# TRANSPORTATION - FOCUSED GEOGRAPHIC

# INFORMATION SYSTEM FEASIBILITY STUDY

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<u>Abreviations</u>:

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|---|---|
| ALDOT: | Alabama Department of Transportation |
| CAD: | Computer Aided Design |
| DOT: | Department of Transportation |
| DS: | Dynamic Segmentation |
| ESRI: | Environmental Systems Research Institute Inc. |
| GADOT: | Georgia Department of Transportation |
| GIS: | Geographic Information Systems |
| GPS: | Global Positioning System |
| HRC: | Highway Research Center |
| KYTC: | Kentucky Transportation Cabinet |
| LRS: | Linear Referencing System |
| MDOT: | Mississippi Department of Transportation |
| MGE: | Modular GIS Environment (Intergraph Corp. software product) |
| MGSM: | MGE Segment Manager (Intergraph Corp. software product) |
| NCDOT: | North Carolina Department of Transportation |

# I. Introduction

## I.A. Background

Geographic Information Systems (GIS) is a set of tools that has revolutionized the analysis of spatial data. It has been used to study topics as varied as: stress on endangered animal species, spatial variation in the probability of earthquake damage, diffusion of infectious diseases, migration of ethnic groups, and others; and new applications are being discovered each year. Enhanced capability and ease of use of the software, as well as ever increasing hardware speed and storage capacity ensure that computer-intensive implements such as GIS will continue to develop.

A fuller definition will be presented below in section II.B.1, but in brief, GIS is a set of computer applications that permit the simultaneous and interactive analysis of spatially encoded data collected from a diversity of sources and in a diversity of formats. When all of the information is registered to a common geographic coordinate system (latitude and longitude, for example), queries regarding relationships among elements of the data can be posed. A simple application might be as follows. Four themes (spatially variable data with feature attributes) presenting: a transportation network, hydrology, the availability of property for sale and its value, and population density might be used to identify possible sites for constructing a resort facility. A GIS could be used to define potential sites which are located: within 100 meters of a major highway, within 200 meters of a river or lake, on available property that is valued below a specified threshold, and in a area of moderate population density. The GIS software is able to create a map or tables indicating sites that meet the specified criteria, or alternatively, probability zones with a variable range of conformity to the demands of the model.

GIS has been used extensively for at least two decades, but its application to transportation-related issues did not develop as rapidly as for other purposes. For many years transportation agencies and firms have made use of spatial information maintained in tables, maps, route diagrams, etc., but many users have been slow to fully implement GIS to assist in the management of their data collections. The reasons for this lag are varied and include: simple inertia, the unique characteristics of the type of data associated with transportation, limited capabilities of the existing software, and other considerations. Some of these conditions will be discussed more extensively below.

## I.B. Project Objectives

This report outlines the results of a project whose purpose was to examine the feasibility of implementing a GIS at the Alabama State Department of Transportation (ALDOT). Implementing a state GIS can be expected to create significant advantages within as well as outside the state agency. As identified in the original proposal (August, 1998) for this project, a state GIS can bring consistency and uniformity to the spatial data collected and used by the many engineering firms, district transportation offices, and other units with ties to ALDOT. Establishment of a state GIS would facilitate data sharing and exchange, cooperation among project participants, bid criteria specification, and the interpretation of generated output. The GIS software and data requirements selected for ALDOT would likely become a standard, and the increased uniformity would be expected to create public as well as private cost savings.

This study was funded by the Highway Research Center (HRC), housed in the Department of Civil Engineering at Auburn University. Direct stimulus for the project came from discussions held within the Research Advisory Committee of the HRC, as related by the Center Director; and between the Principal Investigator and members of the transportation community in Alabama. These interactions suggested that implementation of a GIS was under consideration at ALDOT, so the study was proposed as a feasibility study. Information gathered and analyzed during the October 1998 - September 1999 term of the project, however, indicated that completion of some of the specific tasks outlined in the preliminary proposal of August 1998 would be of little value at this time. Meanwhile, other related topics, not specifically developed in the proposal but indicated by members of the transportation community to be of interest, were judged to be worthy of further exploration. The most important reason for the decision to deviate slightly from the proposal was that, at the time of its submission, the Principal Investigator believed that plans to implement GIS at ALDOT were further developed than was in fact true.

Current planning at ALDOT is still very preliminary, and though a commitment to eventually making use of a full GIS exists, no actual work or active consideration will take place until well into the year 2000. Staff members of the Computer Services Division are currently devoting their time to "Year 2000" (Y2K) software date problems. The proposal for this project had included narrowly focused tasks such as identifying GIS data variables and evaluating software options, but these efforts will only be useful after the more general planning takes place. Producing a pilot study was also deemed to be premature at this time.

Rather than specific tasks related to the software and data, this project focused on the broader GIS issues outlined in the proposal. These included:

1) The traditional method of transportation data management at ALDOT and other state DOTs using Linear Referencing Systems (LRS).

2) The application of GIS to transportation management and analysis.

3) GIS as implemented by some state DOTs in the Southeastern United States.

4) The details of spatial data management at ALDOT.

5) Implementation of GIS at ALDOT; the current status of planning and issues to be considered.

6) Transportation/GIS and a program of data exchange.

## II. Transportation Data Management

### II.A. Linear referencing system

Managers of transportation information must be able to reference location. They need to know where: an accident occurs on a highway, a low-clearance bridge may hamper truck movement, a roadbed needs repair, etc. In most cases, these locations are specified in relation to identifiable points along a route. The referencing system, therefore, consists of a set of uniquely designated routes; each including a start point, an end point, and periodic markers which show distance from the origin. ALDOT and most of the other state DOTs make use of this approach which is referred to as a Linear Referencing System (LRS).

In a LRS, spatial referencing is restricted to one-dimensional space along the specified routes rather than two-dimensional space as shown on a map. The routes do correspond to real features on the ground, so positions along the route may be displayed in two-dimensional map space. However, location identification within the system (and database) is one-dimensional, and for that reason, LRS data management is fundamentally different from similar functions performed by GIS in two-dimensional space.

