USING GEOGRAPHIC INFORMATION SYSTEMS TO DETERMINE STREET, ROAD, AND HIGHWAY FUNCTIONAL CLASSIFICATION ACCURACY

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Abstract

Federal Highway Administration (FHWA) functional classification of streets, roads, and highways reaches into many processes of highway planning, design, and management. The classification system has not been updated in forty years. Many issues with its definition and use, such as propagated error, bias, and ambiguity are discussed as well as the ramifications on the Highway Performance Monitoring System (HPMS). Travel demand modeling relates to functional class in that the data used and derived from models are the same as the data used to define functional classification. Trip length, trip purpose, traffic volume, and vehicle miles traveled (VMT) all have bearing on functional class. Design criteria are tied closely to functional classification, as is funding eligibility. The functional classification system is in need of redevelopment, as shown by the results of this comparison of observed and prescribed criteria. GIS and travel demand model data was used to examine average daily VMT and minimum horizontal curve radius values for segments in the Kansas City metropolitan area. Statistical Chi Square tests were used to attempt to show a significant difference exists between measured, observed values and prescribed, expected values, and potential sources of error are discussed. Samples from the Kansas City urbanized area show that a significant difference exists for average daily VMT, which supports a call for better definition and procedures regarding the FHWA functional classification system. Better definition and procedures will result in better decision making for the ailing U.S. transportation infrastructure.

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Definition of Terms

AASHTO Green Book – Federal Highway Administration/United States Department of Transportation/American Association of State Highway and Transportation Officials (ASSHTO) published policy documentation formally named A Policy on Geometric Design of Highways and Streets (American Association of State Highway Officials 2001).

Average Daily Traffic (ADT) – an average of the daily traffic volume collected for a given traffic segment for a given period of time. A total traffic count is divided by the number of days in the period to get ADT. ADT is sometimes a collected actual count but due to resource constraints, many segments are assigned an ADT using calculations and estimations.

Average Annual Daily Traffic (AADT) – ADT based on a period of one year.

EMME/2 – Travel Demand Modeling software used by the Mid America Regional Council for planning purposes. The acronym EMME/2 is derived from “Equilibre Multimodal, Multimodal Equilibrium” which refers in French and in English, to the theory of network equilibrium, which underlines the multimodal travel forecasting models that can be implemented using EMME/2. The “2” indicates that its development followed EMME, which was an experimental code developed in the late 1970’s at the Center for Research on Transportation (CRT) of the University of Montreal.

Highway Performance Monitoring System (HPMS) – a reporting system required by the U.S. Federal Highway Administration (FHWA) to provide various functional and physical data for FHWA and BTS statistical purposes.

Microstation – Computer Aided Design software, used in the engineering fields.

MPO – Metropolitan Planning Organization, a statutory organization of local, county, state, and federal government agencies representing a region for the purpose of coordination of planning efforts.

Route – For this study, a route will be synonymous to any segment of public street, road, or highway of a common name, such as Main Street, Long Road, or a Highway named MO Route 23.

Travelway - all types of roads, streets, and highways including any linear feature used by vehicles. Travelways can be roads, waterways, airways, railroad corridors, or shipping lanes. For this study, travelways will focus on those used by automobiles (roads, streets, and highways). Travelways are linearly referenced and are directional, so for any two-way road, there are two travelways. Using linear referencing, analysis can be performed and attributes can be assigned to positions or ranges. Travelway is synonymous to what GIS professionals know as a route.

Vehicle Miles Traveled (VMT) – One VMT is one vehicle traveling the distance of one mile. Thus, the value for total vehicle miles is the total mileage traveled by all vehicles (U.S. Environmental Protection Agency 2006); a unit of measure that calculates the total miles traveled by all vehicles in a specified area for a specific period of time. VMT is used to evaluate the use a roadway receives at different times of the day (Southeast Michigan Council of Governments 2007).

Agency Acronyms

AASHTO – American Association of State Highway and Transportation Officials, the defacto organization of state DOTs and other roadway engineering professionals. The organization is active in maintaining standards of operation for the U.S. road, street, and highway transportation system.

APWA – American Public Works Association, the defacto organization of local and county public works officials. The organization is active in providing policy and procedures focusing on the needs of local and county governments rather than state or federal agencies, although some state and federal officials are active members.

BTS – Bureau of Transportation Statistics – an independent agency within the U.S. federal government structure, with ties to FHWA, USDOT. BTS is part of the Research and Innovative Technology Administration (RITA). Its function is to collect and disseminate transportation statistics independently of FHWA, the Federal Transit Administration (FTA), the Federal Aviation Administration (FAA), or any other agency that deals with transportation policy or allocation of transportation funding.

DOT – Department of Transportation, referring to state agencies

FHWA – Federal Highway Administration, the U.S. Government agency that governs policy and standards for DOT regulation.

MARC – Mid America Regional Council, the Metropolitan Planning Organization of the greater Kansas City Area

MoDOT – Missouri Department of Transportation

MSHD – Missouri State Highway Department, a previous official name for MoDOT.

USDOT – United States Department of Transportation.

Chapter 1
Introduction

One goal of public works is to provide safety and mobility in the transportation system. Another aim is to create a livable community. An important tool used by transportation planners, traffic engineers, and officials to achieve these goals is the street, road, and highway functional classification system. Street, road, and highway functional classification is a methodical categorization of roadways used for planning, design, and maintenance of the street and highway system.

This research used geographic information systems and statistical analyses to attempt to determine whether functional classifications approved by the Federal Highway Administration (FHWA) are representative of the design criteria and planning data as defined by published guidelines and widely practiced procedures of classification. The reason for the research and statistical testing is to support a call for further study regarding the functional classification system. To introduce this study, I begin with the research objectives, then describe the rationale and significance of the study, and follow with a description of the background and key concepts. I wrap up the introduction with a description of the study area and a short account of the limitations of the study.

Research Objectives

The main goal of this research was to explore whether more study should be performed to develop the definition of functional classes. The statistical methodology focused on the use of GIS to analyze a typical urban transportation system to answer two questions: (1) Does the design criteria (minimum horizontal curve radius) of currently approved functional classifications in the study area represent the actual design criteria? (2) Does the planning data value (vehicle miles traveled, or VMT) of currently approved functional classifications in the study area represent the actual measured planning data value?

The design criteria compared was the minimum radius of horizontal curvature. The actual minimum radius of each sampled segment was compared to the minimum radius prescribed for that segment's FHWA approved functional classification. The planning data attribute used in comparisons was VMT. In a separate test, the VMT of each sampled segment was compared to the FHWA prescribed VMT value ranges for that segment's functional classification. It is important to mention here that having an FHWA approved functional classification for a segment does not necessarily mean that all the criteria have been met for that segment. As I will describe in more detail later, there is subjectivity in classification and in the approval process that allows this situation to exist. The statistical tests were performed to determine if there were significant differences in order to decide if more study is warranted to further develop the definition of highway functional classification.

Potential error, ambiguity, and bias exist in this study. Later I discuss how these could affect the outcomes of the analysis and the validity of the results.

Background and Key Concepts

The main concept in the functional classification system in the United States is that of mobility versus access. The functional classification system is based on two rank-ordered variables that are inversely related. On one end of the ordered system, mobility for travelers is high, allowing quick, easy travel from place to place over long distances. Interstate Highways, ranking highest in mobility, fit this description. On the other end of the spectrum, easy access is provided to all land parcels and land uses. Local streets in residential zones and other local routes, ranking highest in access, fit this description. Conversely, Interstates rank lowest in access and local streets rank lowest in mobility. Figures 1 and 2 from the FHWA Guidelines (FHWA 1989) show different representations of how mobility and access are balanced for a given route. Where access is provided, mobility is sacrificed; where mobility is provided, access is sacrificed.

The Federal Highway Administration (1989) republished guidelines that define how a DOT should go about functionally classifying the system. Included are separate guidelines for rural, urban, and urbanized areas. For the 2000 Census, the U.S. Census Bureau (2000, 2002) used a geographic area's (block groups and blocks)

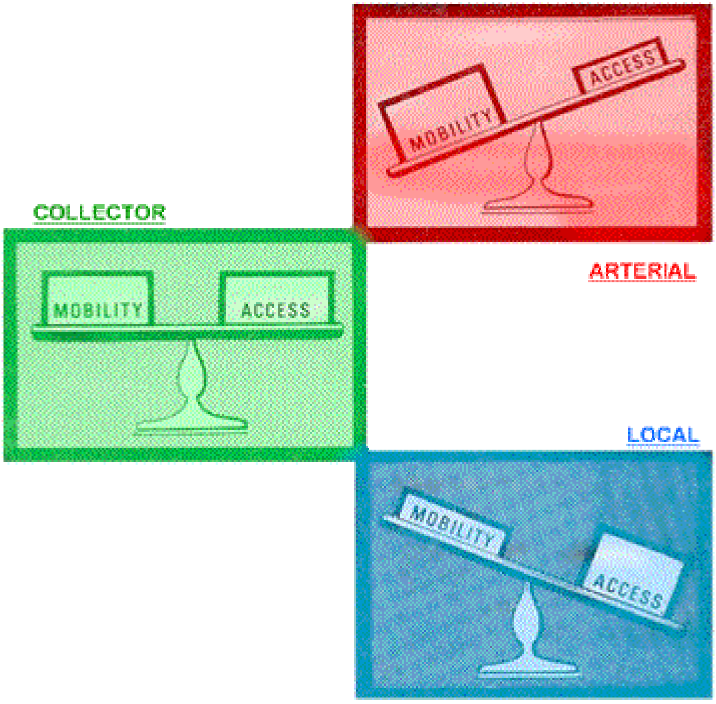


Figure 1: Scales of Mobility vs. Access (FHWA 1989)

population density to define urbanized areas. FHWA allows a modification, or smoothing, to occur for transportation planning purposes, and also calls them urbanized areas. The U.S. Census Bureau abbreviates an urbanized area as a UA while FHWA uses UZA. For purposes of transportation planning, FHWA UZAs are smoothed Census UAs, and federal legislation (23 USC 101 (a)(36) defines urban areas as Census designated areas with population between 5,000 and 50,000. That leaves rural areas as those with less than 5,000 population (FHWA 2006). Each area, says FHWA (1989), should follow a suggested mileage and Vehicle Miles Traveled (VMT) percentage ranges for each functional class. Percentage ranges are given by FHWA as a goal to stay within for each class, but neither agency mandates nor federal statutes back up these guidelines. From personal experience, the processes of classification are loosely adhered to and are viewed

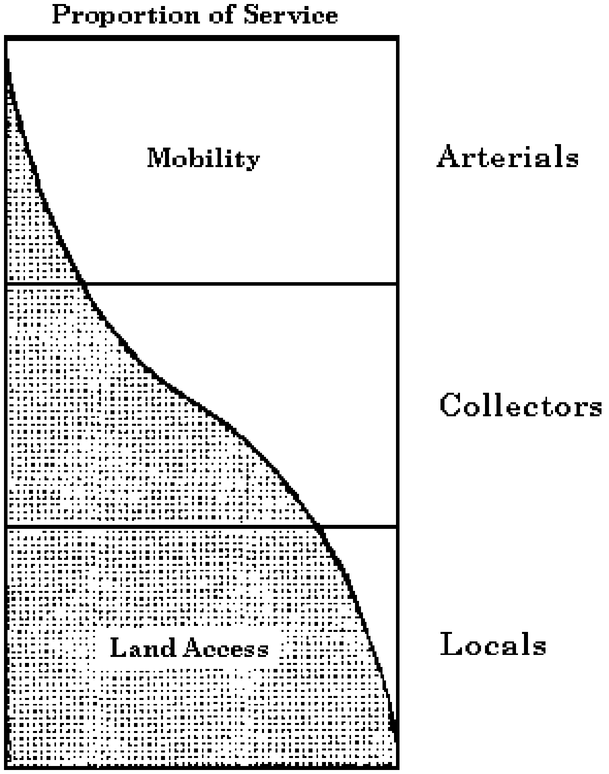


Figure 2: Functional Classification Relationships (FHWA 1989)

as guidelines to use as a target. The guidelines set forth by FHWA (1989) include a classification for all roads as follows:

Local Roads – providing unlimited access and very little mobility. An example would be a residential subdivision street with a driveway for each house accessing the system.

Collectors – providing more mobility than local roads but less access. An example would be a two-lane road that separates subdivisions that connects to both local roads and a four-lane highway. Access to most collectors is limited to commercial entrances and major streets leading into subdivisions. Within this classification there are major collectors and minor collectors in a rural area but only the general class of collectors in urban and urbanized areas.

Arterials – providing a high degree of mobility and a low degree of access. An example would be a 4-lane highway with access to only collector streets. Within this classification, there are Interstates, freeway/expressways (for urban areas only), other principal arterials, and minor arterials. The first three are actually subclasses of the principal arterial class while minor arterial is in its own class. Interstate Highways are a formalized system of principal arterial in which there are no access points other than high-speed ramps and are used for the longest trips. This classification is highly regulated by FHWA. The freeway/expressway subclass of principal arterials includes all other routes with little or no direct access and very few at-grade crossings. Routes classed as freeway/expressway facilitate regional and interstate trips with generally unimpeded flow of traffic. Other principal arterials have comparatively more access points and traffic impediments than freeway/expressway routes. Minor arterials are progressively less mobile but more accessible than the higher classed routes.

Here is a summary of all the classes prescribed by FHWA:

- Principal Arterials
    - Interstates
    - Freeways/Expressways
    - Other principal arterials
- Minor Arterials
- Collectors
- Locals

The American Public Works Association (APWA) uses functional classification in the same manner as prescribed by FHWA, but APWA defines the classes differently to provide more usefulness on a local level (APWA 2004). FHWA classification system is designed to accommodate highways and a larger area. APWA classification system is designed to be limited to a single urban or urbanized area. The Kansas City Chapter of the APWA defines them as follows:

Major Arterial Streets (or Primary Arterial, or Urban Principal Arterial):

Streets that serve the highest traffic volume corridors and the longest trip. Provides travel between business districts and outlying residential areas, between major inner city communities and between major suburban centers, and connects communities to major state and interstate highways. No or limited access is allowed from residential streets. Access usually partially controlled. Spacing of major arterial streets is generally from one mile to five miles.

Minor Arterial Streets (or Secondary Arterial, or Urban Minor Arterial): Streets that interconnect and augment the major arterial streets. No or limited access is allowed from residential lots. Accommodate trips of moderate length at a lower level of travel mobility than major arterial streets. Spacing of minor arterial streets is generally from one-half mile to three miles.

Industrial/Commercial Collectors (or Collector, or Urban Collector): Streets that collect traffic to and from commercial or industrial areas and distribute it to arterial streets.

Residential Collector Streets (or Collector, or Urban Collector): Streets that collect traffic to and from residential areas and distribute it to arterial streets. Limited access is allowed from residential lots. Desirable maximum ADT = 3,000 for residential collector streets.

Residential Local Streets (or Local, or Urban Local): Streets that carry only traffic having its origin or destination within the immediate neighborhood. Desirable maximum ADT = 1,000 for local streets. (ADT = ten trips per day per typical single-family residence.)

Residential Access Streets: Streets that carry traffic between residential local streets or residential collector streets. Residential access streets usually carry no through traffic and include short loop streets, cul-de-sacs, and courts. Desirable maximum ADT = 200 for cul-de-sacs and 400 for loop streets. Maximum length of cul-de-sacs = 500 feet and 1,000 feet for loop streets. (ADT = ten trips per day per typical single-family residence.)

When comparing the FHWA and APWA classes, there are likenesses in their described purposes, although the FHWA class definitions are somewhat more flexible or ambiguous, depending on the point of view. Generally, Table 1 acts as a crosswalk for APWA and FHWA classes when comparing design criteria and planning data. Interstates and Freeway/Expressways are excluded from the table, as they are exclusive of highways and do not apply to streets. The crosswalk is necessary for the study due to different jurisdictions using different design criteria for each class, while cities and counties usually use APWA standards, which are more suitable to urban street design and functional needs. For this study, I am attempting to make a case for further development of the national functional classification system, which is the FHWA system.

