care of the elderly and disabled in response to an emergency. Analysis of Table 3 indicates that all selected census variable categories show the same pattern, where the shortest-distance route through rural communities would impact the smaller total population count and minority individuals who may be considered the most vulnerable because of language or mobility should an incident take place.

		Shortest-distance Route (A)	Least-transit-time Route (B)	Difference (B – A)/A
	Route Length (miles)	327	329	0.68%
	Travel Time (minutes)	382	304	20.50%
	Total Population	548875	645414	17.59%
	Pop. of Age 65 and Up	66937	82415	23.12%
	Pop. with Disability	221687	25797	16.37%
within	Hispanic	53289	59506	11.67%
5-mile	Black	64402	75727	17.59%
of the	American Indian	31919	35434	11.01%
route	Asian	13888	15065	8.47%
	Hawaiian	291	318	9.24%
	Others	322	411	27.32%
	Two and More Races	23518	26396	12.24%
	Total Population	970482	1049240	8.12%
	Pop. of Age 65 and Up	123334	132285	7.26%
	Pop. with Disability	370721	388882	4.90%
within	Hispanic	72370	76104	5.16%
10-mile	Black	99022	110657	11.75%
of the	American Indian	49786	52011	4.47%
route	Asian	21445	23606	10.08%
	Hawaiian	439	457	4.39%
	Others	634	685	8.17%
	Two and More Races	38943	41554	6.70%

TABLE 3 Comparison of demographic composition of waste routes.

Least-Cost Routes based on Total Population and Derived Population Index

A least-cost route based on population count is also calculated for this waste routing case. Population counts are summed for the general population in the state, people of age 65 and up, and people with disabilities that reside within five miles of each road segment in the NHPN layer. The NHPN line segments are prepared as described in Chapter 3, with each segment buffered and intersected with the Census block group information. The summed population counts are used as the linkage weight assigned in

Network Analyst to the road network for calculating the least-cost route. Figure 9 shows the least-cost route based on population count.

Significantly different from the previous two routes, this route runs through areas with lower population. It not only avoids the urban area of Oklahoma City, but manages to bypass most of the cities in the northern half of the state. This includes Shawnee, Tulsa, Stillwater, Enid, Woodward, along with Clinton and Weatherford located on west I-40. It also drops south of the interstate after leaving the state border with Arkansas. The route is about 70 percent longer than the shortest-distance route and takes more than double the time of the least-travel-time route (Table 4). However, the population under potential exposure to the waste in this route is less than one-quarter of the population of the shortest-distance route and is about one-fifth of the population of the least-travel-time route.

The final routing analysis presented in this study involves the creation of a derived index which combines population count, distance, and travel time. Again, this index measure is calculated for each road segment in the NHPN layer based on one unit of population divided by the length of one segment of road. This value is multiplied by the travel time of the segment. Using this derived index as the weight taken against the total population count, a new total population acts as the evaluator for the routing analysis. The resulting least-cost route is displayed in Figure 10.

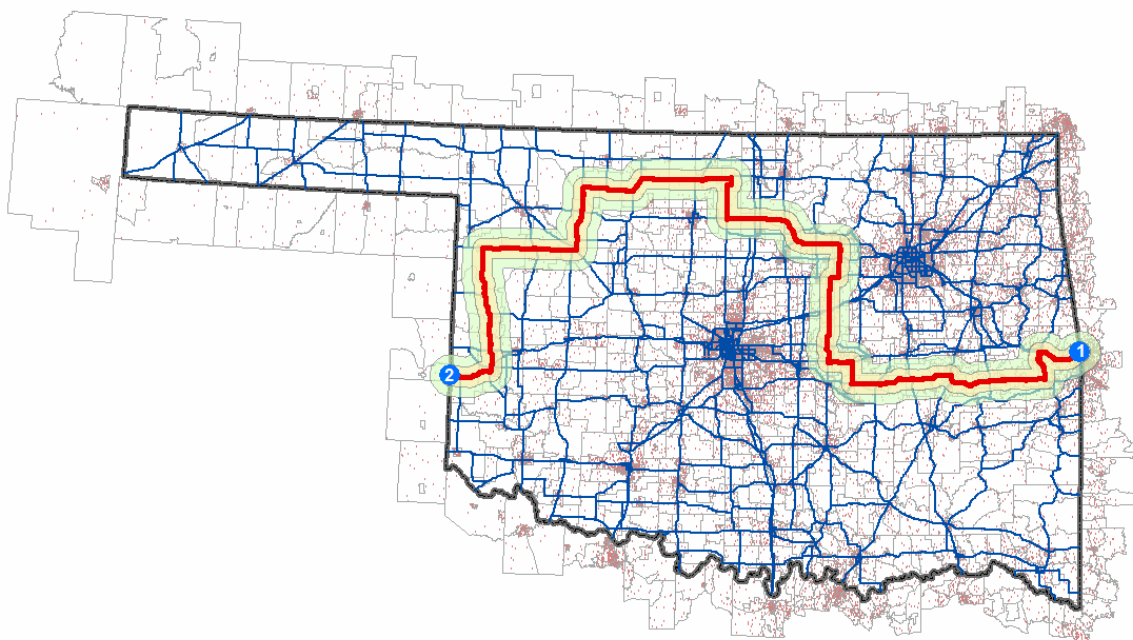


FIGURE 9 Least-cost route based on population count.