Significant variability can exist among LRSs. For highway/road transportation, the base routes may include Interstates and other federal highways, state highways, and county roads in various combinations. The base point of origin may be where the road begins (or enters the state), or the origin may be reset every time the route enters a new county or parish. The end point can be reset as well.

The position and interval of the periodic markers (creating a series of line segments or links) may also vary. The segmentation may be regular by mile or kilometer, or irregular. It is important to note that the distance markers related to data management and storage may be different from the signage displayed along the road. Signs may be placed near, but not exactly at, the reference positions. The interval used for the signs may also be different from that associated with the LRS in the database. A regular interval is most often applied, but intersections with other routes, political or census boundaries, hydrology, and other features may also be used as distance reference points in the system.

### II.A.1. Fixed-Length Segmentation

Data in a LRS can be stored by two different methods: fixed-length segmentation, and variable-length segmentation. In systems employing fixed-length segmentation, data elements consist of line segments of uniform length from the beginning of a route to its end. Attribute data are then assigned to the segments. In a database storing information about highway maintenance, for example, each segment would be attributed with variables such as: date of segment completion, type of asphalt used, date last repaired, etc. The segments, therefore, are fixed and the attribute information is measured.

This form of representation creates rigidity and can involve tradeoffs between data resolution and data storage/handling capacity. Where segment lengths are in whole miles, this system will probably not be very useful because of an inadequate level of detail. Pavement is not replaced in fixed, mile-long segments. Subdividing the segments into smaller units can refine the level of detail but will also increase the storage and computational requirements. Database representation of the fixed-length segmentation model would include rows corresponding to the standard-length segments, and columns showing the attribute variables.

In its simplest form, fixed-length segmentation does not allow for network analysis because the database contains no information regarding a route's linkage to other routes. To overcome this problem, the LRS may include additional variables that are used to identify the topology associated with some or all of the links and nodes. This permits an indication of connectivity among the routes, and network analysis is possible. Note that topology indicators can be used to differentiate among nodes at crossing routes which may or may not connect on a network (intersections vs. overpasses).

### II.A.2. Variable-Length Segmentation

A second method for representing spatial data in a LRS is variable-length segmentation. In variable-length segmentation the attribute value is held constant while the location along a highway is allowed to vary. The change in distance can be indicated in small units (feet or meters, for example) by including variables that reference the distance of an event to (or beyond) a milepost. Variable-length segments can be created dynamically. Dynamic Segmentation (DS) computer algorithms are able to produce variable-length segments on the fly, at run time, based on the attribute values. DS can identify a series of segments of variable length based on a specified attribute condition. Using the maintenance database example described above, DS is able to identify (with start and end points) all route segments where re-paving has taken place during the past two years. The segments will most likely be of variable length, and the precise location of the start and end points of each segment will be noted. In contrast to the fixed-length segmentation model, DS holds the attribute constant and measures the location and distance in linear space.

### II.A.3. Shortcoming of LRS

Though useful, LRSs suffer significant limitations in comparison to GIS. Attempts to overcome these problems have led several state Departments of Transportation (DOTs) to move away from complete dependence on LRS and toward a greater reliance on the two-dimensional spatial analysis capability provided by GIS. Among the shortcomings, the following are among the most significant.

#### II.A.3.a. Lack of a linear datum.

Geographical coordinate systems make use of a standard datum that links the theoretical description of space (latitude and longitude values, for example) with actual locations on the surface of the earth. If the datum is reliable, then new locations can be identified by careful measurement of distance and direction from points of known position. With linear systems, there is no standard datum. Each linear referencing system stands alone. A real need exists for the establishment of a linear datum with surveyed anchor points (along the Interstate Highway System, for example) to which other links and nodes can be connected. Though a significant amount of discussion and writing has been devoted to the topic, a standard for the U.S. seems far off.

II.A.3.b. An inability to merge LRS information with engineering graphics produced at a large scale.

Highway builders and maintainers rely on engineering and architectural drawings. Because the graphics are produced at a large scale, the elements under construction or repair are displayed as features on a scaled, two-dimensional diagram of the area. This is necessary because on the site, at close range, the area of construction or repair must be dealt with in two, and sometimes three-dimensional space. LRSs are by definition one-dimensional, so they are of little value at these scales. An LRS shows variation along the route, but it is incapable of describing attribute variability perpendicular to the center-line. Incorporating data from engineering surveys, produced at a large scale, into a LRS is impossible.

II.A.3.c. Difficulty in using spatial data from non-transportation sources.

A wide variety of location information is available from many sources such as the Bureau of the Census, U.S. Geological Survey, satellite images, various planning agencies, etc. Most of these data are found on maps or stored in spatially referenced digital format. Because LRSs are fundamentally different from other methods of showing location, incorporating spatial information from these sources into an LRS can be difficult. An LRS is not geographically referenced (tied to a spatial datum), so there is no reliable method of overlaying the routes described by the LRS onto other sets of spatial information. For example, it might be useful to know where a highway passes through different land uses zones including: urban, forest cover, farmland, marsh, etc. A GIS can easily overlay these distributions onto a transportation network when both are geographically referenced. But merging the data into a LRS would not be so easy because the elements of a LRS are not linked to a coordinate system. The data attributes from the land use map would have to be input manually by someone visually comparing the link positions in the LRS, the mapped transportation system (with judgements regarding which links go with what sections of the mapped network), and the land use map. This sort of limitation creates difficulty for anyone trying to use the LRS for planning or analysis purposes. Tasks that are relatively simple in a GIS (for another example: correlating accident rates with ethnic characteristics of a neighborhood) are difficult or impossible within the limited realm of a LRS.

#### II.A.3.d. Problems in displaying the information on maps.

A LRS can output large volumes of information, but map making is difficult. The routes, links, and nodes are spatially referenced solely to other features within the LRS, so it is impossible to accurately place them on a map. And maps are the most effective method for displaying and understanding spatial relationships. While this may not be a very significant difficulty when examining a diagram of a single, relatively straight route, it does become important when complex route networks are considered. An LRS does not include information on curvature of the segments or angle of intersection and branching. Networks appear very differently on a LRS route diagram in comparison to a true map.