Rationale and Significance

Functional classification affects planning and design very comprehensively, but it is sometimes not given the attention it needs in the transportation planning and design field. In some government agencies, functional classification is somewhat given a back seat to other priorities, even though many procedures and policies rely on a sound choice of functional classification of a street, road, or highway to be planned, designed, or maintained. The potential of the system promises renewed emphasis on procedures and guidelines regarding the functional classification system. This is needed to realize more sound planning processes in order to make decisions regarding transportation improvements. The system has the ability to bring more efficiency and objectiveness to the transportation planning process, which includes closer ties to land use planning. Mackett (1994) relates the importance of transportation modeling to the planning-policy

Table 1. Crosswalk of FHWA and APWA Functional Classes (APWA, 2004)

FHWA Class	APWA Class
Principal Arterial	Major Arterial Street
Minor Arterial	Minor Arterial Street
Collector	Industrial/Commercial Collector
Collector	Residential Collector Street
Local	Residential Local Street
Local	Residential Access Street

relationship and the importance of the land use-transportation relationship to the planning process. This supports the notion that land use should play a significant role in functional classification.

Functional classification seems to have evolved, in many ways, to being solely a tool to secure funding. Evidence of this trend is present in several documents. The Ohio DOT’s Highway Functional Classification Background Information (Ohio DOT 2007) and its Procedures for Processing Revisions to Highway Functional Classification, Federal-aid Systems, and Urban/Urbanized Area Boundaries (Ohio DOT 1999) and the McHenry County, Illinois Council of Mayors Functional Classification Process (2006) all imply that eligibility requirements based on functional classification often give rise to the game of changing the functional classification based solely on the desire to secure funding rather than on sound purpose, need, and travel characteristics of the travelways. Based on my personal experience working at MoDOT from 1999 to the present, as the other documents imply, when an agency desires to build a project, it lobbies for a change in functional classification to make the roadway eligible for one of a number of pots of FHWA funding programs. Several U.S. federal transportation funding sources require that a route be on the collector system or above, while other funding programs require that pairs of travelways be local roads only. In order for the system to have more usefulness, policies and procedures regarding the functional classification management should be revised.

Official functional classification guidelines defined by FHWA do not exhaustively define break points for criteria for each class in the system (FHWA 1989). Instead, FHWA allows a somewhat subjective fuzzy overlap between classes regarding most of the criteria used to determine classes.

Functional classification in the U.S. reaches into many areas of transportation planning and design. When planning a new or relocated route or planning enhancements to an existing transportation corridor or facility, functional classification is one of the first decisions to be made. Functional classification answers the question, ‘What is the purpose and need of the facility?’ Once determined, functional classification is tied to many criteria used to design the travelway. It is linked to typical section, horizontal curve data, design speed, shoulder and lane type and width, maximum grade, stopping distance, and several more. The size, shape, and quality of the construction of a new route or improvements to an existing route are highly dependent upon the choice of functional class.

Various other classification systems also exist simultaneously to serve different needs. A roadway designation system includes Interstates, U.S. highways, state routes, county roads, and other designations as a classification system. Jurisdictional boundaries also form a classification system by which streets, roads, and highways are owned and maintained, useful for funding mechanisms. Area designations of urbanized, urban, and rural as described above are also useful for funding and aid in choice of design criteria.

Also a part of functional classification is the Interstate Highway System. As mentioned above, the Interstate Highway System is a very defined and documented system in which access control is closely adhered to and regulated. Close oversight by FHWA is present with Interstates. Another system is the National Highway System (NHS), which is not part of the functional classification system, but serves as a way for the U.S. Congress and FHWA to make decisions regarding funding and approval priorities. There are also other systems. Military highway priorities are determined using the Strategic Highway Network (STRAHNET), and the Congressional High Priority Routes system is used for funding special priorities as seen by the U.S. Congress. MoDOT has recently implemented a formal macro classification system of Major and Minor Highways that is loosely based on functional classification. This classification arose out of a need for funding and maintenance priorities. Missouri also has a statutory State System Classification consisting of Interstates, Primary Routes, and Supplementary Routes. In Missouri, Major Highways are characterized by a majority of the vehicle miles traveled on a minority of the roadways, defined collectively as all routes with a functional classification of principal arterial or higher. Minor Highways are all other routes on the State System Classification as described above. The Major and Minor Highways classification excludes travelways like ramps, outer roads, and cross streets that are explicitly owned and maintained by MoDOT. This grouping of routes gives MoDOT an effective method of managing the Missouri State System for setting priorities. All these different systems could feasibly be incorporated into one comprehensive system if policy is written and enforced to support its use.

Functional classification is not an exact science. There is overlap between classifications, which is somewhat undesirable if we want to maximize the usefulness of the classification system. In order to adequately define classes, there needs to be more definition in the criteria by which we classify.

To compound the effects of loose class breaks, there has also been a shift away from statistical methods when classifying roads. The Missouri State Highway Department (1967) published a report that detailed procedures in deriving functional classifications including variance testing and linear correlation statistics, but no other statistical record can be found in any of their libraries, reports, correspondences, or other records. I found no other reference to statistical methods being performed specifically on functional classification other than mileage and VMT percentages. Even those are only satisfied within certain fairly broad percentage ranges. An emphasis on quick decisions using heuristic knowledge and a wide overlap between classes seems to have created a classification system that is very subjective.

Congressional earmarking is also an issue related to classifying routes. Without a strong classification system backed by strong policy, funding of transportation projects has become bogged down with earmarking of funds by the U. S. Congress for pet projects prior to apportionment of funds to DOTs and other public agencies. This seriously hampers the abilities of transportation planners to plan the system according to true needs. Zimmerman (2005) of the watchdog group *Taxpayers for Common Sense* said in a Senate brief, “The simple fact is that earmarks drive up the overall cost of the bill. Earmarks also take a great deal of decision-making power away from local officials.” Senator McCain (2001) spoke of the number of transportation earmarks growing drastically over the last several years. He referred to numbers from the U.S. Office of Management and Budget in stating that overall earmarks went from 1,724 in 1993 to 3,476 in 2000 and 6,454 for 2001 (McCain 2001). In the 1950s, during the Eisenhower administration, there were only two earmarks when the push for a uniform nationwide transportation system began. Earmarking threatens to undermine the usefulness of functional classification, so a strengthened system is essential to encourage sound planning processes.

There is a close relationship of functional classification to policy and procedures. Although varying slightly for different governmental levels in the U.S., design standards are driven by functional classifications. Most agencies follow American Association of State Highway and Transportation Officials (AASHTO) guidelines described in the Green Book or by the APWA standards. Procedures are such that functional classification is the first decision made about a proposed route prior to beginning design work.

The lack of objectiveness in functional classification, the trend of using functional classification as a means to secure funding, the trend of more and more systems of classification being created, the fact that earmarking is seriously hampering planning policy, and the importance of functional classification to design standards all point toward a need for a strengthened functional classification system and policy to control and enforce its use. These statistical analyses presented here showed support for further study to determine if and what to further develop regarding the definition and procedures of functional classification.

Studying functional classification is important for the development and use of GIS. First, using GIS to analyze transportation characteristics is important to further the use of GIS in DOT workflow and business processes. Many DOTs and public work departments do not adequately incorporate GIS into their business processes. The current state of GIS practice by state DOTs is mostly data storage and map creation. There is some analysis being performed, but further use of GIS for analysis to support decision-making, in this case the decision to further study functional classification or not, is an important step in more incorporation of GIS into transportation business processes. The progression to include more robust analysis into workflows can help introduce more objective support for decision-making.

Another area of improved technology is that of GIS over traditional modeling techniques. A study found that GIS offered time savings and an increased ability to model patterns and relationships over using simply traffic volumes and link lengths as seen in most traditional travel demand models. (Sarasua *et al*. 1999)

Most DOTs and private engineering firms have been driven by computer-aided design (CAD). Only in the past ten to fifteen years have DOTs ventured into GIS. In many DOTs and public works departments, CAD and GIS have not been married together well. This is in contrast to many county assessors' offices where GIS has mostly been embraced by these organizations and been integrated fully into their workflows. The hope is that using GIS for more than just storing attributes for Highway Performance Monitoring System (HPMS) reporting and other map creation tasks will urge the DOT and public works agencies to further integrate GIS. If they see studies that show results of improved business processes, they will be more likely to buy into the potential power of GIS.

Secondly, if a goal of the GIS community is to provide an improved modeling environment to examine and analyze earthly phenomena, then extending GIS to model functional classification is a useful effort to extend an important part of the transportation model. Some authors reaffirm the relationship between land use and transportation and study the growth affects of each on the other. (Sanchez *et al*. 1999) They conclude that land use growth and transportation growth both act as cause and effect in the relationship. This gives further validation of studying both design criteria (capturing physical transportation system characteristics and how they relate to surrounding land use) and travel characteristics (capturing functional properties of the system and how they relate to land use characteristics).

Study Area

Although rural functional classification also warrants study, the study area for this project will be the urbanized Kansas City Metropolitan area in Missouri. The U.S. Census Bureau designates geographical areas as rural, urban (cities and towns), or urbanized areas (UZAs) (metropolitan areas and major cities). The rural, urban, and urbanized areas are based on U.S. Census designations. As described above, FHWA directs DOTs to smooth the boundaries after each decennial census for transportation planning purposes. This process yields an FHWA approved boundary for rural, urban, and urbanized areas that is slightly different and more logical for transportation purposes than the U.S. Census boundaries. FHWA gives state DOTs, in cooperation with metropolitan planning organizations (MPO), the responsibility of smoothing the boundaries. The Mid America Regional Council (MARC), the Kansas DOT and MoDOT have completed the Census year 2000 boundary adjustment for the MARC UZA. Comprehensive average annual daily traffic (AADT), VMT, and other data for the year 2000 are available. Functional classifications for roads and highways are constantly in a state of flux, with roadway classifications continually being reviewed and changed by authorized agencies. For the above reasons, the study area will be the 2000 FHWA smoothed urbanized Kansas City metropolitan area (KC UZA) as shown in figure 3. Even though the MARC area includes areas in Kansas City, Kansas and other Kansas areas, the study area will only include the Missouri portion of the MARC area. This research focuses on one state because there is inconsistency of classification procedures among agencies in different states directing the work. The analysis can later be duplicated for the Kansas side or be applied to other areas.

The Kansas City metropolitan area is ranked 27th in population in the U.S. with around 2 million inhabitants (U.S. Census Bureau 2003). It is a somewhat sprawling area with low population density when compared to larger cities like New York, San Francisco, Los Angeles, or its close neighbor St. Louis. As for the transportation system, it is atypical for large cities in that it does not have a rail transit system such as Chicago or New York, but the highway and street system is the typical layout including a strong network of freeways that cut across a grid street system. The sprawling nature of the metropolitan area creates a difficult situation for commuters to carpool and for area transit authorities to feasibly and effectively provide mass transit.

Numerous major traffic generators exist in and near the study area. Several large corporations have their headquarters in the area. Hallmark, the greeting card maker, has a major office/retail complex south of downtown Kansas City as well as a distribution

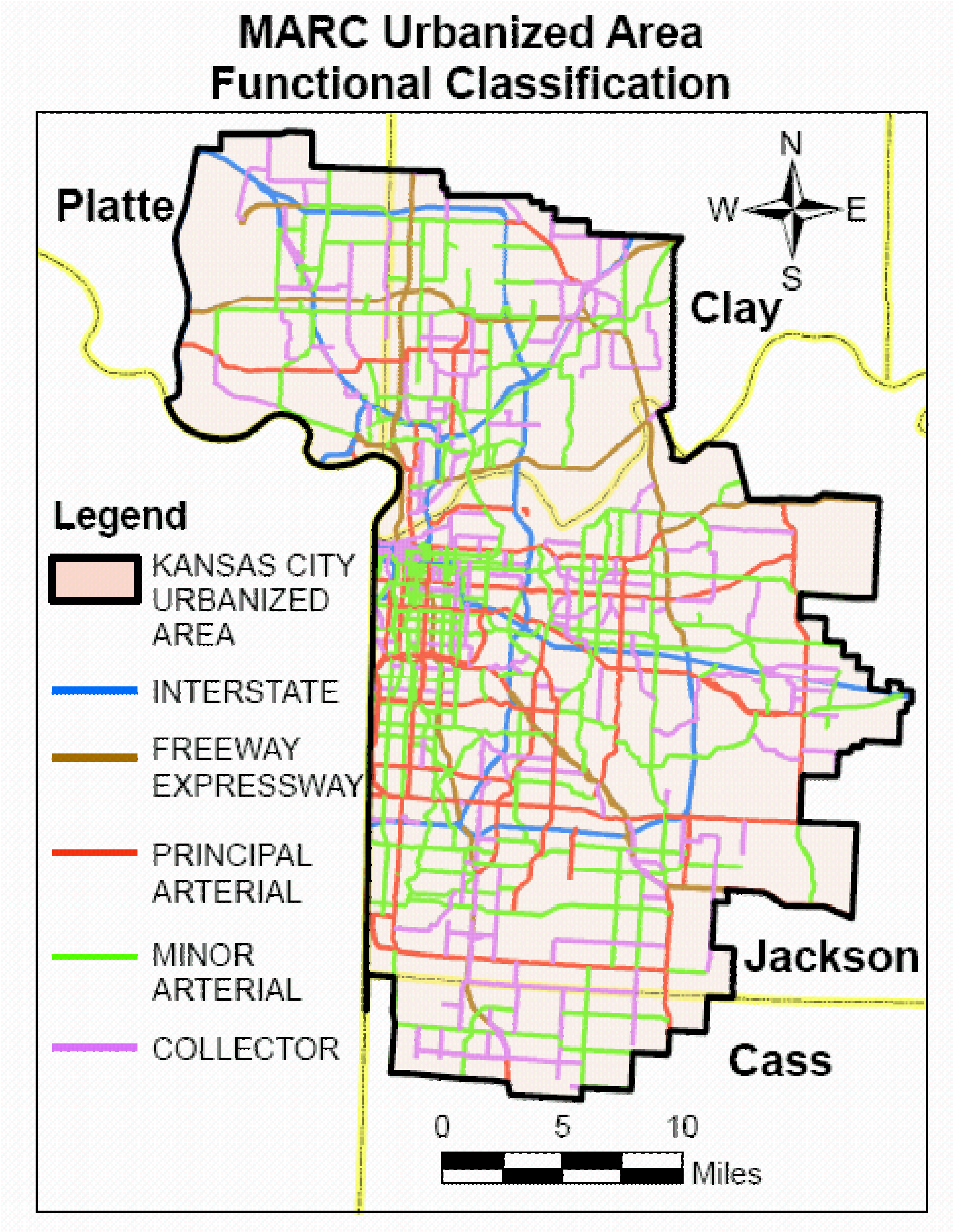


Figure 3: Study area

center north of Liberty, Missouri. Sprint/Nextel is headquartered in Overland Park, Kansas. Also in the area are other traffic generators such as the Kansas International Speedway and surrounding retail areas, the Kansas City International airport and related industrial areas. There is a major freight terminal on the south side of the metro area and several other recreational and business traffic generators in the area.

The nature of the transportation system in general in the Kansas City area is fairly typical of most large cities in the United States, with a good balance of Interstate Highways and other roadway types. One unique feature worth mention is the emphasis on a parkway system in Kansas City. Since around the turn of the twentieth century, Kansas City has emphasized a build-out of a very robust system of parkways compared to other large cities.

Overall, the Kansas City metro area is a typical average urban area, suitable for a study of this nature.