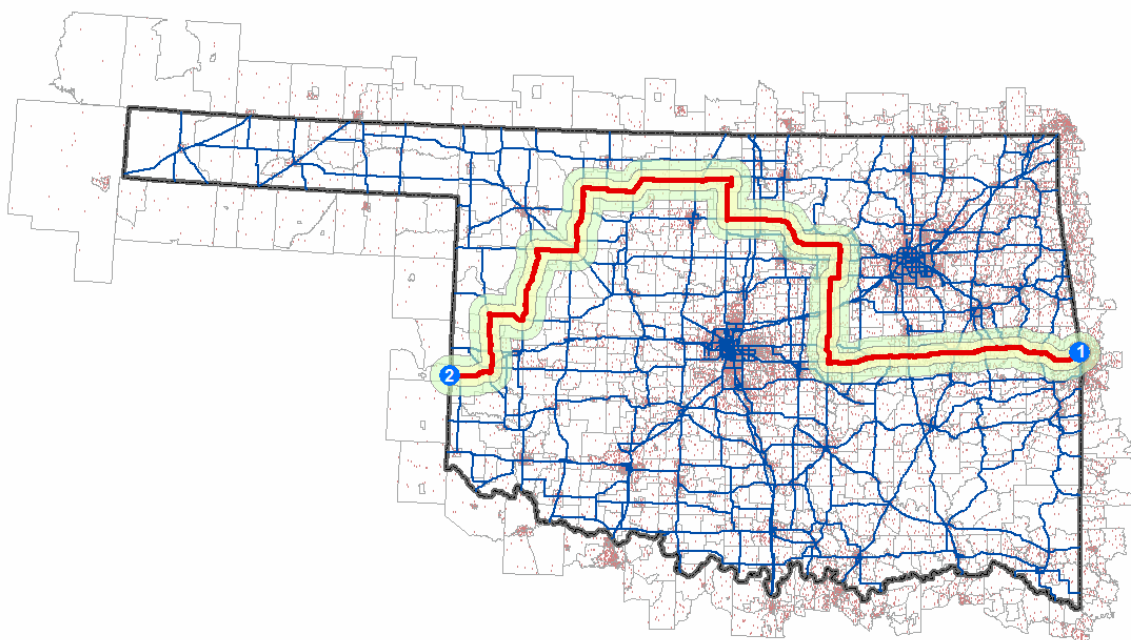


FIGURE 10 Least-cost route based on a derived index combined with population count and travel time.

Population Summaries – Total Population and Derived Index

The derived index route is similar to the least-cost route based on population count. It does use I-40 as it travels west from the Arkansas border and it deviates on the northwest portion of the state. It has about 5% more people in its five-mile proximity than the least-cost route based on population count, but takes one and a half fewer hours to transport the waste out of the state than the total population route. Table 4 provides a detailed comparison of the study's four routes in route length, travel time, and population characteristics of people in the five-mile and ten-mile buffer zones.

What is interesting in the comparison between the route based on total population and the combined index route, the totals of the population variables are greater in the five mile buffer zone for combined index, but then the comparison switches in the 10 mile buffer where the totals are less. Since the routes are virtually the same, except for the I-40 stretch out of Arkansas, this is the area of the route that appears to increase the population on the combined index route. But then the combined index population drops back in the ten mile buffer zone. On examination of the communities within the total population route ten-mile buffer, the communities of Holdenville and Seminole are included in this count, which could account for the difference.

		Shortest-Distance Route	Least-Transit-Time Route	Least-Cost Route based on Pop. Count	Least-Cost Route based on a Combined Index
	Route Length (miles)	327	329	554	514
	Travel Time (minutes)	382	304	671	573
within 5-mile of the route	Total Population	548875	645414	129278	135915
	Pop. of Age 65 and Up	66937	82415	19739	20559
	Pop. with Disability	221687	257971	60295	61317
within 10-mile of the route	Total Population	970482	1049240	318308	312771
	Pop. of Age 65 and Up	123334	132285	47874	46270
	Pop. with Disability	370721	388882	136982	131404

TABLE 4 Comparison of alternative waste routes

What is evident from analysis of all four routes, is that one routing system may not fit the state's need or be in the best service to all of Oklahoma's population. The additional time expended on the total population and population index routes may not be acceptable in routing the waste through the state in the least amount of time. But, exposing the large populations located along the least-transit time I-40 route may garner public resistance. A compromise amongst the routes may be the key to routing waste through the state. It is evident that state policymaker would want to gain as much

perspective as possible regarding the options they have in the decision making process.