## II.B. GIS and transportation (GIS-T)

### II.B.1. What is GIS?

In a narrow sense, GIS refers to specialized software capable of managing and analyzing spatial data. In a much broader definition, GIS has been described as: "A system of hardware, software, data, people, organizations, and institutional arrangements for collecting, storing, analyzing, and disseminating information about areas of the earth."(Ducker and Kjerne, p. 99). According to this view, GIS technology must be considered in the context of the data of interest as well as the people and organizations that will make use of the information. From this perspective, GIS applied by transportation agencies to analyze transportation data is different from GIS used for other purposes. Prior to discussing these differences, however, some general information about GIS will be presented.

GIS is a set of tools that combines spatial and thematic (or attribute) data. Information that varies from place to place may be compared to, merged with, or analyzed in the context of other spatial information as long as all sets of data can be linked to a common spatial referencing system. A crude version of this can be accomplished with map overlays, but GIS software facilitates the process. Each data element includes both attribute information and location references to a coordinate system. For example, the database representation of a residential lot might contain the following: an indication that the feature is a polygon, several unique latitude and longitude values (or references to other grid systems) for the points that form the outline of the polygon, and various thematic attributes (assessed value, owner's name, etc.) for the piece of property.

II.B.2. Data formats; raster and vector

The spatial data used in a GIS are most often stored in one of two formats: raster or vector. Raster data consist of a matrix of rectangular grid cells, each of which contains attribute information. A field containing wheat would be represented in the database by array elements (corresponding to area units or pixels) with attribute codes representing wheat. The array element attribute codes for the non-wheat areas would be different. A vector model uses combinations of points, lines, and polygons to represent features. The wheat field would then be stored as a polygon, with a location description of its outline, and one attribute entry for the complete field.

Most of the current GIS software products focus on one form of data or the other. Raster GISs are effective for analyzing remotely sensed imagery, digital elevation model data, and in general, anything collected in a regular grid pattern. Computations are rapid, but large amounts of storage usually are required. Raster GIS packages are rarely used for transportation-related analysis.

Vector GISs, on the other hand, may require less storage, but computation is slower. Comparison of polygons from different themes in a vector system is a more complex task because a full identification of each thematic outline must be developed before the areas of overlap can be determined. With a raster system, the grid cells are the same for the various themes, so overlap can be determined immediately. Vector GISs are most suitable for land use planning, network analysis, managing urban utilities, tracking sales and marketing, and other similar applications that involve spatial units of different sizes and character.

Though a GIS software package can be classified as vector or raster-dominant, most sophisticated programs have the ability to import and transform data from the other category. A vector GIS, therefore, will usually include the ability to bring in raster images and display or overlay them onto the vector features. The vector GIS, however, will be limited in its ability to include the raster layer as part of the analysis and query process.

Because route features are more often displayed as lines and points than as a sequence of pixels, vector GIS is the type usually preferred for transportation-related study and management. Vector GIS also has the greater ability to handle complex topological relationships, facilitating network analysis.

### II.B.3. Special problems in applying GIS to transportation

As mentioned in the Introduction, transportation users have been slower to adopt GIS than other groups. Departments of transportation maintain large databases, and many of these were established before GIS was widely used. There may have been a substantial level of investment and commitment to a LRS. State and local offices are often short on personnel and resources, and they are subject to political forces. Many of the employees have long job tenures. All of these factors can produce a reluctance to change.

The data maintained in a LRS are not easily converted into a GIS format because they lack references to two-dimensional coordinate space. Most popular vector GIS packages were designed for applications other than transportation, so there can be some awkwardness in applying the software in this area. For example, transportation data management systems usually maintain attribute data by line segments (fixed-length or variable-length), but most GISs store attribute data with point or polygon features. This can also lead to organizational inertia.

Private firms working with transportation-related data do not appear to be as affected by the limitations listed above. Engineering and architecture firms make frequent use of GIS software, often linked to computer aided design (CAD) drafting programs such as *AutoCAD* (Autodesk Inc.) or *Microstation* (Bentley Systems Inc.) Other commercial firms use GIS for routing deliveries, tracking the locations of clients or suppliers, analyzing market areas, industrial location, and other tasks. These applications include a significant amount of transportation network analysis. In some of these circumstances, the necessary data may be available from public sources, but obtaining up to date and reliable information may force a firm to purchase or collect the data directly.

### II.B.4. Commercial software

Among the providers of transportation-related GIS software, the greatest market shares are held by Environmental Research Institute Inc. (ESRI) and Intergraph Corp. ESRI is by far the largest of the GIS software producers, and their flagship product, *ARC/INFO*, has been the dominant vector GIS for years. Recently, ESRI's *ArcView* has captured a sizable market share. Though *ArcView* still lacks the computing versatility of *ARC/INFO*, its simpler user interface and lesser cost have made it popular for a broad spectrum of GIS applications. ESRI products are especially dominant in planning, environmental, and resource analysis studies.

Though its products are not as widespread across the GIS market as those of ESRI, Intergraph Corp. is a major supplier of GIS for users in transportation-related fields as well as for other specialized needs. Intergraph's *Modular GIS Environment (MGE)* consists of an assortment of interlinked programs which, as a group, provide substantial computational power. *MGE* is commonly used by engineering firms because it functions in an integrated manner with Bentley's *Microstation*, one of the leading CAD programs on the market. *MGE* can import *Microstation* design files directly, and the GIS attribute information is linked directly to the graphic design feature elements. Another advantage of *MGE* is that the suite includes *MGSM*, a module for handling dynamic segmentation in a LRS.

Within the past three years Intergraph has released *Geomedia* and *Geomedia Professional.* These recent products include a more user-friendly interface similar to that of *ArcView*, and Intergraph is marketing them to a broader, non-expert audience. As new upgrades and add-ons increase the power of *Geomedia* and *Geomedia Pro*, they are expected to replace *MGE* as Intergraph's dominant offering. An important advantage of *Geomedia* and *Geomedia Pro* are their ability to read spatial input in a variety of formats produced by other GIS software including: *ARC/INFO*, *ArcView*, *MGE*, *MGSM*, and others. *Geomedia* stores and reads tabular data from standard databases including *Oracle* and *Access*, so the product is especially well suited for accessing information from a broad array of sources.