Chapter 2
Literature Review

When I reviewed literature regarding functional classification, it became clear that an examination of the chronological development of functional classification on the federal or national level was necessary. There are four other important aspects found in the reviewed literature. Studies published by State DOTs are another review area that supports my view that the functional classification system is an ambiguous one and in need of more definition. There have been calls for other classification systems and comparisons with other countries' classification systems, my third review subject. Issues about data and definitions of key terms comprise a fourth area. Lastly, there has been considerable discussion about the relationship between functional classification and FHWA's Highway Performance Monitoring System (HPMS).

Historical Development of Functional Classification

Functional classification of roads, streets, and highways might best be reviewed by its historical development, since most research and development of the system occurred from a core set of documents by a few key organizations. The system has its roots in 1928 with a definition of traffic capacity. In 1950, the American Association of State Highway Officials (AASHO) republished their Policies on Geometric Highway Design comprised of several previous documents. (AASHO 1950). In the Policy Guide, the Committee on Traffic Analysis of the Highway Research Board recommended the definition as, "The traffic capacity of a roadway is reached when any further increase in traffic volume, all other factors remaining constant, results in a marked decrease in traffic speed." (AASHO 1950, p. 5). Dean Johnson, in a 1932 report of the study of two, three, and four lane highways, offered the term working capacity or free-moving capacity as, "the point at which congestion first becomes apparent [road is filled, passing becomes impracticable for more than a minute]" (AASHO 1950, p. 6). In 1933, Hawley S. Simpson, at the proceedings of the American Society of Civil Engineers (ASCE) gave this definition, "The capacity of a city street is reached when the volume of traffic is so great that any further increase will result in conditions of movement so unsatisfactory to the users that less favorably situated routes are preferable by a considerable portion of those who would normally find the original street most useful" (AASHO 1950, p. 6). Sivald Johanneson offered another definition, "Traffic capacity is the maximum number of vehicles which may pass a given point on the highway in a given time" (AASHO 1950, p. 6). In 1940, AASHO adopted, "The traffic capacity of a highway is the maximum traffic density which will permit vehicles to travel at the assumed speed without appreciable delay" (AASHO 1950, p. 7).

The significance of listing these definitions is that all of them contain considerable ambiguity or lack of definition. In the 1928 definition, the term "marked" is open to interpretation; in the 1932 Johnson definition, the words "apparent" and "impracticable" both have an element of uncertainty; in the 1933 Simpson definition, the terms "unsatisfactory" and "considerable portion" are not definite. Johanneson's definition does include a definite metric in using "maximum", but does not give any way to measure. In the definition AASHO adopted, the word "appreciable" is also rather undefined. What this means is that at the time, there were still metrics being developed to measure traffic, and that classification was still more of an art than a science. AASHO mentions in its first section of the collection of policies that metrics would be studied to determine objective points at which traffic capacity would occur.

AASHO also played a part in the development of the functional classification system. Originally published in 1940, the first section of the AASHO Policy (1950) also details classes formed in 1931 based on travel density. The classes were to be straightforward and simple, and appeared as:

A- 4000 vehicles per day or more
B- 750-4000 vehicles per day
C- 300-750 vehicles per day
D- 200-300 vehicles per day
E- Below 200 vehicles per day

In 1936 class E was revised to be 100-200 vehicles per day and classes F and G 50-100 and fewer than 50 vehicles per day, respectively, were added. These classes at the time were seen as an incomplete representation of expected traffic volume services of highways. In 1940, the services of travel density, character of traffic, and assumed design speed were approved by ASSHO as the way to classify roads and highways. In describing a specific route, a number representing travel density was defined as a number of vehicles in a period of time. The character of traffic was denoted as a letter "T" for primarily truck traffic, "P" for passenger traffic, and "M" for mixed traffic. Within each designation, the metric was not well defined. For example, a T did not represent a fixed percentage of trucks and the designation could differ for different locations. Design speed was listed in miles per hour (mph) and limited to 30 mph through 70 mph at 10 mph intervals. Design speed is the average speed the majority of travelers would adopt on a given route. So, for a given route, after 1940, the classification might be denoted as 1000 M 60 for 1000 vehicles per hour, mixed traffic, and a 60 mph assumed design speed. AASHO (1950) studied the pros and cons of longer and shorter time intervals for the travel density but settled upon hourly as satisfactory for design purposes. This is important in describing the development of the functional classification system because it shows the need and desire for a common classification system, and one that would lead to design guidelines based on the services needed for a classified route.

In its 1940 Policy, AASHO (1950) also gave classifications of highways based on type. The criteria here included cross section (two, three, and four lane), divided or undivided, existence of protection for turning traffic, curbs, and sight distance. In these classifications, Truck routes, from the above class system, had wider lanes than mixed or passenger routes. In 1944, the industry saw the beginnings of measurable traffic volume warrants for grade separation, which added a new criterion, that of freeway or allowable at-grade crossings, to the situation.

From 1950 to 1964, I found no references to any specific developments regarding the functional classification system, but a document by the American Association of State Highway Officials (AASHO), the National Association of Counties (NACO), and the National Association of County Engineers (NACE) appears to be the first published mention of the term functional classification (AASHO / NACO / NACE 1964). The 1964 document was included as an appendix in Functional Classification in Missouri (Missouri State Highway Department 1967). The 1964 document gives technical procedures for classifying routes. The document describes urban arterials as providing direct service to principal traffic generators and the central business district (CBD). Urban arterials, the document continues, also serve major employment centers, goods distribution/transfer centers, and transportation terminals. Additionally, urban arterials interconnect all portions of urban areas, provide connections to rural areas, furnish adequate width and alignments, and use traffic engineering techniques to optimize utility (MSHD 1967, p. A61). The AASHO / NACO / NACE document (1964) describes urban collectors as highways that collect from local roads, and channel traffic to arterials and vice versa. Collectors, the document goes on, provide cross connections between arterials and provide direct service to neighborhood traffic generators not served by arterials. (MSHD 1967, p. A62). Commercial local streets, says the reference, may serve substantial traffic volumes but not provide through service. Through traffic is discouraged by layout and design of these facilities (MSHD 1967, p. A62). The 1964 document specifies source data for classification that includes U.S. Census data, traffic volumes, road logs, VMT, origin-destination (O-D) data, and trip generation data. This shows that possibly the functional classification system is basically sound and has been for many years. I contend that a possible issue may be that the data being specified for criteria was, and still is, hard to acquire and that the data is also hard to break into logical classes.

There seems to have been very similar documents published in 1969, 1970, 1976, and 1989. (FHWA / USDOT / BPR 1969, FHWA / USDOT / BPR 1970, FHWA/USDOT 1976, FHWA 1989). They all seem to be minor revisions of the previous document. The AASHTO (1973) Policy Guide contains a section that is almost verbatim of the 1969, 1970, 1976, and 1989 documents. The changes I noted from 1969 to 1970 are that the Highway Performance Monitoring System (HPMS) sampling techniques were evident in the 1970 document (FHWA / USDOT / BPR 1970) that were not in the 1969 document (FHWA / USDOT / BPR 1969). In 1973, the AASHTO Policy

Guide discusses land use more in detail than previous documents. In addition, it contains the beginnings of transportation modeling as we know it today. The 1973 document (AASHTO 1973) also discusses goals consistent with functional classification of serving trip desires providing mobility and providing land use access.

FHWA added discussion of trip channelization in its Guide for Functional Classification of Highways (FHWA / USDOT 1976). The definition given for functional classification is, "…the nature of the traffic channelization process by defining the part that any particular road or street should play in serving the flow of trips through a highway network." (FHWA / USDOT 1976, p. 2) The Guide also details utility of the functional classification system for planning purposes of defining travel paths, providing a means for traffic volume estimation, and provides a means to determine dominant travel distances served by various segments of routes.

Functional Classification Guidelines: Concepts, Criteria, and Procedures (FHWA 1989) has become the dominantly referred to document for engineers and planners in practice today. A few significant changes were made to the 1989 Guidelines from previous documents:

Graphical representation of traffic generators was removed
VMT percentage ranges were slightly changed
Reference to small urban areas was added
Volume Trip Length Index was eliminated

There has been no update of the 1989 document (FHWA 1989), although an effort is underway to consider changes to it as part of the HPMS Reassessment (FHWA 2005, 2007a, 2007b). The importance here is that there has been no substantial major development, refinement, or consideration of new measures and criteria of the functional classification system, except for minor changes and additions from 1969 to 1989, for nearly forty years. During this same period, much research has been done regarding travel characteristics and the technologies to collect the data to process these characteristics. Traffic simulation and travel demand modeling have become mainstream parts of DOT business in many states.

To summarize the development of the functional classification system from an official government agency and professional society capacity, the system saw beginnings in the 1920s, and then developed considerably through the 1930s and 1940s. In the late 1960s and early 1970s, and again in 1989 some development was done to the definitions, criteria, and procedures. Since 1989, there has been no substantial change or development of the system. Currently the system exists in a somewhat ambiguously defined state, with loosely written guidelines on definition of classes, criteria of classes, and procedures by which to classify route segments.

Studies Published by State DOTs

My second grouping of reviewed literature focuses on studies and publications by State DOTs. They are relevant to the history of the functional classification system. The Missouri State Highway Department (MSHD) in the above mentioned report of functional classification (MSHD 1967) utilized a special class for routes to recreation areas showing that the system was not robust enough to address those perceived needs at that time. Since the system has not changed much, it stands to reason that it still is not robust enough.

The report recognized two important points about the functional classification system. First, Missouri acknowledged that functional classification should undergo an ongoing review. The report states, "It is recognized immediately that a continuing study of classification needs to take place." (MSHD 1967, p. 20). Further detail reveals that Missouri recognized that political-socio-economic change would occur that would continually affect transportation systems. The second point is U.S. Census designated areas needed more definition with respect to functional classification. The report states, "There also is the undefined gray area, that lies between the urban and rural area road networks. This transition zone needs to be defined better so that service level standards of highways can be developed." (MSHD 1967, p. 20). This supports further development of the criteria and definition of the classification system. Furthermore, Missouri identified the importance of functional classification to transportation planning, "Functional Classification is essential in determining needs and is an effective tool for planning, priority programming and development and operation of streets, roads, and highways." (MSHD 1967, p. 1).

Allinson, Inc documented design criteria for each classification in a study for Massachusetts (Allinson, Inc. 1969a). This report contains an appraisal of functional classification and an engineering assessment of highway needs for the Massachusetts Highway system. In another part of this three-part report, the authors also state, "No single principle or formula can wholly define functional road classes." (Allinson, Inc. 1969b, p. 15). They note the importance of functional classification, "The cornerstone of highway policy in any state is system classification." (Allinson, Inc. 1969b, p. 14.).

These state studies confirm that the functional classification system is not as robust as desired. Although I had easy access to the Missouri study as a MoDOT employee, other state studies were not found so easily. Since FHWA mandated functional classification study throughout the last several U.S. Census cycles, no doubt there were more studies done throughout the last thirty or forty years by or for other states that are likely housed in DOT libraries that are not easily accessed.

Other Classification Systems

Third, there have been calls for other classification systems and comparisons with other countries' classification systems.

Fitzpatrick *et al*. (2003) began the development of a design class scheme. They recognize the similarities of their scheme to the traditional functional classification system (Fitzpatrick *et al*. 2003, p. 3). Their system classifies by geometry type and seeks to group like travel speeds within classes. They identify that functional classification does not serve all needs in the transportation industry. This shows a need for development of the functional classification and possibly other systems to gain utility in practice.

The Functional Classification Guidelines (FHWA 1989) use travel characteristics, or planning data, as determining factors for functional class breaks for U.S. highways. Other countries factor in criteria different than those prescribed by FHWA. As seen in the Rural Road Classification Report from Saskatchewan (Saskatchewan Association of Rural Municipalities 1999), Canada's functional classification system is similar to that in the U.S. for urban areas, but rural areas have a somewhat different classification system based on population of the places connected by the system segments. Roads that connect to the U.S. border and those that connect areas of heavy crude oil industry also get special consideration. Canada's functional classification system also takes into account a more industrial economy present in Canada, which contributes a considerably higher truck traffic percentage than in the U.S.

Garrick and Kuhnimhof (2000) discuss Germany's classification system in detail. They state that authorities overlook the importance of the functional classification. They also discuss the criteria of the German system, which includes consideration of surrounding land uses and non-vehicular uses of streets. Criteria for road classification include whether the road is near a built-up area, whether buildings surround the route, and whether the street serves as a pedestrian gathering place. None of these criteria are included in the FHWA functional classification criteria. The authors do not use or refer to any statistical methods or scientific comparison, but only give singular comparisons to specific criteria in the German and United States classification systems.

Issues with Data and Definitions

The fourth literature review group involves data considerations and definition of terms. As for definitions, the two basic definitions at the heart of functional classification are access and mobility. Hamburg *et al*. (1995) discuss these in terms of rights and privileges rather than only the technical aspects of them. Relating access and mobility as social institutions shows the importance of functional classification to more than just transportation planning. This study shows that classification has its heart in access versus mobility, and that it is very important in society. Definitions of each class are also ambiguous within the functional classification system. Current FHWA Guidelines (FHWA 1989) do not adequately define objective class breaks, allowing subjective judgment to define class breaks from state to state and region to region.

Other than definitions, a portion of the literature reviewed deals with data considerations such as error and its propagation, data accuracy, alternative data, sampling design, and other considerations.

Pierce and Kinateder (1999) examine a sampling approach that takes into account the correlation between transportation links. The authors contend that since vehicles travel along consecutive route segments or links, that vehicles likely use both, so it is inefficient to sample both links. I think this may not be valid for sampling characteristics of the traffic on links but may be rather valid for sampling of travel characteristics of vehicles on those links. In other words their premise holds true that adjacent links have the same type of vehicle distribution on both links, but due to other factors such as intersections and entrances, traffic volumes and other travel characteristics are not dependent on adjacent links. The authors show that link relationships can be quantified by correlation. They discuss links and the travel patterns along them in terms of multiple links and time intervals. They give two estimates of correlation. One deals with connecting links into routes or patterns, the other with simulation.

Their first correlation estimate uses information on variability on pathways for attributes being measured. This estimate calculates pair wise correlation among links in a network. Their second correlation estimate accounts for fleet and temporal flow. It uses the premise of temporal snapshots of a network and uses proportions of vehicles with desired characteristics. This relates to this study in that in historical sampling designs, it was possible to include highly correlated links. Their conclusions show the possible shortcomings of my sample design, which does not eliminate adjacent segments from the sample.

In his lecture documentation, Pisarski (1999) states the need for objective representation of reality, “We need to spend a tremendous share of our efforts heavily focused on objectively describing what exists and how it relates to other elements of society and the economy, without hyperbole, without selling an angle, just stating what it is.” (Pisarski 1999, p. 5). He also stresses that with the age of information, we tend to distort data, and “We are more and more capable of rapidly transferring and effectively manipulating less and less accurate information.”(Pisarski 1999, p. 5). Pisarski contends that data is inextricably linked to planning and policy. He discusses that there is no established guide to what to collect, to what level of detail and precision. I disagree that there is no guide as to what to collect. I believe we have the knowledge of what to collect, but political pressures often trump following through. There is also an ignorance of what to collect and use as data or a conscious choice to use certain data. HPMS is well developed as to what to collect. I agree with Pisarski that there is no guide as to what level of detail to collect data. We have not developed the accuracy standards regarding data we need to collect. I contend that the knowledge of what to collect has been there for a long while, but in the past we could not feasibly collect data in the manner that we can today due to technology. Pisarski contends that the current policy decision-making paradigm we practice under dictates that all decisions will be made with existing statistical data because data collection takes too long for perceived decision-making timeframes. I agree and further think that this is partly due to the reactionary nature of some of our policy issue needs.

Pisarski (1999) describes 3 periods of data in recent history. 1962-77 saw a rise of emphasis on data, 1977-90 saw a disinterest in data and analysis, and 1990-forever more saw a reawakening of the value of information. I think that this may be somewhat of an overgeneralization; I see several organizations that do not truly value data and information and only manipulate it to support or refute preconceived solutions and decisions. He discusses the Bureau of Transportation Statistics with regard to goals of data partnering being unrealized.