The incorporation of GIS technology and its capabilities for spatial analysis can be a useful tool in acquiring this perspective.

CHAPTER V

CONCLUSIONS

The NRC recently reported that by the year 2010 they expect 22 applications will be submitted from various national nuclear power producers seeking approval to build 33 new reactor units in the nation (U.S. Nuclear Regulatory Commission 2008). As a consequence, in the future a growing amount of radioactive waste will be transported from generation sites to disposal facilities across the country.

As more of the nation's energy production relies on nuclear power, public concern regarding potential exposure to the waste while it is in transit will also increase. A better knowledge of the demographic composition of people living along the potential radioactive waste routes will be of even greater importance to government officials and emergency response planners when they make decisions on designating preferred radioactive waste routes and preparing for accidents.

Evaluation of Purpose

This study attempts to bring the spatial analysis power of GIS to facilitate radioactive waste routing analysis with specific considerations on the population characteristics along the route. GIS procedures have been developed to help extract demographic composition information of populations living within proximity of

potential waste routes and calculate a least-cost route based on population count. The proposed GIS procedures are applied to a routing case in Oklahoma. A route with the fewest people under potential exposure is calculated and can be used as a benchmark for evaluating other routes' performance on limiting public exposure.

Population characteristics of several alternative routes calculated for the Oklahoma case are also derived and compared to one another to help decision makers gain a better understanding of their potential impacts on people from different demographic groups.

Limitations of Study

Many of the studies in the Chapter 2 Literature Review discuss limitations in the way computers interact with large amounts of data, or data that has a complicated structure. The TRAGIS model is one example of a software adaptation that has slowly evolved over a number of years with the end goal that it will be versatile enough to route waste across the United States and incorporate the various socioeconomic, environmental sciences, and transportation based data variables. But currently the software has limited capabilities outside of set study parameters and cannot be easily adapted for localized use.

This study revealed it too would be difficult processing the least-cost smallest population portion of the procedure for multiple states with a computer that does not have sufficient Central Processing Unit or Main Memory capability. The NHPN road network consists of thousands of line segments with nodes joining the segments. Adequate computer capacity would be necessary to successfully complete the GIS process of

intersecting the individual road segment buffers with the block group geometry for multiple states. Future research could also include automating the GIS procedure necessary to processing the information and yield the routing results. To date, all the steps are carried out manually.

Also helpful to the routing process, future development of a computer interface for the compiled population index portion of the study which would allow users to input standardized weights for different demographic groups (e.g., a factor of 1.8 for populations with disabilities or 1.2 for the elderly, etc.). With such capabilities, the GIS procedures will allow users to choose more reasonable settings that fit their problems.

Application of Study

This study provides a foundation for further development of GIS-based routing decision support systems which can effectively and efficiently incorporate population characteristics into the process of identifying preferred radioactive waste routes. Such a system is expected to provide useful tools to help decision makers evaluate different routing choices with more complete information regarding potential public interaction along the routes. The described methodology has applications for all kinds of hazardous materials routing. It can also be applied to routing radioactive waste materials by train or other modes of transportation. With support of GIS spatial analysis, emergency equipment and personnel with the necessary expertise can be stationed appropriately and where the need is greatest within the routing corridors.

An important aspect of this research is that it tested GIS capabilities and provided answers regarding how to be creative with routing methodology to gather more data that

provides perspective and supports decision making. If faults are present in the technology, this will only improve with increased use and research.

Ultimately, a better understanding of affected populations living along radioactive waste routes helps industry advocates and those with concerns about the industry do their job more effectively. While the incorporation of new GIS procedures into a routing problem does not on its own cure societal problems, the information produced through its analysis capabilities can aid in the effort.

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VITA

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Because of Oklahoma's geographical location in the nation, all types of radioactive waste can potentially be routed through the state from points-of-origin to designated waste repositories. Numerous governmental regulations have been implemented to ensure public safety. However, population characteristics are not explicitly included in the routing process. This study uses GIS techniques to incorporate population characteristics in exploring the routing problem in Oklahoma. First, potential Oklahoma radioactive waste routes, weighted by total distance or transit time, are identified for a set of origination and destination sites. Next, GIS procedures are developed to derive and report the demographics of people who live along the routes. Finally, a new routing criterion of least population being potentially impacted is discussed and implemented in GIS to help explore the potential radioactive waste routes in Oklahoma. The GIS procedures developed in this study can be used to help make better decisions on routing radioactive waste.

ADVISER'S APPROVAL: Dr. Hongbo Yu