Though not as widespread as those listed above, other GIS packages are used for transportation analysis. *MapInfo* (MapInfo Corp.) includes some useful features related to network analysis, and *Maptitude* (Caliper Corp.) has been heavily marketed as a tool for commercial retailing enterprises. It is sold with a large volume of attached census data and includes a function for determining the shortest distance for serially linking a set of nodes in a network (the traveling salesman problem), a feature that is not standard on other packages.

## II.C. GIS Implementation in DOTs of Southeastern states.

Public agencies, departments, and private firms use many different software and hardware products for a wide variety of transportation-related purposes. The Lee-Russell Council of Governments planning office and the City of Auburn, for example, make use of ESRI software to evaluate and manage local and regional spatial data. These organizations depend on *ARC/INFO* and *ArcView* to maintain data base information about city streets, property ownership and zoning, utility networks, and planning projects.

A meeting among GIS users in the Mobile area indicated that *ARC/INFO, ArcView, MGE, ERDAS, and GRASS* (a public domain program) were implemented in PC as well as workstation environments. CAD programs such as *Autocad* and *Microstation* are used to create design and map output. A continuing problem expressed by all was that data incompatibilities among the various software and hardware configurations make it hard to exchange information (see discussion below).

Despite the difficulties in bringing traditional LRS data into a two-dimensional spatial framework, several state DOTs have begun to make significant use of GIS. In most cases, GIS has not replaced the LRS, but it complements and takes over some of the functions that are best performed in two-dimensional space. As mentioned above, Alabama's DOT does not use a full GIS, and consideration will only begin in 2000. DOTs in several neighboring states, however, have been applying GIS for several years.

The Office of Information Services at the Bureau of Transportation Statistics (BTS), U.S. Department of Transportation, has established a program of site visitations for the purpose of determining the extent to which GIS is being used at the state level. Alabama and most other southern states have not received a site visit, but among neighboring states, visits were made to Georgia, Kentucky, and North Carolina during 1997. Listed below are summaries based on information provided by the Bureau of Transportation Statistics (see References section at the end of this report).

Mississippi has not yet received a site visit under the program, but the state has made important upgrades to its transportation data management system. Mississippi's experience may be useful to Alabama officials as GIS implementation is considered in the year 2000. A summary of Mississippi's revisions is also included below. In addition to these states, the Principal Investigator had contacts with individuals in Florida and

Louisiana, but a full report of GIS implementation was not available. The discussions indicated that GIS is being used for various purposes in those states.

II.C.1. Georgia

At the Georgia Department of Transportation (GADOT), GIS is maintained in the Office of Information Services in Atlanta. GADOT is connected to the Information Technology Policy Committee, a group charged by the governor's office with expanding information services. A substantial amount of technical support is provided by the University of Georgia. In 1997 the Office of Information Services included 96 positions, 9 of which were assigned to mapping and graphics. Almost all made use of GIS. In 1997 GADOT had 15 site licenses for *ARC/INFO* and 90 for *ArcView* running on UNIX workstations and Pentium PCs.

According to state officials, the primary objective was to use GIS to create spatial databases that would be available to GADOT personnel and other state officials, especially at the local and district level. A substantial effort has gone into producing a state digital basemap of the transportation network. The spatial database conforms to the USGS Digital Line Graph (DLG) standards. Georgia's existing LRS is being incorporated into the GIS through special software packages from ESRI, and the system has mapped LRS reference points at all of the road intersections. In April, 1997, the networks maintained in the state database were: federal, state, and county roads; city streets; hydrography; administrative boundaries; cultural features; and additional transportation items including railroads, pipelines, airports and transmission lines.

II.C.2. Kentucky

In Kentucky, GIS activity is housed in the Division of Information Technology under the Department of Administrative Services. Data collection and map development, however, are handled separately in the Kentucky Transportation Cabinet (KYTC) Department of Highways' Office of Multi-modal Planning. Kentucky's state GIS office conducts spatial analysis for all state agencies including the KYTC. At the time of the BTS site visit in 1998, Kentucky was in the process of digitizing all local roads from 1:24,000 quadrangle maps. As sections were completed, the digital information was being made available to the public. The digitizing was accomplished with *ARC/INFO*, and *ArcView* was used for querying the database. Fifty *ArcView* site licenses were available in the KYTC, and all 12 district offices had access as well. Maptitude was also being used at the KYTC, especially to analyze census data. At the time of the site visit, GIS was used primarily for displaying highway information.

Additionally, Kentucky has a fully implemented LRS with dynamic segmentation. The system is county-based (route start points are reset to zero at each county line), but interstate highways and parkways maintain a continuous mileage reference across the state (do not reset to zero at county lines). Special provisions for coding ramps, couplets (divided highways), and other anomalies are included in the system.

### II.C.3. North Carolina

At the time of the BTS site visit in 1997, the GIS unit at the North Carolina Department of Transportation (NCDOT) include 34 people in three units devoted to mapping, analysis, and road inventory. NCDOT uses *ARC/INFO* for much of the work, but Intergraph's *Geomedia* and Bentley's *Geographics* are also applied. Twelve *ARC/INFO* site licenses and 24 *ArcView* licenses were supported at the time of the site visit. The systems run on UNIX work stations, but an evaluation of *Windows NT* is under way. The GIS section provided analytical services to other units within NCDOT including Traffic Engineering, Planning, and Environmental sections. Much of the effort in 1997 was aimed at improving data visualization and presentation. Additional activity was developed through agreements with metropolitan planning organizations which can make use of NCDOT spatial databases. The GIS unit is also involved in establishing a National Spatial Data Infrastructure node that will serve as a clearinghouse for distributing state geographical data.

Funding for GIS at NCDOT comes from an annual operating budget as well as from Federal research grants. In 1996-97 the total operating budget was $2,519,200; divided more or less equally among the mapping, analysis, and road inventory sections. Additionally, almost $4,000,000 was received from Federal grant sources, and $2,500,000 was provided by state matching sources.