The accuracy of data related to functional classification was also a topic of review when surveying literature. Since the statistical method of this study uses linear data, the accuracy of linear referencing can be important. Quiroga (1999) discussed the error present in linear referenced data due to the algorithms in popular GIS packages. Since functional classification currently includes a wide range of mileage percentages for each classification and further ambiguity is introduced in the lack of definition of areas to apply the percentages, the greatest potential error introduced by linear referencing algorithms is smaller than the range of mileage percentages defined in the class breaks prescribed by FHWA (1989). Furthermore, my study did not compare lengths and mileage percentages, only whether segment criteria matched their approved classification. I did use segment lengths for VMT calculations, so this error could have some bearing on that portion of the analysis.

Quiroga and Bullock (1999) discuss advancements in travel time data using GPS and GIS. This is important to note that data relating to travel characteristics is improving with advances in technology. One of the problems with defining functional classification is the fact that data cannot easily be collected or accurately estimated for travel characteristics such as origin-destination, trip length, and others. Since the data associated with functional classification is being researched and inadequacies being addressed, the transportation industry should use these advances to further the definition of functional classification.

Traffic volume data, which is a traditional surrogate to obtaining true trip characteristic data, also has some issues. Sharma *et al*. (1999) show that neural networks are a viable alternative to a traditional approach of traffic volume estimation using factoring. Their study shows that neural networks can have less error in estimation of calculated volumes. Xia *et al*. (1999) also recognize the potential lack of accuracy in estimated data for traffic volumes. Their Florida model used six predictors of traffic volumes and was only accurate to 63 percent.

Estimating Origin-Destination (O-D) data is a common problem for traffic and travel demand modelers. Alternate procedures are continually being tested. The fact that O-D data is still only estimated shows how much error is potentially propagated into functional classification due to data error and ambiguity (Van Aerde *et al*. 2003). Estimation also occurs in trip generation and trip assignment, leading us to believe that functional classification, if it is so full of ambiguous data, does not have a very objective base and is subject to great bias and error. This further supports the need to develop the criteria and the classes for a more useful functional classification.

Functional Classification and Highway Performance Monitoring System

The last of my groupings of literature focuses on the relationship between functional classification and FHWA's Highway Performance Monitoring System (HPMS). To adequately cover the significance of the Functional Class/HPMS relationship, the discussion can be broken down into sampling and error considerations and also the bias produced by inconsistent procedures practiced among and within the state DOTs.

First, what is HPMS? It is a data collection program that mandates that state DOTs collect samples of the public road system for use by the Bureau of Transportation Statistics and other uses. According to the California Department of Transportation (2007), "Highway Performance Monitoring System data are used for:

> Allocation of Federal Funds to the States.
> Federal and State policies.
> Travel trends and future transportation forecasts.
> Environmental Protection Agency (EPA) air quality conformity tracking.
> Data for Biennial Report to Congress on the State of the Nation's Highways."

Generally, each state DOT collects data of samples of public roadways. There are 98 data fields required for each sample. Several fields are identifiers, such as area designation (urbanized, urban, or rural), location and ownership information and descriptive fields such as number of lanes, widths, and pavement types, among others. Many of the fields are condition and function attributes such as functional system (same as functional classification), pavement roughness, age of surface, traffic volume, accident (crash) rates, etc. Data collection by state DOTs is done on an annual basis as is the compilation by FHWA of data from all states.

HPMS contains several issues regarding sample design and error. The HPMS Field Manual (FHWA 2005) discusses the precision required by FHWA for all reporting of HPMS data. The manual tells us that the HPMS sample data is stratified by area designation (urban, rural, urbanized), functional system (functional classification), and by volume group (traffic volumes). Of these stratifications, a traffic volume is the only truly objective data. Area designation, derived from the U.S. Census, although based on objective data, contains fuzzy boundaries between urbanized/urban and rural areas that are also subjectively smoothed by States to provide better logical termini for roadway segments by which to perform sampling and functional classification. In the HPMS Field Manual, Chapter VII and Appendices C and D list confidence levels and values for sample size within the volume group stratification but the manual does not mention the potential error of misclassification of functional class nor area designation. The manual also discusses samples that potentially change in classification over time and the handling of them, but gives no guidance on determining error or correctness within a class. The manual does provide an attempt to have HPMS samples remain normalized on length on a national basis and from year to year by limiting the lengths to ranges within urban and rural and controlled access groupings. Even though HPMS does not address some issues identified here, the program does hold functional classification as a very important element. Functional system is mentioned as a stratifier in roughly two-thirds of the ninety-eight required data fields. Of the other third, nearly all of them are either location identifiers or other stratifiers.

There is bias introduced into the HPMS by inconsistent procedures by various state DOTs. Timing of data collection is one area that HPMS acknowledges possible bias. The manual states, “Timing of the State’s HPMS data processes is an important issue since sampling is dependent to a certain degree upon up-to-date traffic and functional classification data. A number of elements should be considered when making a review of HPMS sample adequacy. These should include not only the assessment of number of samples by volume group, but also checks for potential sample biases.” (FHWA 2005, p. VII-5). The manual further states that sample adjustments need to be made due to functional class changes, “Changes in the existing functional system length and HPMS sample panels are likely to result from functional reclassification, non-Census related changes in urban boundaries, or new road construction.” (FHWA 2005, p. VII-6). The manual implies a subjective bias that functional classification of a route segment changes when the area designation changes by stating, “Functionally reclassify roadway sections that have moved from rural areas into new or expanded urban/urbanized areas or out of contracting urban areas into rural areas; use appropriate classification criteria and good engineering judgment to determine the extent of change warranted.” (FHWA 2005, p. VII-6). I see “appropriate classification criteria” and “good engineering judgment” as sources of wide interpretation and bias that can carry through to any statistical inference HPMS data is used for. There can also be a loss of normalization across classes due to some states interpreting definitions differently and applying percentage ranges on different types of geographies. Some states uses the VMT and mileage percentage ranges for only the entire state while others apply the percentage ranges to individual counties, urbanized areas, urban areas, DOT Districts, or other subjective geographies.

There is also bias present in how states follow the mileage and VMT percentage ranges also. For example, the guidance recommends that the extent of principal arterial mileage should be within 2-4 percent for rural areas and 5-10 percent for urban areas. According to the HPMS Reassessment Draft Recommendation Report (Federal Highway Administration 2007b), over half the states exceeded the mileage range for rural areas and at least seven states exceeded the urban mileage range. Current guidance is subject to a wide range of interpretation for both mileage and VMT ranges. The Draft Report suggests some remedies I discuss later in Chapter 4 in more detail, but they include eliminating area designation as a stratifier but keeping it as a separate item, updating the guidance and providing additional training regarding classification, and developing functional classification for non-centerline facilities such as ramps and one-way connectors, among other recommendations. Since functional classification has a drastic effect on HPMS data, and HPMS data is used by the U.S. Congress to make decisions regarding allocation, definition and objectivity in functional classification becomes very important to ensure objective decision-making.

Given the points shown above about the HPMS manual, although it may be a desirable choice, functional system seems to me to be a poor choice as a stratifier for HPMS data unless more definition is added to dictate class breaks and objective data used to determine the class of a given roadway segment. A more definite, objective classification system would greatly reduce error propagation and possible bias, and make functional classification a more useful stratifier.

I have reviewed several pieces of literature with regard to a chronological development of functional classification. I discussed studies published by State DOTs. I have given comparisons to classification systems from other countries. I have examined issues regarding data and definitions of key terms. I have considered the relationship between functional classification and the HPMS. There has been much study regarding metrics and measures of travel characteristics, but no significant advances in the definition of functional classification. One could argue that it is too generalized a system, but then I ask do we leave it general and yet tie it to so many of our planning and design processes? All the literature, although showing incremental developments in functional classification and related subjects, shows that for the most part, there have been no recent advances in the definition of functional classification. One could also argue that more detailed metrics are more useful, such as traffic volumes, highway capacity, and others, but a macro classification system such as functional classification that is more objectively sound and more definite in terms of class breaks would give a basis for planners, engineers, and funding administrators to have better decision making support tools. Of the literature reviewed, most contain evidence that supports my view that functional classification is in need of further development.

Chapter 3
Analysis Framework and Methodology

The purpose of the statistical study is to decide whether there is enough evidence that functional classification metrics need further development. To determine this, I performed two Chi Square (χ^2) comparisons on the sample of segments. The tests separately compared observed attribute values to expected criteria values for minimum horizontal curve radius and VMT for the functional class of those segments. A summary of the comparisons performed is:

1. Measured minimum radius of horizontal curve (observed) vs. MoDOT/APWA prescribed minimum radius of horizontal curvature (expected)
2. VMT derived from GIS length of segment and EMME/2 forecasted AADT (observed) vs. FHWA guideline prescribed VMT (MoDOT/APWA derived) percentage ranges for the functional class system (expected)

For a detailed description of the research framework, I begin with a definition of the measures of the transportation system used in the comparisons, and then I describe the data and data sources. Next, I give a depiction of the GIS model of the routes, attributes, and functional classification and methods used in deriving the statistical data. Subsequently, I give a detailed explanation of the sampling design and then the statistical testing process used. Lastly I discuss the limitations of the statistical testing, sampling design, and overall study.

Measures of the Transportation System

The street, road, and highway system is like the circulatory system in the human body, with central arteries, veins, and capillaries. The highways act as central arteries, major roads and streets generally act as veins, and local roads and streets as capillaries.

As with the blood system, different parts of the transportation system have different purposes for the movement of people and freight. Functional classifications are derived as an aggregate of several basic measures of the transportation system. Traffic volume, VMT, trip length, and trip purpose all play a role in how a route segment is assigned a class. Afterward, the functional classification is used to determine design criteria for designing, building, and maintaining that route. Among the design criteria are:

- Access control – Type of access attached to Right of Way purchases for the roadway. Types include various temporary easements, unlimited access, partially limited access, and fully limited access.

- Design speed of the roadway – Maximum safe driving speed determined by horizontal and vertical curve values, sight distance, and other criteria

- Interchange, Intersection, Entrance, and Driveway Spacing – Prescribed distances between access points for a roadway to control access and facilitate mobility.

- Maximum Vertical Gradient – Lower classified segments are allowed greater gradients than higher classed route segments.

- Minimum Radius of Horizontal Curvature – A minimum radius is prescribed for segments of certain functional classifications.

- Minimum Sight Distance – A function of speed, this is the shortest distance of the line of sight for a driver to see other vehicles along a route segment.

- Minimum Slope Ratios –Typical slope ratios are 3:1, 4:1, 6:1 where the ratio is listed as horizontal distance:vertical distance for ditch slopes and side slopes.

- Number of Lanes – Higher functionally classed routes may have four, six, or more lanes, whereas lower classed routes may only have two lanes.

- Pavement Design – Includes thickness and type of material, thickness and type of base and sub-base material, and under drainage requirements. Material types for pavement and shoulders include reinforced and non-reinforced concrete, asphaltic concrete, aggregate, earth, and others.

- Pavement Edge Treatment – Denotes whether the roadway will be striped and what type of striping will be applied

- Type of median – Grassy ditched median, curbed grassy median, curbed concrete median, dedicated turn lanes or not, continuous turn lane, or simple yellow striping

- Vertical curve sag value – This is called a “k” value, a higher value means a less comfortable ride. Roller coaster designers strive for a higher “k” value, while highway and street designers strive for a low value.

- Width of the driving lane – Typical width is ten, eleven, or twelve feet

- Width and material type of the shoulder – Typical widths range from zero to ten feet, materials same as described in Pavement Design above.

I examined the design criterion of minimum radius of horizontal curvature for a few reasons. It is a fundamental criterion that is related to design speed. The speed at which traffic is able to travel is a determining factor of how that route will function. A better design criterion to examine when analyzing functional classification might be access control, but access control is a difficult criterion to compile and measure. The ease of measurement and very objective nature of minimum radius of horizontal curvature makes it a good choice for an exploratory study of this nature. In highway design, as the curve radius of a centerline alignment gets smaller, the speed needed to safely navigate the curve also decreases. Assigning a minimum value for radius of curve allows planners to help control the design speed of a highway. Higher functional classifications are accompanied by higher design speeds.

Planners use many types of data to perform studies for transportation. Included are functional attributes about a transportation corridor such as traffic volume, trip length, percentage of commercial vehicles, level of service, prevailing speed, average crash rates, and others. Travel demand models provide forecasts of AADT to aid planners in decision-making. Planners also use demographic data such as population, traffic generator points, land use, planned and proposed development, and others.

ADT can be derived by counting actual traffic for logical segments. Since counting all traffic segments is not feasible, only a portion of segments are counted, while the others are calculated using the actual counts of adjacent segments and known turning movement counts at key intersections. Estimated factors for growth, seasonal fluctuation, and day of the week variability are also used to derive the values for AADT. To clarify the difference between ADT and AADT, ADT is the average daily traffic, which could be averaged over a short span of time. AADT, average annual daily traffic, is a more normalized ADT that takes into account seasonal differences, day of the week differences, and other factors. AADT is mostly used at the planning level, where functional classification is determined.

VMT is actually a rate, given as an integer, to represent a total vehicle miles traveled for a given logical route segment for a given period of time. It is customary to use an annual VMT to coincide with other data collection frequencies. Since AADT or ADT are daily averages (the number of days must be factored back in to get an annual VMT. To derive annual VMT, traffic volume (ADT) is multiplied by the length of the segment multiplied by the number of days in the year. Because traffic volume cannot feasibly be collected at every point along a transportation network, the network is divided into logical segments. Since VMT is an aggregate distance per time, the length of the segment must be factored in. This will yield the calculated total number of miles traveled on a given segment for the entire year. For this study, when referring to VMT, it will be the annual VMT. There are possible limitations with VMT that I discuss later.

For this study, I chose to use VMT derived from a travel demand model in conjunction with a GIS model. Traffic volumes (AADT) were forecasted to the year 2010 by the travel demand model and multiplied by the segment lengths derived from the GIS roads feature class. The resulting observed VMT values were compared to expected values as defined in FHWA guidelines and derived from MoDOT and APWA standards.

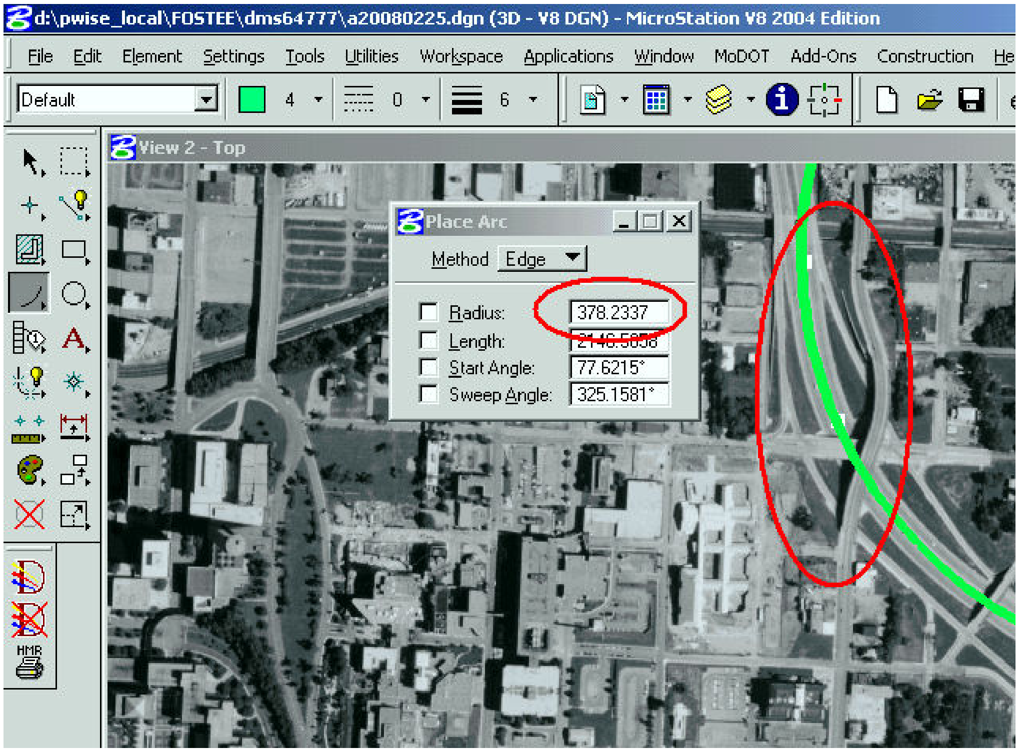
Though there are many measures of the function of the street, road, and highway transportation system, I chose VMT due to its widespread use and common acceptance in many sources for sound planning practices. This is supported by reference in AASHTO policies and guidelines (AASHTO 2001), APWA specifications (APWA 2004), and MoDOT Policy, Procedure, and Design Manual (MoDOT 2007).