NCDOT has produced a standardized state digital base map at 1:24,000 that includes all roads, railroads, pipelines, political boundaries and trails. NCDOT also maintains two different LRSs. The first is a link-node system that is used to identify pavement management sections, and the second is a road inventory file based on county route mileposts. In 1997 the integration of these LRSs into a GIS had not been completed.

II.C.4. Mississippi

During the past few year the Mississippi Department of Transportation (MDOT) has taken steps to upgraded and standardize its LRS through the establishment of a comprehensive Transportation Management Information System (TMIS). Included in the project are procedures that will facilitate the eventual incorporation of the LRS into a true GIS. MDOT has standardized the coding of information for its LRS and made provisions for special tag codes that are applied to difficult features such as ramps, circular drives, dog legs, divided highways, multiple entry and exits of routes in a single county, overlapping routes, and re-aligned routes. MDOT uses Intergraph's *MGE* Segment Manager (*MGSM*) to maintain the database. *MGSM* requires a control network of links connecting points whose location is specified in two-dimensional space. *MGSM* is a dynamic segmentation program which can create variable-length segments based on attribute information coded along uniquely identified routes. Because *MGSM* requires coordinate positions for the anchor points of its control network, it operates as a true GIS; and in fact, can be run in concert with other modules of the *MGE* suite of programs.

Developers of the Mississippi information system also examined methods for inputting into the LRS information provided by Global Positioning System (GPS) devices. A patrolman reporting an accident is able to use an inexpensive GPS reader to locate the site, and a software routine translates the coordinate data into a point in the linear space of the LRS. Mississippi's experience of upgrading and standardizing the LRS, use of the *MGSM* software package, and development of procedures that can eventually be used within a GIS are steps that facilitate the transition to a full GIS environment without sacrificing the large amount of LRS legacy data.

# III. Alabama Department of Transportation

## III.A. Present data management system using LRS

As Mississippi, the Alabama Department of Transportation (ALDOT) relies on a linear referencing system to manage spatial data. Responsibility is held by the Computer Services Division at ALDOT headquarters in Montgomery. Alabama's LRS is spread across several databases that are used to store information about bridges, signs, railroad crossings, accidents, and maintenance. ALDOT maintains information only for those highways for which the state has primary responsibility: federal and state roads. County roads are not included in the system.

The Alabama state highways are the primary inventory routes in the system. The LRS defines a route origin as the location where the road enters the state in the south or west, or, for highways that do not extend into a neighboring state, its most extreme point to the south or west. The end point is a similar location to the north and east.

Coding is by milepost or kilometer post. In response to pressure from the Federal government in recent years, Alabama changed from a system based on standard miles to one based on metric kilometers. At the time of the conversion, very precise distance measurements were taken, so the kilometer markers are set with an accuracy of one meter or less. Due to state and local political pressure (and a weakening of the Federal mandate to convert to metrics), ALDOT was ordered to change back to standard distance measurements. The conversion and reversion have consumed many man-hours at ALDOT.

All events and features are encoded with database fields that provide references to linear location as well as attribute information. Four digits are reserved for the state inventory route, and an additional digit is used to show direction of travel where the highway is divided (couplet). Regardless of the direction of travel, non-point features such as bridges, repavement stretches, and others are referenced to the feature's point nearest the route origin. A linear distance extent of the feature is also included, so the reference point for the feature's termination (end of the bridge, for example) can also be determined. If State and Federal highways overlap, the reference points and mile (or kilometer) posts identify positions along the State road.

As highways are maintained, realignment often occurs. This leads to changes in distance, so the positions of the reference points along the realigned segments, as well as beyond the affected section, also change. ALDOT maintains gap equations to handle these circumstances. Realignment can also affect the point of origin or destination of a route, so special directives are used to deal with these situations. If a road is extended further to the south or west, the zero point is maintained at the former origin and the new section is coded in the negative direction (toward the south or west) with artificial distance values in the 800-mile range (see appendix A).

ALDOT's LRS does not take into account some of the special conditions that can cause analytical difficulties. Ramps are not indicated in the system, and this makes it difficult to automate procedures such as those for providing permits for trucks with overweight loads. Bridges and underpasses are coded for clearance along the inventory routes (for underpasses) and secondary routes (for bridges). For divided highways, bridges are also coded according to the direction of travel. This is necessary for routing vehicles, for bridges in one direction of travel will have different clearance tolerances and load capacities from those for the opposite direction. Note that bridge data must be updated when roads are repaved, for the extra layer of asphalt will reduce the total clearance.

## III.B. GIS at ALDOT

Dynamic segmentation within the LRS is provided by Intergraph's *MGSM*, but at present, ALDOT does not use a full-featured GIS. A survey of district and regional offices was undertaken for this project, but very little returned information was received. The survey, as well as conversations at the state headquarters, indicated that GIS use at the district or regional level is very limited, if it exists at all.

Though GIS has not been implemented at ALDOT, some interesting and innovative output is being generated. A map of the road system for the entire state has been linked to the bridge data maintained in the LRS, so that a user, with access to a standard Internet browser (*Internet Explorer* or *Netscape*), is able to zoom in on a portion of the map and view the location of bridges. Each bridge symbol is coded with attribute information including clearance, capacity, age, etc. The information can be very useful for routing trucks and for other purposes.

Officials at ALDOT recognize the need to move toward implementing a full GIS. They are aware of the potential benefits that GIS would offer. Possible activities are: generating a statewide digital map, establishing a clearinghouse for data exchange, promoting broader interaction with other state agencies, generating output for the public, and offering access to the spatial data that are available from Federal agencies and the public domain. The Computer Services Division is responsible for maintaining the LRS, and implementing a GIS would also fall to the unit. The Division is staffed by 3 individuals in addition to the Director, so the human resources of the unit are very limited in view of its responsibilities. A significant amount of time over the past years was devoted to converting to (and back from) the metric system, and at present, all energy is being devoted to ensuring "Year 2000" (Y2K) compliance. They have purchased and experimented with *Geomedia* on a *Windows NT* system, but nothing substantial will take place prior to the year 2000.

# IV. Findings.

## IV.A. Present state of affairs

GIS is proving an effective aid to the management of transportation information in many state DOTs around the country. As the Bureau of Transportation Statistics report summaries indicate, many southern states are already well on the road to taking full advantage of the capabilities offered by GIS. Alabama, however, is lagging behind. ALDOT possesses what appears to be an effective transportation information management system using LRS, but the state cannot accomplish many of the tasks that are being done in neighboring states. The purpose of this report was not to identify blame for this lag, but the Principal Investigator suspects that a lack of human and financial resources, officials responding to political pressure (mandating conversions to and from the metric system), and the limited commitment to GIS technology at major universities (in contrast to the University of Georgia, for example) are possible causes.

The Director of the Computer Services Division indicated an expectation that planning for GIS will begin some time next year. He feels that there is a general understanding of what GIS is and what it can do to improve data management and analysis at ALDOT. There appear to be little encrusted inertia or other systemic conditions within the department that would hinder a move toward full implementation of GIS over the coming years. The potential obstacles are more general, namely: limited resources and competing demands from the large number of other needs.

## IV.B. Items to consider in planning for GIS.

The scarcity of resources in Alabama means that officials at ALDOT will have to do everything possible to make wise use of whatever support is provided. The state is in a favorable position because most neighboring states have already implemented at least elements of a GIS. Alabama may be able to learn from their experiences. Especially useful would be a careful examination of the experience in Mississippi, a state that probably has more in common with Alabama than Georgia or Florida. Individuals involved in future planning for GIS at ALDOT should give careful consideration to the following items.

IV.B.1 The fundamental objectives for implementing a GIS.

What sort of output will be sought, and by whom will it be used? How much of the system will be devoted to data maintenance and management as compared to analysis? What sorts of problems will be subjected to analyses with the GIS? Planners should examine perceived limitations attributable to the present use of a LRS and evaluate GIS's capability to overcome those limitations. Will an initial investment in GIS be recovered through costs savings realized from improved efficiency?

IV.B.2 The types, quality, and sources of available data.

What input will be used and where will it come from? An inventory of digital data present within the State as well as from other sources should be performed. Much data are available at little or no expense, and if the quality is acceptable, these can provide significant savings. How much will need to be developed directly by digitizing from existing map sources? During the recent remeasurement of the LRS reference control points occasioned by the conversion to the metric system, the latitude and longitude position of each point were determined along with its route-distance position. Though the geographical coordinate data are not used in the LRS, the fact that it is included in the database will facilitate moving information from the linear system to a GIS.

IV.B.3 Basic costs of the initial implementation and continued operation.

Only a small fraction of the expenses associated with GIS are for the initial purchase of software and hardware. The cost of data can be high, especially when a large number of hours must be spent digitizing information from analog maps. Continuing costs for software upgrades, data updating, technical personnel, etc. can also be significant. Planners should evaluate not only the sources of State or Federal support but also possible income generating potential from products derived from the GIS.

IV.B.4 Coordination with other agencies and firms.

There should be an effort to coordinate GIS planning with State agencies and private firms that interact with ALDOT. Much of the transportation output will be of value to other units, and in turn, ALDOT can make good use of information housed at planning agencies, municipal offices, etc. Software and database compatibility will help create future efficiencies and foster cooperation.

IV.B.5 The capabilities of the software and hardware options.

In addition to the fundamental computational power of a software package, the quality of its documentation, the dependability of technical support, the frequency of updating, compatibility with existing software, and other similar items should be taken into consideration. The selected GIS software should be able to incorporate the data presently maintained in the LRS. Preference should be given to a GIS that is able to read tabular attribute information maintained in a standard database such as *Oracle*. Many GIS users are moving from UNIX workstation environments to *Windows NT*. The relative benefits of different operating systems should also be looked at. Access to the Internet must be provided.

IV.B.6 A planning and implementation schedule.

A reasonable time frame and step by step schedule for the entire process should be put into effect. The actual steps and target schedule must be worked out at the beginning of the process, and they should be incremental and logical. Periodic buffers and evaluation steps should be incorporated into the schedule. Some aspects of the planning clearly involve a logical sequence, but in other cases, some elements will need to be considered concurrently. There is little value in selecting software before a decision is made on the desired output. On the other hand, planners need to know something about the capabilities of different software packages as they consider data output. Similar consideration applies to data input.

IV.B.7 Possible sources of outside support.

A full examination of the resources available from the Federal government should be undertaken. The availability of funds from transportation sources (Federal Transportation Agency) as well as other sources that traditionally have supported GIS should be examined. Private funds should also be sought. ALDOT is a user of Intergraph's *MGE* product, and implementing a *Geomedia*-based system is possible. Intergraph Corp. is located in Huntsville, AL, and the firm may be willing to offer incentives in order to gain exposure for its products. Other companies may be interested as well.

IV.B.8 GIS expertise present in Alabama.

A significant core of knowledge is available at institutions such as Auburn University. Faculty, researchers and technicians at colleges and in other state agencies can serve as sources of information and counsel. In general, the advice provided by professionals at educational institutions and public agencies is not likely to be colored by links between the expert and commercial interests. Consideration of the needs of ALDOT in light of the capabilities offered by different software and hardware products is more apt to be objective.

IV.B.9 Building a base of support.

An early effort to obtain full institutional support within ALDOT and at different levels of state government should be put forward. This will involve setting aside time to meet with key leaders and groups in order to explain the benefits of moving toward development of a full GIS.

IV.B.10 Plans for follow-up.

The post-implementation stages should be considered in the plan. What will be the continuing activity of the GIS section; how will the system grow and develop; what evaluation process will be used to update and redirect activities; and how will cutting-edge technical expertise be maintained? These and similar questions should be given careful consideration.

IV.B.11 Education

A healthy dose of training should be built into the process. Implementing a GIS will create a need for workshops, short courses, and information dissemination to users at the central office as well as in the field. Topics related to coordinate systems, GPS use, map projections, data reliability, spatial analysis and others will need to be taught. Instruction on the functions and applications available in particular software packages will also be needed.