Description of Data and Sources

The expected values for minimum horizontal curve radius were based on the MoDOT Policy, Procedure, and Design Manual (MoDOT, 2007), APWA Standard Specification and Design Criteria (2004) and the AASHTO Green Book (AASHTO, 2001). The observed values of curve information were available on as-built plans from MoDOT for MoDOT highways. Due to the difficulty of compiling this data for the sampled segments, and the difficulty in getting as-built plans for city streets and county roads, I was not able to use the data from as-built plans.

Although GIS software packages are capable of modeling circular curves, many GIS datasets that I have worked with do not store curve data explicitly, rather storing curves as a series of short straight arcs. The line feature class for roads, streets, and highways used in this study was derived by MARC using Digital Ortho Quarter Quadrangle (DOQQ) photography. Since the line feature class used in this study does not model curves as circular curves but rather as a series of the line features, I chose to measure the curves from Aerial Photography. I was not able to obtain the photography specifically used to derive the line feature class. I used another ortho photo product, the National Aerial Imagery Program (NAIP). NAIP photography in Missouri in 2007 was acquired as leaf-on color imagery with a spatial resolution of two meters per pixel). Using Microstation CAD software tools, I measured the radius of curves of a sampled segment. This method was not as accurate as having the documented curve data from as-built plans, but was adequate to measure curves to determine if they met the prescribed criteria or not. The method used Microstation tools to use heads up digitizing to draw a circular arc or curve using the aerial photography as a traceable guide. If the radius measurement of a sample curve was close to the critical expected radius value, I made several sketches with Microstation tools to get a better measurement. Figure 4 shows a typical measurement of a sample in Microstation, with the radius measurement and the digitized curve circled in red.

For the second comparison, the VMT comparison, the data proved to be more difficult to obtain, and the data proved to be somewhat less objective than the horizontal curve data. Trip length and travel density data were only available through MARC as an estimate for the year 2010. Furthermore, the data was derived from a travel demand model using EMME/2 software, which does not model the transportation network as accurately as GIS. Travel demand models use current data to forecast potential future



Method Edge

☐ Radius: 378.2337

☐ Length: 2146.5658

☐ Start Angle: 77.6215°

☐ Sweep Angle: 325.1581°

Figure 4. Typical Measurement of a Horizontal Curve in Microstation

data of transportation systems. Travel demand modeling output data is derived using various input data such as current AADT, population, traffic generator points, and highway capacity information.

Data sources are listed below for both the GIS model of functional classification derived from actual on-the-ground design criteria and the FHWA guideline criteria.

Data sources to create base network of roadways and basis for sample

Data Type	Source
Road Centerlines	MoDOT and MARC
2007 Aerial Photography	2007 NAIP (National Aerial Photography Program) two-meter spatial resolution leaf-on color aerial photos, Missouri Spatial Data Information Service

FHWA Approved Functional Classifications	2008 MoDOT TMS Enterprise Database
2000 Kansas City Urbanized Area Boundary	MARC

Data sources for on the ground minimum horizontal curve radius values

Data Type	Source
Horizontal Curve Radius (minimum)	2007 NAIP Aerial Photos, Missouri Spatial Data Information Service

Data sources for compared VMT values

Data Type	Source
Travel Demand/Traffic Simulation Model	MARC EMME/2 Model
AADT	MARC EMME/2 Model

Table 2 shows a summary of the sources of the observed and expected minimum horizontal curve radius and average daily VMT values for each of the statistical tests.

Table 2. Expected and Observed Data Sources

Expected and Observed Data Sources	
Data	**Source**
Observed Curve Data	Measured using CAD (Microstation) tools from 2007 NAIP Photography and entered in to spreadsheet.
Expected Curve Data	Derived from MoDOT and APWA standard design criteria. AADT and functional classification taken into account
Value Meets Expected or Not	Spreadsheet IF functions used to determine if the value meets standards (MoDOT or APWA) or not.
Observed Average Daily VMT Data	Calculated from EMME/2 Travel Demand Model from MARC from shape_length field and AADT value
Expected Average Daily VMT Data	Derived from FHWA percentage ranges applied to total average daily VMT for study area by functional classification
Value Meets Expected or Not	Spreadsheet IF functions used to determine if the value meets standards (FHWA) or not.

GIS Model Methodology

The general methodology used for this statistical study was to build a GIS model containing various data layers representing functional classification derived from different sources and compare the data layers for statistical significance. The GIS package used was ArcGIS 9.2 by ESRI. The data format used to store the vector feature classes was the File Geodatabase. I used county level 2007 aerial photography for the study area from the Missouri Spatial Data Information Service (MSDIS).

The base data layer consisted of road centerline data from MARC and MoDOT and EMME/2 travel segments, which are all line feature classes. Roadway segment logical termini are naturally occurring breaks in traffic patterns that are natural places to change functional classification. Logical termini include interchanges, intersections, major entrances, or changes from divided to undivided or vice versa. The road centerlines allowed matching of EMME/2 segments visually to ensure proper functional classification for sampled segments.

For a comparison of this nature, there may be no best basis for definition of a segment of functional class. Functional class can continue along a route for great distances or be as short as node-to-node. I used the segments defined in the EMME/2 model as a basis for segment length for this study. With linear referencing, functional class attributes can be easily stored as route events on the centerlines. The segment lengths from the EMME/2 travel demand model were also used as the sampling basis. Each segment in the model is a straight-line segment connecting traffic generator points used as inputs for the model. Although the EMME/2 data was not as spatially accurate as GIS, the schematic EMME/2 links generally coincided with the GIS street centerlines.

The EMME/2 data contained an attribute for functional classification, theoretically the same as the FHWA approved functional classification found in the MoDOT Enterprise database. However, the EMME/2 functional class attribute did not always match the functional classification of the corresponding centerline segment. To alleviate this problem, I began with the EMME/2 segments as a basis of samples, and then matched the segments visually in ArcMap and recorded the FHWA approved functional classification attribute value manually in the spreadsheet data. Two route feature classes were used to verify the EMME/2 segments. The MoDOT centerline feature class contained FHWA approved functional classification values. The MARC centerline was a more complete, up to date and spatially accurate dataset. Although, the MARC staff used the MoDOT data to transfer functional classification attributes to the MARC centerline feature class, there was some incorrect values of functional class found in the MARC data. For this reason, the MoDOT data and MARC data were both used in this study. The MARC data was used to find the spatially corresponding EMME/2 segment. The MoDOT data was then used to verify that the functional classification attribute of the EMME/2 sample segment was correct. Figure 5 shows a typical sample of the EMME/2 data and its corresponding centerline data that it was matched to.

After sample selection and matching, the attribute data was exported to a spreadsheet for the statistical analysis. The values of observed minimum radius of horizontal curvature, measured from NAIP aerial photos in Microstation, were stored as a created field in the spreadsheet, since it was derived outside GIS.

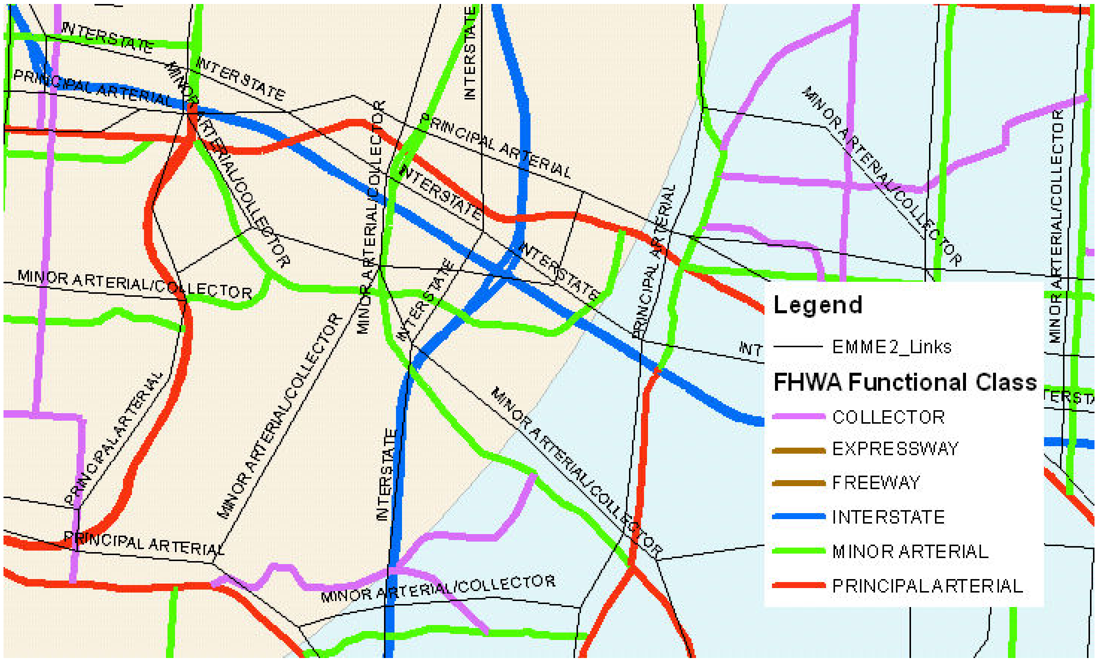


Figure 5. Typical FHWA Approved Functional Class and EMME/2 Segments

For the VMT data, the EMME/2 software provided a forecast of traffic volumes (AADT) for year 2010 using an expected scenario of expansion of the route network. Calculations and estimates were made about the number of vehicles that may use a road in the future. Trips were assigned to segments using demographic data, information about the highway capacity, and current traffic data. The model was calibrated with a sample of current and past year actual counts from MoDOT and other local public works departments. The EMME/2 links also contained a functional class attribute. The EMME/2 model was able to provide an ESRI Shapefile output which was easily imported into the File Geodatabase. MARC staff did all the EMME/2 work. I only received the output shapefile. Using the output shapefile, I calculated the observed average daily VMT using the EMME/2 output data, as explained in the next section.

The expected minimum radius field was a created field derived from MoDOT/APWA standards, while the expected average daily VMT was calculated from the EMME/2 data as prescribed by FHWA percentage ranges. More explanation of these fields and calculations to create them is provided in the next section.

After samples were taken and matched with the centerline data, I measured the minimum horizontal radius using Microstation tools and the NAIP aerial photography for each sampled segment. The values were then entered into the created field for that attribute in the spreadsheet.

After creating the value fields and populating them, I also created fields for whether the expected values of curve radius and average daily VMT matched the corresponding observed values. After this data was derived, I used spreadsheet functions to perform the statistical tests.

Sample Design and Statistical Methods

The study area consisted of all the public roads, streets, and highways in the Kansas City urbanized area in Missouri (FHWA smoothed boundary). The samples were not taken from a total of all segments in the population for each FHWA approved classification but from the EMME/2 links representing travel demand for the region. Each link in the EMME/2 model did not necessarily represent a single route. Some links represented the total traffic assigned between two generators, which could be more than one centerline segment of differing functional classification. During sampling, if I encountered such a segment, I treated it as an outlier and replaced it with the geographically closest segment of the same class that did represent a single route.

I used a stratified systematic approach to the sample design. There was a desire for some spatial dispersal to spread the samples geographically. The study area comprised several municipalities and four different counties. Each governmental structure potentially interprets functional classification differently when they request functional classification changes. There are also areas that differ as to travel characteristics, population, and development patterns that affect mobility of route segments. The transportation network in the Kansas City metropolitan area is also generally denser near the center at the central business district and gets less dense with distance from the core.

To gain a sampling of each of these unique areas, I used concentric rings as a stratified approach to the sample design. To provide adequate spatial distribution, I placed a point in the center of the Central Business District by which to create buffers around. After experimenting with various thickness schemes to balance the population of segments, I settled on a graduated scheme shown in Figure 6. I used four rings of varying thickness to reflect the density of the road network and get a dispersed sample of different governmental jurisdictions. Beginning with the outside ring and working inward, Ring 4, was approximately twelve miles thick, Ring 3 was approximately six miles thick, Ring 2 was approximately four miles thick, and Ring 1 was approximately two miles thick.

To choose the sample segments, I systematically chose five sample segments from each of the five functional classes used for each ring. The five functional classes used were Interstate, freeway/expressway, principal arterial (other than Interstates and freeway/expressways), minor arterial, and collector. To systematically sample, I selected all segments of a class for a given ring and divided the segments in the selection set into five groups, then selected the last segment in each of the five groups.

EMME/2 modeled some actual Interstates as Freeway/expressways, some as principal arterials. It also modeled some FHWA approved Freeway/expressways as Interstates and some as principal arterials. Before systematic sampling, I manually corrected the selection set for each of these classes.

For the innermost ring, there were only three logical freeway/expressway segments total. Since there are not very many freeway/expressway segments in the entire study area, I used all three in Ring 1 and chose six from Rings 2 and 3. I chose five from the outermost ring for a total of twenty samples from that class. Figure 7 shows EMME/2 links and samples within stratified rings.

The EMME/2 model also aggregated minor arterials and collectors into a single class. For these classes, I systematically sampled twenty segments each from the aggregated EMME/2 data, and then disaggregated them into minor arterials and collectors. If I had too many of either class, I again substituted with the geographically closest appropriate segment. I excluded local roads as a sampled class due to the EMME/2 model only containing a very few segments.

The overall sample for the five functional classes was spatially dispersed as shown in Figure 8. Figure 8 appears to have good dispersion, but Table 3 shows a percentage breakdown of each sample ring-functional classification combination. There are some samples that are very large percentages of the population. The small numbers of total population for those combinations dictated a relatively large sample size to ensure statistical validity in the sample. Another point to consider is that segment termini could have been defined in many other ways, yielding a larger or smaller population of segments. The segments I used were defined in the EMME/2 data inputs, which I had no control of.