# V. Data Exchange

## V.A Expressions of need for a data exchange

In addition to considering the status of GIS implementation at ALDOT, this study looked briefly at another aspect of GIS use by the transportation community. Concern was expressed over the lack of mechanisms to facilitate the exchange of data within the state. Private firms and public agencies collect and adapt data from a wide variety of sources, but these data are rarely made available beyond the primary user or for purposes other than the original reason for their collection. In some instances, similar data for the same area are collected by different users for different purposes. This is done because the individuals or firms are not aware of or do not have access to the data that may have already been gathered. The data are collected by different organizations for many different purposes such as rough planning, design, utilities management, etc. Serious problems can occur when these data are mixed and used for other applications without a clear understanding of the standards, accuracy, collection date, special conditions, etc. associated with the original data.

The accurate maintenance of "metadata" files would help alleviate the difficulties. Metadata is a file that contains information on items such as tolerances, date of collection, collecting agency, purpose for which data were collected, etc. about the spatial data. A need exists, therefore, for:

1. Information about the availability of spatial data

and

2. Methods for facilitating the sharing of data between their owner and other potential users.

## V.B A data exchange clearinghouse

Data sharing is not a new issue among GIS users in Alabama or across the nation. Several national initiatives have been undertaken to promote a freer flow of information about data availability. The importance of metadata is frequently emphasized in GIS publications, and the U.S. Geological Survey has produced a metadata form to be used each time data are collected. Unfortunately, the length and tedious nature of the form lead many to neglect attaching any sort of metadata to primary files. Information regarding the date of collection, digitizing standards, original project for which the data were use, and other vital information, is not available. Sometimes when metadata are available, the accuracy of the information may be questionable. A precondition for any data sharing will be the establishment of well thought out procedures for creating and maintaining accurate and up to date metadata files.

If owners of spatial data are willing to make them available for use by others, and if reliable metadata have been developed, information about the availability can be posted on to an Internet site or distributed on a CD. The information might include: content of the metadata file (source of the data, date of collection, accuracy, scale, resolution, etc), how to get in touch with the owner, and any charges that might be required. The server or CD could also include a small sample of each available dataset so that potential buyers would have an good idea of whether or not it would meet their needs.

The CD or server linked to the Internet would not include the full spatial data files but would contain information about those files. The information in the metadata files would allow providers and users to establish contact with each other and to negotiate data purchase or sharing arrangements. The server or CD could also offer various public domain files for the state of Alabama such as the DEM (digital elevation model) and DLG (digital line graph) of the U.S. Geological Survey; and demographic and housing files from the Bureau of the Census. Continuing costs might be defrayed by a modest subscription fee charged to users.

Though development of the clearinghouse could be included as an element of the more general plan to establish GIS at ALDOT, it would also be feasible to move forward with the idea independently. One of the universities might provide space on a server linked to the Internet, so the greatest portion of the costs would be associate with contacting potential data providers and organizing the database. Availability of data sharing will benefit GIS development at ALDOT, but one project is not contingent on the other.

# VI. Conclusion

## VI.A Next steps.

This project examined the status of plans to implement a GIS at ALDOT. This investigation revealed the following.

1. Alabama is already well behind neighboring states in applying GIS to transportation management.

2. ALDOT presently has in place an adequate LRS and appropriate dynamic segmentation software to effectively manage data describing important elements of Alabama's highway system. Increasing analytical and display capability, however, will be difficult without moving to a GIS.

3. Though informal plans to implement a GIS are under way, serious consideration will not occur until well into 2000. Software capability analysis, development of a pilot project, the selection of variables for inclusion in the database and similar specific tasks should be carried out only after the more general planning has occurred.

4. Significant resources will be needed if ALDOT is to create an effective GIS implementation plan.

5. Auburn University GIS expertise can make a significant contribution to the process by providing a) advice; and b) training and education.

6. As plans to implement a state GIS move forward, a parallel but independent project should be undertaken; the establishment of a clearinghouse for spatial data available from public and private sources.

## VI.B. Final comments.

This project was proposed under the impression that planning for a state GIS was already well underway at ALDOT. Unfortunately, that is not the case. There is some informal consideration of the matter, but serious planning has been put off at least until 2000. For that reason, it would be difficult or impossible to follow through on some of the specific tasks put forward in the original proposal. What this project did look at was the current status of ALDOT's data management procedure in the context of standard practices elsewhere in the U.S. GIS is a tool that has been shown to be very useful in a variety of fields, and though somewhat delayed in coming to transportation, it is also proving itself in this area. Private firms, local municipalities, and departments of transportation in neighboring states are all making extensive use of GIS. It is only a matter of time before its promise will be realized at ALDOT as well. The time is here for decision makers to begin to examine the steps necessary to make the transition as smooth and efficient as possible. Continuing contact with members of the transportation community, at Auburn University and elsewhere, should be maintained.

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Appendix A.

Alabama Department of Transportation Guidelines for Operation.

ALABAMA

DEPARTMENT OF TRANSPORTATION

GUIDELINES FOR OPERATION

SUBJECT: ADDING AND DELETING KILOMETER POST ON THE STATE HIGHWAY SYSTEM

I. INTRODUCTION
II. PROCEDURES
III. REVISIONS
IV. IMPLEMENTATION

## I. INTRODUCTION

The purpose of this document is to provide guidance and document procedures to assure that the location reference system provides for identifying the location of emergency incidents, traffic accidents, highway maintenance activities and physical features such as utilities, bridges and traffic control devices. In addition the reference system is to assist the driver in estimating his progress of travel through a distance measuring technique. These goals are established in order that the existing data base may be preserved and modifications to the State Highway System may be integrated into this data base.

In response to the provisions of the Highway Department Safety Program Standards, a mileposting method of location references was implemented on the State Highway System. These mileposts provided the required accuracy in identification of accident locations and the continuing surveillance of the roadway network for potentially high accident locations.

Since the project stage of implementation in 1969, both the US Numbered Highway System and the State Highway system have had many additions, extensions and revisions. The Department has documented each of these changes.

In 1995 the mileposting method was discontinued and a kilometer marking system established.