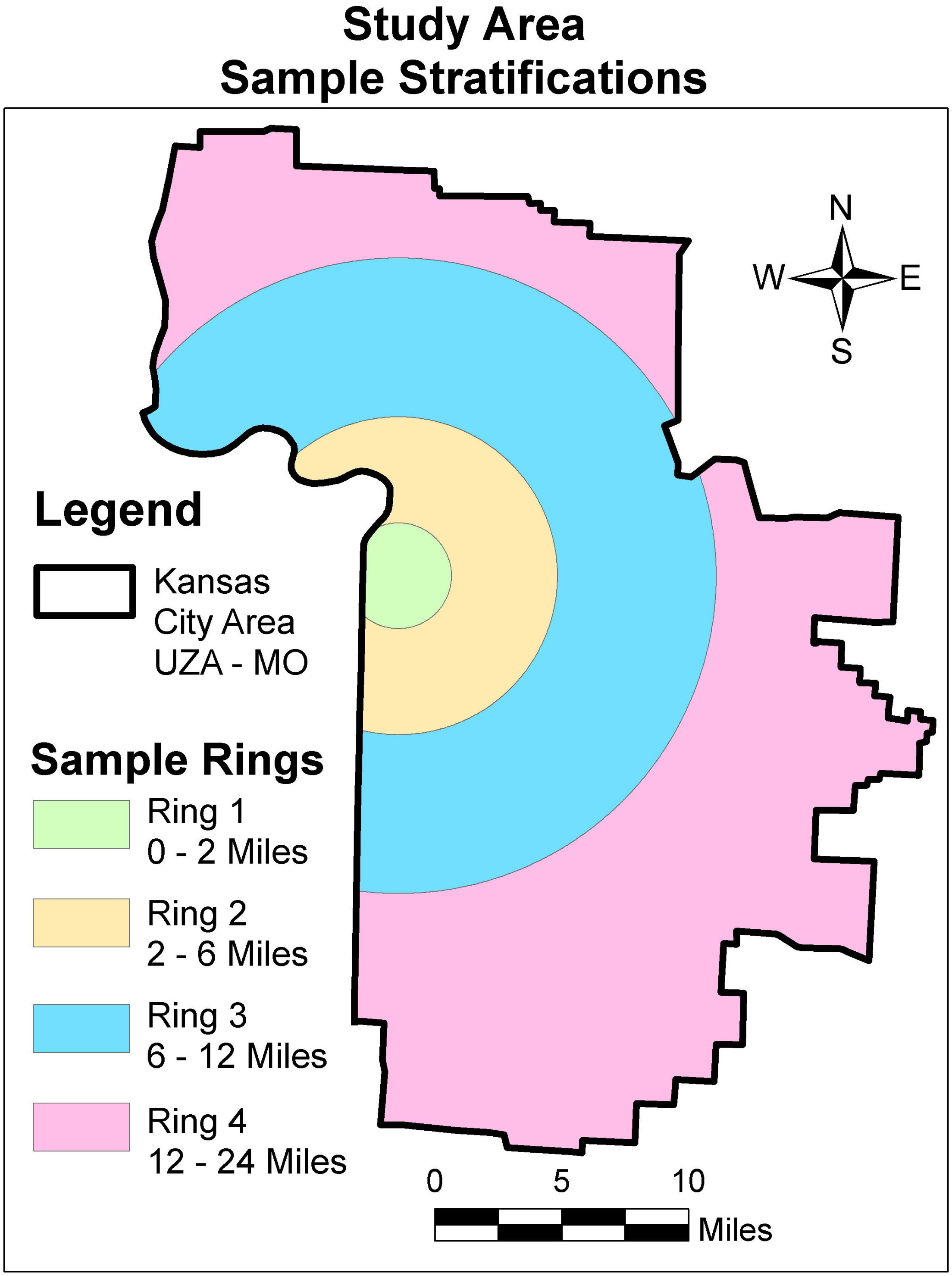


Figure 6. Study Area Sample Stratifications

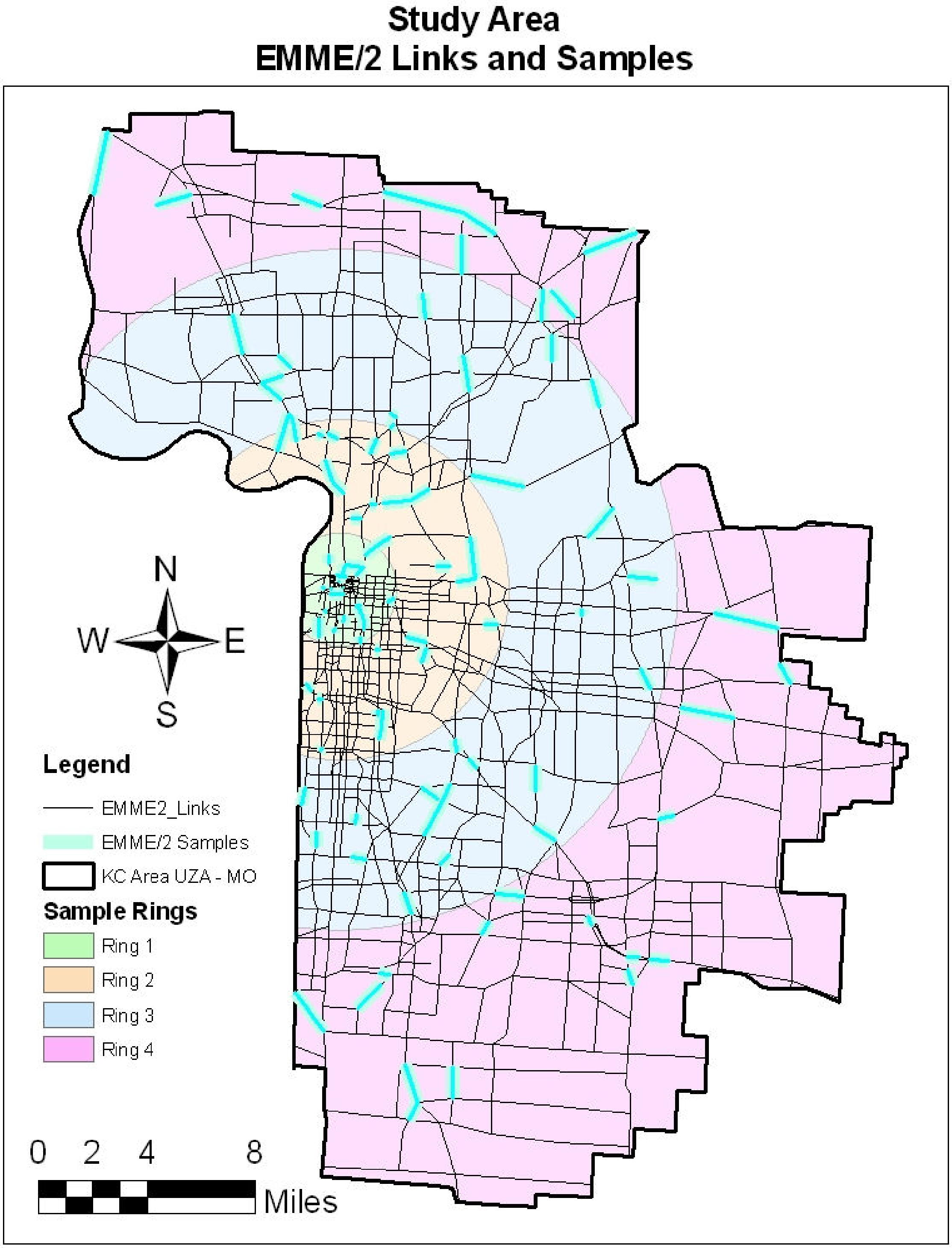


Figure 7. EMME/2 Links and Samples

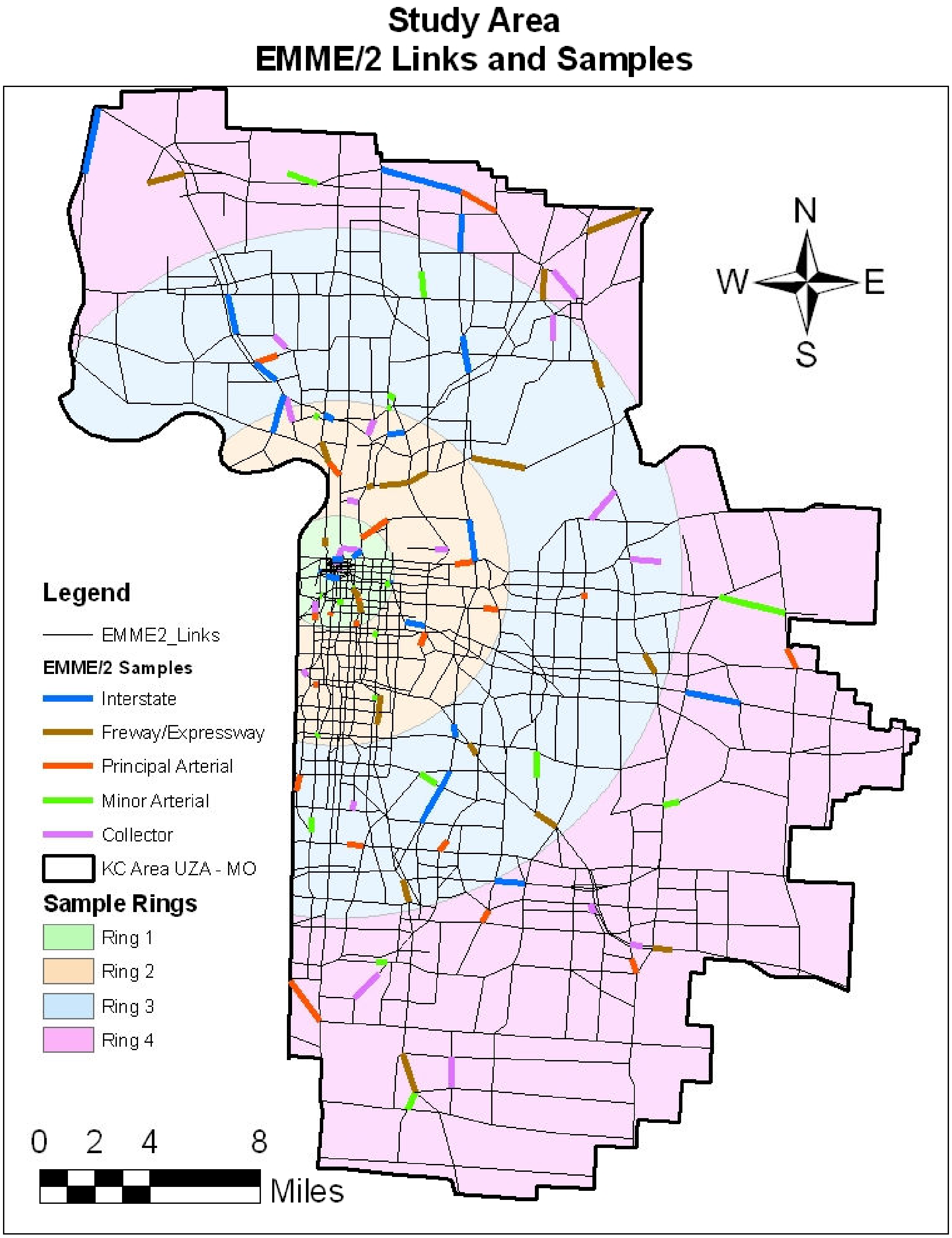


Figure 8. EMME/2 Links and Samples with Functional Class Symbolization

Table 3. Totals and Percentages of Samples and Populations

Ring	Classification	Number of segments	Number of samples	Sample percentage of all segments
1	Interstate	82	5	6.1%
1	Freeway / expressway	6	3	50.0%
1	Principal Arterial (other)	120	5	4.2%
1	Minor arterial / collector	747	10	1.3%
1	Subtotal	955	23	2.4%
2	Interstate	92	5	5.4%
2	Freeway / expressway	28	6	21.4%
2	Principal Arterial (other)	316	5	1.6%
2	Minor arterial / collector	788	10	1.3%
2	Subtotal	1224	26	2.1%
3	Interstate	138	5	3.6%
3	Freeway / expressway	70	6	8.6%
3	Principal Arterial (other)	372	5	1.3%
3	Minor arterial / collector	906	10	1.1%
3	Subtotal	1486	26	1.7%
4	Interstate	123	5	4.1%
4	Freeway / expressway	66	5	7.6%
4	Principal Arterial (other)	167	5	3.0%
4	Minor arterial / collector	679	10	1.5%
4	Subtotal	1035	25	2.4%
All	Interstate	435	20	4.6%
All	Freeway / expressway	170	20	11.8%
All	Principal Arterial (other)	975	20	2.1%
All	Minor arterial / collector	3120	40	1.3%
	Total	4700	100	2.1%

I used the Chi Square (χ^2) statistic as a goodness-of-fit test to check for significant difference for each of the two attribute variables. Each test was a separate attempt to show the need for further study of functional classification. The choice of sample design and statistical test were modeled after McGrew and Monroe (2000).

For the first test, the null and alternative hypotheses were:

H_0: The observed values of minimum horizontal curve radius are greater than or equal to the expected values of minimum horizontal curve radius to a P-level of 0.05.

H_a: The observed values of minimum horizontal curve radius are less than the expected values of minimum horizontal curve radius to a P-level of 0.05.

The hypotheses for the second test were:

H_0: The observed values of average daily VMT are within the range of expected values of VMT to a P-level of 0.05.

H_a: The observed values of average daily VMT are not within the range of the expected values of average daily VMT to a P-level of 0.05.

For the first test, I sampled segments of each classification according to the sample design, measured the horizontal curves using measure tools in Microstation software with the NAIP photography, and recorded the smallest radius in each segment as an observed value. The expected values were derived using the design criteria from APWA (2004) and MoDOT (2007) standards.

Then I derived a value for a field denoting whether the observed radius was greater than or equal to expected radius field that compared the observed (measured) minimum horizontal curve radius value to an expected (derived) value for that class. The result was either a YES or NO value. A “YES” value meant that the smallest curve in the sample segment has a radius that is greater than or equal to the expected minimum radius for that class. A “NO” value meant that the smallest curve of the sampled segment has a radius that is less than the expected minimum radius for that class.

Since streets and highways are built by different agencies, and each follows a slightly different design criteria standard, expected minimum curve radius values for a segment can vary according to the agency that constructed that segment and according to the traffic volume that segment carries. In order to determine whether a segment meets either the APWA standard (for non-MoDOT segments) or the FHWA standard (for MoDOT segments), the jurisdiction and the AADT were factored into the expected values. The expected values for the minimum radius of curve use the crosswalk for functional classes between FHWA and APWA shown in Table 1 to determine which FHWA functional class they were in. Then the AADT and jurisdiction were factored in and the appropriate minimum radius value was applied to that combination resulting in an expected value. The result was an expected minimum radius value for each possible combination as shown in Table 4. The minimum radius of curve prescribed by the MoDOT (2007) and APWA (2004) specifications varied for each classification, so the resulting expected values for minimum radius were not necessarily the same for each combination of functional class, AADT, and jurisdiction. For example, if a principal arterial was a MoDOT built route, with an AADT 1700 or above, it is expected to have a minimum radius of 1207 feet. Likewise, a MoDOT built principal arterial with an AADT below 1700 is expected to have a minimum radius of 764 feet. If a principal arterial was built using APWA standards, with any value of AADT, it is expected to have a minimum radius of 1091 feet.

Since MoDOT specified a maximum degree of curve, instead of minimum radius of curve, the values for MoDOT specifications were calculated using the formula for a circular curve:

Degree of curvature (D) in decimal degrees
Radius of curvature (R) in feet

$$\mathbf{D / 360 = 100 / 2 \Pi R}$$

solving for R,

$$\mathbf{R = 5729.58 / D}$$

The APWA included horizontal curves already specified as a minimum radius of curve, so there was no conversion needed for those values. Table 4 details the various expected values for minimum radius of curve. Note that there are no APWA Interstates. This is because all Interstates are built by MoDOT. Note also that values for APWA built freeway/expressways and principal arterials are both 1091. This is because APWA standards do not have an explicit standard for freeway/expressways.

For the observed values of average daily VMT, I calculated VMT using the EMME/2 forecasted AADT values and the Shape_Length field created by ArcMap. Even though the street centerline data was more spatially accurate than the EMME/2 segments, I did not have a common field to join the street centerline data with the EMME/2 data. Therefore, I was forced to use the less accurate segment lengths contained in the EMME/2 model for the VMT calculation. The expected values for average daily VMT were derived from the FHWA prescribed ranges applied to the total average daily VMT represented by all EMME/2 segments. Since VMT fluctuates, usually increasing from

Table 4. Expected Values for Minimum Horizontal Radius of Curve.

Functional Classification	**Jurisdiction**	**AADT**	**Expected Minimum Radius (ft.)**
Interstate	MoDOT	All Values	1910
Freeway/Expressway	MoDOT	<1700	764
Freeway/Expressway	MoDOT	>1700	1207
Freeway/Expressway	APWA	All Values	1091
Principal Arterial	MoDOT	<1700	764
Principal Arterial	MoDOT	>=1700	1207
Principal Arterial	APWA	All Values	1091
Minor arterial	MoDOT	All Values	764
Minor arterial	APWA	All Values	700
Collector	MoDOT	<400	252
Collector	MoDOT	>=400	468
Collector	APWA	All Values	500

year to year for a given segment, percentage ranges of the total average daily VMT for a given area (rural, urban, or urbanized) is prescribed by FHWA. The prescribed ranges for urbanized areas are shown in Table 5. The ranges mean that for any given class, or combination of classes, the percentage of total average daily VMT for all of the segments of that class should fall into the percentage range calculated from the total average daily VMT of all classes. Using the FHWA prescribed average daily VMT ranges in Table 5, I disaggregated the values into single classes to derive Table 8. In order to be able to compare observed average daily VMT for the desired functional classes, I had to derive a VMT percentage range for minor arterials using the prescribed range for principal

Table 5. VMT Percentage Ranges for Functional Classifications (FHWA 1989).

Table II-3 -- Guidelines on extent of urban functional systems

	Range (percent)	
System	**VMT**	**Miles**
Principal arterial system	40-65	5-10
Principal arterial plus minor arterial street systems	65-80	15-25
Collector street system	5-10	5-10
Local street system	10-30	65-80

arterials and the prescribed range for principal arterials plus minor arterials. To do this I checked all the combinations of ranges that would be possible to achieve both ranges. In order for both FHWA prescribed ranges to be satisfied, minor arterials could have a possible range of zero to forty percent of the total VMT. This was derived by calculating all the possibilities for minor arterials, shown in Table 6. It was naturally undesirable to have a class with no vehicle miles traveled, so I used 15 for the low percentage in the range and used the highest possibility of forty percent for the high end of the derived range. The fact that the prescribed ranges allow minor arterials collectively to have zero VMT percentage shows that there is lots of ambiguity in the classification system. The other percentage ranges remained the same. Then I totaled the average daily VMT in the EMME/2 model for the study area and applied the percentages to the total to derive ranges for the study area. The derived VMT percentage ranges are shown in Table 7, and the expected VMT percentage ranges are shown in Table 8. Since the Interstate, freeway/expressway, and other principal arterial classes are all actually subclasses of

Table 6. Calculation of Minor Arterial Percentage Ranges

Principal Arterials + Minor Arterials	Principal Arterials	Minor Arterials
80	65	15
80	40	40
65	40	25
65	65	0

Table 7. Derived VMT Percentage Ranges by Functional Classification

Classification	Derived VMT percentage ranges
Principal arterials	40-65
Minor arterials	15-40
Collectors	5-10
Local Streets	10-30

Table 8. Expected VMT Percentage Ranges by Functional Class

Functional Classification	Expected Range of Average Daily VMT
Interstate	1441 – 2341
Freeway/Expressway	
Principal Arterial (others)	
Minor arterial	540 - 900
Collector	313 - 626

principal arterial, their derived value range was the same. Also, local streets are excluded from the table since they are not being sampled in this study.

For the statistical tests, I used a Chi Square (χ^2) binomial case proportional goodness of fit test to determine whether there was a significant difference between the sample and the population. The test was performed for each variable (curve radius and average daily VMT) using functional class as different categories or bins. For each statistic, a 1 x 5 contingency table was used. The column was the observed distributions of YES (for meets expected values) and the five rows were the functional classes (Interstate, freeway/expressway, principal arterial, minor arterial, and collector). The expected values were all "YES" values while the observed could contain "NO" values.

Limitations

The potential error of the data and analysis along with the possible ambiguity and bias involved with the functional classification system limit this study to being exploratory in nature. These limitations make this study adequate only to determine if more in-depth study can or should be done to further develop the definitions of functional classification. My discussion of limitations includes general potential error of functional classification and potential error from the methodology and sample design. I also discuss ambiguity and bias that are potentially present that could affect the validity of this analysis.

General error in functional classification includes evolution of design standards, design exception error, spatial variation of attribute values, and differences in design criteria. As evidenced in the literature review, standards of transportation planning data have not remained constant. Measurements are still being refined and becoming more objective. Design standards have also evolved. This could have potential error introduced into the analysis due to a segment being built to a certain design standard, but that standard no longer is in effect for that functional classification. The minimum radius of curvature for a sampled segment may have been valid at the time it was built, but now the radius is too small for the standards for that functional classification, making a comparison of those attributes for that segment invalid, thus possibly skewing statistical results.

Design Exceptions can also cause errors in classification. A Design Exception is an official document giving FHWA permission for a given segment to have been built to substandard design criteria. These are needed and approved on a case-by-case basis. Design Exceptions could cause a sampled segment to appear different for the minimum radius of curvature whereas it was an accepted and approved instance, allowing the functional classification to remain at the higher classification than is allowed by horizontal curve criteria.

Values of VMT, ADT, AADT, and trip data generally vary inversely with the distance to an urban core. Although the attributes in my comparison are not point or area patterns, this negative spatial autocorrelation could cause some error in the study due to a lack of randomness in the samples.

Design standards used for highways differ from those used for local roads and streets, AASHTO vs. APWA, respectively. This introduces some potential error in the above-mentioned crosswalk between the classification systems. The criteria used to define APWA functional classifications is likely significantly different than the criteria used to define the AASHTO and FHWA criteria. This makes it difficult to prove statistically that mismatches of segments when compared were due to misclassification.

There is potential error in the methodology and sample design of this analysis. The potential error in methodology includes measurement error and aggregation error. There is potential technical error in measurement of the radii of horizontal curves. The measurements were done using heads-up digitizing using Microstation tools, with potential for human error. The data used to measure from, 2 meter and 1 meter orthophotography, could also contain some error propagated from the DEM used to derive the orthophotography as allowed in the National Aerial Photography Program specifications. The data in the EMME/2 travel demand model also contained some potential technical error. Some segments in the model were grouped together as a normal part of the model functioning. This means that for some schematic segments in the EMME/2 model, they represent more than one on-the-ground segment. In other words, the travel demand data was more generalized than the base roadway data. Those links or segments were unsuitable for comparison of attributes in this analysis. In the cases that samples were represented in the travel demand data as two parallel routes, that segment was discarded from the sample and another chosen in its place so that comparing EMME/2 segment attributes and GIS segment attributes could remain a valid comparison. That came with a cost of a less random sample.

The sample design has potential technical error also. The disaggregation of minor arterial/collector segments in EMME/2 model and the EMME/2 forecasts being the same for both minor arterials and collectors have possible negative ramifications on the study.

EMME/2 modeled minor arterials and collectors as one aggregated class, while the study examined each classification separately. Since I only disaggregated these segments upon sampling, by matching the MoDOT attributes to the EMME/2, the actual sampling of these segments could introduce error in classification or contribute to a nonrandom sample. Since EMME/2 used the same calculations for segments of both functional classifications, error in estimating traffic volumes could also have been introduced. This would affect the VMT values used in the study.

There is ambiguity in the definition of the functional classification system due to overlapping class breaks, a lack of objective data, and the method of deriving AADT and VMT data. The functional classifications are overlapping in their definitions in that classes that are adjacent in rank have some of the same characteristics. For instance, FHWA states that minor arterials and principal arterials both carry regional trips (FHWA 1989). As well as the overlap, there is no objective definition of what a regional trip is. VMT is also ambiguous in that there is some overlap and some gaps. For example, referring to Table 8, a segment with an observed average daily VMT of 600 could fit into the expected average daily VMT for collector or for minor arterial, and a segment with an observed average VMT of 1100 would not fit into any expected category.

AADT, and subsequently VMT, for the statistical testing are not all actually counted for all segments, which could introduce error in estimation. This could propagate to the comparisons also. I could have limited the samples to being only those segments with actual counts, but since there is some logic involved in choosing which segments to count traffic for, this could have unduly biased my sample design. It likely would also have reduced my sample size to an unacceptable level for valid statistical significance.

There is also ambiguity present in the definitions of functional classes across the three area stratifications (urbanized, urban, and rural). Although my study focused on an urbanized area, the practices and interpretations of those functionally classifying route segments could have been applied inconsistently.

Functional classification is also an aggregate measure of several other criteria that demands generalization in definition of criteria for classes, making a single functional classification somewhat difficult to measure. Some of the criteria that functional classes are derived from are very objective while others are more subjective. There is also a certain art form to the process of classification, to meet VMT and mileage percentage ranges and to attain a “good” spacing and connectivity within the whole system that is problematical.

Differences between procedural methods of classification are a potential bias, along with a practice of subjective, rather than objective method of assigning classification. Various state DOTs have different methods of applying the ranges to areas. One state may apply the ranges only to all the urban areas collectively while others might apply the ranges to each urban or urbanized area. This introduces bias, but is indeed what I was trying to demonstrate with my comparisons to support a call for better definition of functional classification. Difference in state procedures does not directly affect this study, but it does have bearing on whether functional classification should be further studied on a national level or whether to further study the procedures and definition of functional classification.

Another potential source of error is that of misclassified segments in EMME/2 being excluded from the possibility of being sampled in their proper classes. Also the error in the lengths of the EMME/2 segments could affect the VMT values adversely. Not only were the EMME/2 segments not accurately modeled, but also there was the phenomenon of splitting the segments in different, but still valid logical termini resulting in vastly different VMT values.

A final possible error comes from the validity of the use of Chi Square (χ^2) for the data sampled. VMT, since it is measured as a quantity of vehicles over a specific timeframe, is actually a rate. McGrew and Monroe (2000, p.155) state that rates should not be used with the Chi Square (χ^2) statistic for Goodness of Fit tests.

Even though there are many sources of potential error, the statistical test is of an exploratory nature and is in no way a fully objective study that determines the overall validity and usefulness of the functional classification system. The fact that potential error exists so readily by itself supports my claim that the functional classification system needs more definition.

None of the potential limitations, error, and ambiguity mentioned here is readily measurable or has an ability to be quantified without difficulty. Corrections for these should be considered for further study, but I did not use any corrections for this exploratory study.

Chapter 4
Analysis Results and Discussion

Data and Statistical Testing

There were one hundred samples taken, twenty from each of the functional classes included in the test according to the above sample design. The spreadsheet included descriptive data about each sample, observed and expected values for minimum horizontal curve radius, and observed and expected values for average daily VMT. The County field was used to aid in locating the samples to measure the horizontal curves. Table 9 shows descriptive data for a portion of the samples.

The spreadsheet also contained derived and calculated fields for curve radius and average daily VMT. I added and populated the "Jurisdiction" field for the samples using my experiential knowledge of working with MoDOT data. It simply detailed whether the segment was subject to MoDOT or APWA standards and specifications. The AADT field was used for both the horizontal curve and the VMT data comparisons. The Jurisdiction field, the AADT field, and Table 2 were used to derive the values for the expected minimum horizontal curve radius for each sample. The values differed according to functional class, the traffic volume (AADT), and whether the segment was under MoDOT or APWA jurisdiction. The expected minimum curve radius value was calculated using nested IF statements in a spreadsheet that depended on the other fields. Another IF statement determined if the smallest curve radius of a sampled segment met the expected criteria and get the YES/NO value for the "Meets Expected Radius" field. Table 10 shows the horizontal curve data for a portion of the samples. It is important to note that the expected values can vary within a functional class due to variance of the

Table 9. Portion of Sampled Descriptive Sample Data.

SAMPLE ID	COUNTY	SEGMENT DESCRIPTION	CORRECTED FUNCTIONAL CLASS	SAMPLE RING
738	PLATTE	Route A from US 69 to I-29	COLLECTOR	2
774	JACKSON	Arrington St. South of Main St.	COLLECTOR	4
378	JACKSON	Oldham Rd from Blue River Rd to I-435	MINOR ARTERIAL	3
679	CLAY	US 69 West of Chouteau Trafficway	MINOR ARTERIAL	3
344	JACKSON	Noland Rd. South of Truman Rd.	PRINCIPAL ARTERIAL	3
775	JACKSON	MO 291 South of US 50	PRINCIPAL ARTERIAL	4
2838	CLAY	US 169 from MO 9 to Briarcliff Pkwy	FREEWAY / EXPRESSWAY	2
3091	CLAY	MO 291 from I-35 to MO 152	FREEWAY / EXPRESSWAY	4
2283	JACKSON	I-70 from Benton to Truman	INTERSTATE	1
2342	PLATTE	I-635 South of I-29	INTERSTATE	2

Table 10. Portion of Sampled Horizontal Curve Radius Data

SAMPLE ID	CORRECTED FUNCTIONAL CLASS	OBSERVED MINIMUM RADIUS OF CURVE	JURISDICTION	AADT	EXPECTED MINIMUM RADIUS	OBSERVED RADIUS >= EXPECTED RADIUS
738	COLLECTOR	800	MoDOT	3622	468	**YES**
774	COLLECTOR	69	APWA	960	500	**NO**
378	MINOR ARTERIAL	550	APWA	1963	700	**NO**
679	MINOR ARTERIAL	1515	MoDOT	5253	764	**YES**
344	PRINCIPAL ARTERIAL	550	APWA	7094	1091	**NO**
775	PRINCIPAL ARTERIAL	2110	MoDOT	7677	1207	**YES**
2838	FREEWAY / EXPRESSWAY	1800	MoDOT	18991	1207	**YES**
3091	FREEWAY / EXPRESSWAY	1010	MoDOT	4370	1207	**NO**
2283	INTERSTATE	750	MoDOT	60979	1910	**NO**
2342	INTERSTATE	2750	MoDOT	23456	1910	**YES**

Jurisdiction or AADT. The VMT values were calculated using the EMME/2 values. The shapefile exported by EMME/2 was imported into ArcGIS. ArcGIS assigned a Shape_Length field in meters, which was exported to the spreadsheet. A simple function converted it to the "Length in Miles" field. The AADT field was directly from the EMME/2 data. Another simple calculation of AADT X Length in Miles derived the observed average daily VMT field. The expected values for average daily VMT were actually a range, so I had two expected fields that the "Meets Expected" field depended on for this comparison. Table 11 shows the average daily VMT data for a portion of the samples.

Principal arterials, a class that includes Interstates, Freeway/Expressways, and principal arterials (other), have no upper range limit because they are the top of the class ranking. This includes Interstates, Freeway/expressway, and Other principal arterial classes.

The Chi Square (χ^2) calculations were performed on each set of data in separate attempts to determine whether there is significant difference. In a perfect world, where all rules, standards, and specifications are followed and upheld, we would expect a perfect twenty samples to meet the criteria. Due to the issues mentioned in the Limitations section of Chapter 3, this cannot truly be my expectation. Since I cannot quantify these phenomena, I used a 5% average error and quantified the expected value to be nineteen instead of twenty. Table 12 shows the frequency distribution tables and Chi Square (χ^2) calculations for horizontal curve radius.

Table 11. Portion Sampled of Average Daily VMT Data

SAMPLE ID	CORRECTED FUNCTIONAL CLASS	AADT	LENGTH IN MILES	OBSERVED VMT (EMME2)	EXPECTED VMT (LOW)	EXPECTED VMT (HIGH)	VMT MEETS EXPECTED
738	COLLECTOR	3622	0.96	3473.16	312.60	625.30	**NO**
774	COLLECTOR	960	1.24	1187.15	312.60	625.30	**NO**
378	MINOR ARTERIAL	1963	0.73	1424.18	539.90	1440.00	**YES**
679	MINOR ARTERIAL	5253	0.17	903.58	539.90	1440.00	**YES**
344	PRINCIPAL ARTERIAL (OTHER)	7094	0.21	1486.58	1440.00	No Limit	**YES**
775	PRINCIPAL ARTERIAL (OTHER)	7677	0.56	4335.52	1440.00	No Limit	**YES**
2838	FREEWAY / EXPRESSWAY	18991	0.84	16010.31	1440.00	No Limit	**YES**
3091	FREEWAY / EXPRESSWAY	4370	1.16	5058.75	1440.00	No Limit	**YES**
2283	INTERSTATE	60979	0.09	5739.68	1440.00	No Limit	**YES**
2342	INTERSTATE	23456	1.45	34101.80	1440.00	No Limit	**YES**

Table 12. Horizontal Curve Statistical Testing, 5% Error Correction

CHI SQUARE (χ^2) TEST FOR MINIMUM HORIZONTAL CURVE RADIUS

CATEGORY	OBSERVED	EXPECTED	O-E	$(O-E)^2$	$\frac{(O-E)^2}{E}$
INTERSTATE	11	19	-8	64	3.368421
FRWY/EXPSWY	16	19	-3	9	0.473684
PRINC. ARTERIAL	10	19	-9	81	4.263158
MINOR ARTERIAL	16	19	-3	9	0.473684
COLLECTOR	17	19	-2	4	0.210526
	70	95			8.789474

p=.05
df = (r-1)(c-1)
Df = 4

Statistical (x^2) = 8.789
Critical (x^2) = 9.488
Statistical (x^2) did not exceed Critical (x^2), therefore:
Not a Significant Difference

The results of the horizontal curve tests show no significant difference between observed and expected values, so the null hypothesis was not rejected. This tells us that if we were using horizontal curve radius alone to determine functional class, there is a 95% chance that the FHWA approved classes for the study area are correct. A more detailed interpretation of the results is given below, including looking at the Chi Square (χ^2) statistic for each classification, a discussion of error correction, and next steps.

Before a more detailed look at the horizontal curve comparison, here is a look at the VMT comparison. The frequency distributions for observed average daily VMT were very different at first glance than those of the horizontal curve radius and different from expected. In the Collector category, there was only one sampled segment that met the expected value range, which affects the total statistic immensely. Table 13 shows the frequency distribution tables and Chi Square (χ^2) calculations for VMT.

Table 13. Average Daily VMT Statistical Testing, 5% Error Correction

CHI SQUARE (χ^2) TEST FOR AVERAGE DAILY VEHICLE MILES TRAVELED

CATEGORY	OBSERVED	EXPECTED	O-E	$(O-E)^2$	$\frac{(O-E)^2}{E}$
INTERSTATE	20	19	1	1	0.052632
FRWY/EXPSWY	20	19	1	1	0.052632
PRINC. ARTERIAL	18	19	-1	1	0.052632
MINOR ARTERIAL	16	19	-3	9	0.473684
COLLECTOR	1	19	-18	324	17.052630
	75	95			17.684210

P=.05
df = (r-1)(c-1)
Df = 4

Statistical (x^2) = 17.684
Critical (x^2) = 9.488
Statistical (x^2) did exceed Critical (x^2), therefore:
Significant Difference

The results of the VMT testing show that there is 95% chance that there is a significant difference in observed values of average daily VMT their expected ranges. This means that it is likely that VMT values do not fall in the FHWA prescribed ranges.

Interpretation of Results

If we look further at the tests, we can see that there are various categories (classes) that have high (χ^2) statistical values. In the horizontal curve test, the principal arterial category contains only half of its samples that met criteria. If we look at the statistic, it is 4.263, higher than the critical value of 3.841 (for p=0.05 and df=1). This tells us that there may be a significant amount of principal arterial segments with substandard curve radii in the study area population. Interstates also had a fairly high value of 3.368, but less than the critical value of 3.841. The other classes do not have high values for Chi

Square (χ^2), thus keeping the overall statistic slightly under the critical value of 9.841 for all classes combined.

The statistic for VMT for the collector class was very high at 17.053. Furthermore, seventy percent of the twenty samples of the collector class samples had an observed average daily VMT value that was higher than the expected range. This indicates that many of the segments in the study area that are FHWA approved as collectors might meet VMT thresholds for higher classes. Since there is overlap in VMT ranges, and other criteria are also used to determine functional class, it is difficult to determine or decide from this test that these classes are incorrect without further study with inclusion of other variables. What it does support, though, is that there is some question and ambiguity in at least the definition of the VMT variable used in classification. This lends support to my call for further study of the functional classification system.

Even though the other classes of VMT showed low Chi Square (χ^2) values, the collector class had a high enough value to show a significant difference for the entire test. Since the collector class seems to be a problem area, I looked at the data for this class further. Table 14 shows all the collector samples sorted by the "Meets Criteria" fields. Looking at Table 14, there appears to be no patterns of correlation between sample rings and whether the criteria were met. There does not seem to be correlation between the "Meets Criteria fields and Jurisdiction, either. It appears that the reason for significant difference is due to some other data factor, or process and procedural factor. Further study will be needed to determine any relationships between these fields and to determine whether there is a relationship between the two variables. For this study, each was a separate examination of goodness of fit.

Table 14. All Collector Samples with Expected and Observed Test Values.

SAMPLE ID	SAMPLE RING	JURISDICTION	OBSERVED VMT (EMME2)	EXPECTED VMT (LOW)	EXPECTED VMT (HIGH)	VMT MEETS EXPECTED	OBSERVED MINIMUM RADIUS OF CURVE (FT.)	EXPECTED MINIMUM RADIUS	RADIUS MEETS EXPECTED
957	1	APWA	869.03	312.6	625.3	NO	175	500	NO
1027	1	APWA	1097.42	312.6	625.3	NO	328	500	NO
1322	3	APWA	267.75	312.6	625.3	NO	350	500	NO
1945	4	APWA	1187.15	312.6	625.3	NO	69	500	NO
7908	1	APWA	94.44	312.6	625.3	NO	750	500	YES
738	1	APWA	83.27	312.6	625.3	NO	1600	500	YES
1689	1	APWA	84.34	312.6	625.3	NO	9999	500	YES
1800	2	MoDOT	3473.16	312.6	625.3	NO	800	468	YES
2819	2	APWA	2246.51	312.6	625.3	NO	500	500	YES
4779	2	APWA	258.96	312.6	625.3	NO	9999	500	YES
1416	2	APWA	1859.51	312.6	625.3	NO	2200	500	YES
1962	2	APWA	1654.38	312.6	625.3	NO	9999	500	YES
2196	3	APWA	1963.88	312.6	625.3	NO	750	500	YES
2641	3	APWA	820.35	312.6	625.3	NO	860	500	YES
5174	3	APWA	3742.04	312.6	625.3	NO	1615	500	YES
774	4	APWA	5048.07	312.6	625.3	NO	9999	500	YES
3701	4	APWA	4547.91	312.6	625.3	NO	560	500	YES
4143	4	APWA	2466.89	312.6	625.3	NO	700	500	YES
6338	4	MoDOT	3021.51	312.6	625.3	NO	537	468	YES
7102	3	APWA	429.00	312.6	625.3	YES	990	500	YES

As mentioned above, there is no easy method to quantify the identified potential error involved here. I chose to apply a 5% error correction for the expected values, but I also ran the statistics using a 0% and a 10% error correction in the expected values, making E=20 and also E=18. The results for these were slightly different than those that applied a 5% correction. As shown in Table 15, when using a value of twenty for the expected distribution, the results for the horizontal curve tests were a value for Chi Square (χ^2) of 11.1. This is higher than the critical value of 9.488, showing significant difference. Looking deeper, the principal arterial class was high again at a value of 5, and this time the Interstate class also was higher than the critical value 4.05 over 3.841.

For the 0% error correction test for VMT, shown in Table 16, results were very similar to the 5% error correction test, with the collector class having a high value (18.05) and other classes very low.

For the 10% error correction, shown in Table 17 and Table 18, none of the Chi Square (χ^2) class values exceeded the critical value. The VMT test still showed a significant difference with the collector class value at 16.056 and an overall Chi Square (χ^2) value of 16.722, both higher than critical values. No matter what was chosen as an error correction for the expected value, the results were fundamentally the same. One other point to make is that the test that showed a significant difference is the one that used a variable (average daily VMT) used in actual determination of functional classification. The other test (minimum horizontal curve radius) did not show significant difference, but its variable is actually one that is derived from functional classification and does not have as clear a relationship to the function of a roadway segment. This alone gives more weight to the VMT comparison, which lends support to further study. Of all the tests, the only class that showed significant difference was the collector class. This could be due to error in disaggregation, but since the disaggregation used an objective and more accurate MoDOT functional class data, it is more likely due to ambiguity and bias in the functional classification process and definition. The expected percentage ranges for VMT and mileage (FHWA 1989) have routinely been exceeded for collectors since I began processing functional classification in 1999. Collectors have seemed to be the classification that has been out of range most consistently among the areas I have processed.

Table 15. Horizontal Curve Statistical Testing, No Error Correction

HORIZONTAL RADIUS OF CURVE (0% ERROR IN EXPECTED)

CATEGORY	OBSERVED	EXPECTED	O-E	$(O-E)^2$	$\frac{(O-E)^2}{E}$
INTERSTATE	11	20	-9	81	4.050000
FRWY/EXPSWY	16	20	-4	16	0.800000
PRINC. ARTERIAL	10	20	-10	100	5.000000
MINOR ARTERIAL	16	20	-4	16	0.800000
COLLECTOR	17	20	-3	9	0.450000
	70	100			11.100000

$p=.05$
df = (r-1)(c-1)
df = 4

Statistical (x^2) = 11.100
Critical (x^2) = 9.488
Statistical (x^2) exceeds Critical (x^2), therefore:
Significant Difference

Table 16. Average Daily VMT Statistical Testing, No Error Correction

AVERAGE DAILY VEHICLE MILES TRAVELED (0% ERROR IN EXPECTED)

CATEGORY	OBSERVED	EXPECTED	O-E	$(O-E)^2$	$\frac{(O-E)^2}{E}$
INTERSTATE	20	20	0	0	0.000000
FRWY/EXPSWY	20	20	0	0	0.000000
PRINC. ARTERIAL	18	20	-2	4	0.200000
MINOR ARTERIAL	16	20	-4	16	0.800000
COLLECTOR	1	20	-19	361	18.050000
	75	100			19.050000

$p=.05$
df = (r-1)(c-1)
df = 4

Statistical (x^2) = 19.050
Critical (x^2) = 9.488
Statistical (x^2) exceeds Critical (x^2), therefore:
Significant Difference

Table 17. Horizontal Curve Statistical Testing, 10% Error Correction

HORIZONTAL RADIUS OF CURVE (10% ERROR IN EXPECTED)					
CATEGORY	**OBSERVED**	**EXPECTED**	**O-E**	**$(O-E)^2$**	**$\frac{(O-E)^2}{E}$**
INTERSTATE	11	18	-7	49	2.722222
FRWY/EXPSWY	16	18	-2	4	0.222222
PRINC. ARTERIAL	10	18	-8	64	3.555556
MINOR ARTERIAL	16	18	-2	4	0.222222
COLLECTOR	17	18	-1	1	0.055556
	70	90			6.777778

p=.05
df = (r-1)(c-1)
df = 4

Statistical (x^2) = 6.778
Critical (x^2) = 9.488
Statistical (x^2) does not exceed Critical (x^2), therefore:

Not a Significant Difference

Table 18. Average Daily VMT Statistical Testing, 10% Error Correction

AVERAGE DAILY VEHICLE MILES TRAVELED (10% ERROR IN EXPECTED)					
CATEGORY	**OBSERVED**	**EXPECTED**	**O-E**	**$(O-E)^2$**	**$\frac{(O-E)^2}{E}$**
INTERSTATE	20	18	2	4	0.222222
FRWY/EXPSWY	20	18	2	4	0.222222
PRINC. ARTERIAL	18	18	0	0	0.000000
MINOR ARTERIAL	16	18	-2	4	0.222222
COLLECTOR	1	18	-17	289	16.055560
	75	90			16.722220

p=.05
df = (r-1)(c-1)
df = 4

Statistical (x^2) = 16.722
Critical (x^2) = 9.488
Statistical (x^2) exceeds Critical (x^2), therefore:

Significant Difference

Chapter 5
Conclusion

Summary

The fate of the U.S. transportation infrastructure depends on sound planning and design practices, efficiencies in funding, and clear definition of standards and procedures. Functional classification is closely linked to these and holds great promise as a redeeming system to improve the transportation infrastructure, but it must first be redeveloped and redefined to fulfill its potential. This study supports this notion by its use of GIS, planning data, and design criteria to show the need for functional classification redevelopment and advancement of the definition and procedures of the system. I sampled segments and used Chi Square (χ^2) goodness of fit statistical tests for two variables to attempt to support my claim. For the design criteria variable, minimum horizontal radius of curve, the test showed some support for further study, and the VMT test also showed some support for further study. While the horizontal curve test did not show an overall significant difference in observed to expected values, some of the classes showed signs of having within class statistical differences.

Recommendations and Further Study

I reiterate a call for more study of the functional classification system and also further development of the system definition. I have given a detailed description of what the system is, how it is used, and its metrics. I have reviewed literature that supports my call, and given empirical proof that it is needed with statistical tests. In order for us to make good decisions regarding our transportation infrastructure, it is imperative that we develop the functional classification system to make it more formal, more definitive, more consistent, and more useful.

Due to the conflicting results of the separate tests and the exclusion of more pertinent variables, there is no clear answer that the functional classification system is not defined well enough or that the class breaks are not ambiguous. The results do however, support further study to help determine these answers. Further study of whether redevelopment of the functional class system should do at least the following. It should include more variables, attempt to quantify error correction, and use more accurate measurement techniques for both observed and expected values of variables studied.

Including other variables such as access control, design speed, capacity, trip length, trip purpose, and traffic generators would improve this study by examining the functional variables that are truly involved in the function of roadway segments. Addition of other physical attributes in the study would also improve the value of this study to decide whether the classification system is adequate or not. Addition of interchange, intersection, and driveway spacing as well as vertical gradients, sight distance, slope information, median design, pavement design, and other design criteria would enhance this study and make it easier to make decisions regarding the future of the definition of the functional class system. Future iterations of this study should use more accurate length data, as the next generation of EMME software, EMME/3 software will integrate with GIS data for inputs of links. A simple matching to verify functional class attributes will only be needed then, instead of the tedious schematic to centerline matching done here.

Another area that would improve this study is an examination and quantification of the uses of functional classification. Including factors for how the system is used to secure funding, set design criteria, or determine project and maintenance priorities would help define better parameters for the functional classification system.

FHWA has formed a committee to examine functional classification. The committee arose from the recent reassessment of the HPMS. The HPMS effort reviewed the field guide (Federal Highway Administration 2005) for improvements. It became evident of a desire to also study functional classification. From my short experience on the committee, consisting of several webinar and phone meetings, from my viewpoint there was a possible bias toward changing functional classification mostly to the extent that it affected HPMS. As stated above, HPMS is one of the main uses of the functional class system. Rather than look at functional class from a standpoint of the function of the roadway, the committee seemed to look at it from a viewpoint of how it would affect HPMS reporting. Nonetheless, the committee did arrive at some short-term goals for changing the functional class system. Among them was to consider more definition for the freeway/expressway class. This shows that there is other support for further study. Note that these were deemed short-term goals, with the vision of the committee to eventually examine functional classification in more detail later.

Another mentionable item is that of cartography. As stated earlier, the functional classification system has not been developed much in many years. In the meantime, other fields have been developing. GIS has brought a new interest to cartography. I performed a quick Google search to check various symbologies being used for roadway functional classification. Of the twelve states for which I found map images for functional classification, eleven used the same color scheme as shown in Figure 3. DOTs traditionally did not and still do not employ cartographers to address these kinds of issues, but the color scheme is probably not as appropriate for the rank order data that functional classification is. Because it is a common practice, though, I will not change it for this study, only mention it as a potential area of further study.

Although I have shown enough evidence that the statistical tests support further study, there are other reasons to support further study. The amount of potential error identified shows, by itself, that there is reason to take a further look. The length of time that the functional classification system has gone without development while related fields have developed also supports that further study is needed for the functional classification system. The long-term sustainability of the nation's surface transportation infrastructure is contingent upon further development of the means by which we model the system. Functional classification remains an important system that deserves attention.

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