## II. PROCEDURES

Determination of the appropriate revision to the kilometer posting location reference system must consider the many factors effecting the addition, extension or revisions to the State Highway System. Implementation of any addition or deletion to the State Highway System must be coordinated within the range of the data base which will be formed as soon as the road is opened to traffic. In the cases of previously constructed routes, these procedures are to be followed prior to the change in classification being put into effect.

The procedure for assigning kilometer posts on paper are described below and shown on the attached exhibits as noted.

A. Route Extensions

The addition of kilometers before the point of beginning or end is effected by the location of the extension forming the two cases shown on Exhibit A.

Case 1. Extensions northerly or easterly. The kilometer post continuity as numbering is continued from the previous point of ending in sequential order. The travel distance requirement of the MUTCD is maintained in this simplest form of additional kilometers. Kilometer posts are assigned according to the previous procedures.

Case 2. Extensions southerly or westerly. When the zero point is not at the south or west state line, the Rule of 800 is applied. For uniformity of application, the zero kilometer post is equated to a kilometer post 800. The new point of beginning may be found by subtracting the total length of the extension from 800. The D10-1 sign with zero displayed rather than D10-3 with 800 displayed is to be used at the point of equation. The sign is to be installed only if the installation meets the standards of the MUTCD for longitudinal accuracy of plus or minus 10 meters. Subsequent extensions of a route once the Rule of 800 is applied will not need equations as continuity is possible from the first equation. The choice of 800 as the benchmark is based on avoiding duplication on even the longest feasible routes in the State.

B. Route Alignments

The realignment of a route is affected by both the status of the former route and the length of the change.

1. When the <u>maintenance responsibility</u> on the former route <u>is not</u> taken over by the local agency, new State Route Numbers shall be assigned for the realigned section as shown in Exhibit B. This additional numbering will present the motorist with an apparent duplication, but is necessary to avoid the actual duplication which has taken place when the State Route Numbers have been reassigned.

2. When the <u>maintenance responsibility</u> is taken over by the local agency and the travel distance is shortened by realignment, the existing kilometer posts are to be removed and the new route kilometer posted

before being opened to traffic. The following rules apply for routes which have been shortened:

For realignments that begin more than 5 kilometers north or east of a county line, the equation is to be accomplished in the last kilometer of the realigned segment as shown for Route 2 in Exhibit C. No proportioning is to be done. The last kilometer post in the realigned segment should not be placed if it is closer than 0.5 kilometer from the next previously existing kilometer post to reduce confusion to the motoring public and the data collection personnel.

For realignments that begin 5 kilometers or less north or east of a county line, the equation will be accomplished at the county line as shown in Exhibit D. The kilometer post distance behind will be the kilometer post distance previously established. The kilometer post distance ahead will be established by subtracting kilometers from the first kilometer post located after the realigned segment. The first kilometer post after the county line should not be placed if it is closer than 0.5 kilometer from the last kilometer post before the county line.

In cases where realignment crosses a county line the equation will be established at the county line as shown in Exhibit E. The kilometer post distance behind will be accomplished by adding kilometers to the last kilometer post located before the realignment. The kilometer post distance ahead will be accomplished by subtracting kilometers from the first kilometer post located after the realigned segment. The first kilometer post after the county line should not be placed if it is closer than 0.5 kilometer from the last kilometer post before the county line.

When the beginning of a route is realigned and shortened the equation will be established at the beginning of the realigned segment as shown for Route 2 in Exhibit F. The kilometer post distance behind will be 0.000 as this is the realigned beginning point. The kilometer post distance ahead will be established by subtracting kilometers from the first kilometer post located after the realigned section.

When the beginning of a route is shortened the equation will be established at the existing kilometer post distance as determined by the length of the shortened segment as shown for Route 5 in Exhibit G. The kilometer post distance behind will be 0.000. The kilometer post distance ahead will be the distance as determined by the length of the shortened section.

3. When the maintenance responsibility is taken over by a local agency and the travel distance is lengthened by realignment, the existing kilometer posts are to be removed and the new route kilometer posted before being opened to traffic. The increase in distance is compensated by involking the Rule of 800 as shown in Exhibit C for Route 1. The 800 has been added to the station in kilometers along the realigned section. No overlapping is present due to the addition.

When the beginning of a route is realigned and lengthened the equation will be established at the point of convergence of the existing and new alignments as shown for Route 1 in Exhibit H. The Rule of 800 will apply in cases such as these. The kilometer post distance behind will be 800. The kilometer post distance ahead will be the existing kilometer post distance as determined by the convergence of the two alignments. The new point of beginning may be found by subtracting the total length of the extension from 800.

Equations will be established at identifible points such as, bridge abutments, railroad grade crossings, centerline of road junctions, etc.. These points may be located some distance from the realigned segments but are necessary to allow data collection personnel to physically locate the equations.

Equations are to be shown on all county kilometer post maps.

C. Circular Routes

Circular Routes will be kilometer posted beginning at the southerly terminus and marked in a clockwise direction to end at the southerly terminus, the point of beginning as shown in Exhibit I.

D. Route Loops and Spurs

In instances where the Department maintains short roadway segments that branch off the main state route to form spurs or loops, they will be kilometer posted as shown in Exhibits J and K.

For spurs the kilometer post at the point of beginning will be the kilometer post of the main route plus 1500. This will be the rule for all cases no matter what direction the spur extends.

The loops will be kilometer posted beginning at the southerly or westerly terminus and extending to the northerly or easterly terminus. The kilometer post for the beginning of the loop will be the kilometer post of the main route plus 2500.

Whenever possible, the addition of loops or spurs will be avoided.

These procedures are to be applied upon agreement of the Divisions and Bureaus affected whenever numbering changes for either State Route Number or kilometer post are involved.

## III. REVISIONS

The Transportation Planning Engineer shall be responsible for making revisions to this document when deemed appropriate.

## IV. IMPLEMENTATION

The organization responsible for design roadway plans shall prepare a sketch showing the proposed kilometer posting scheme and submit same to the Transportation Planning Engineer for approval before including same in the PS & E assembly. This procedure shall also be followed by personnel requesting a revision to the existing kilometer post system. The Transportation Planning Bureau is responsible for marking highways for kilometer post re-location.

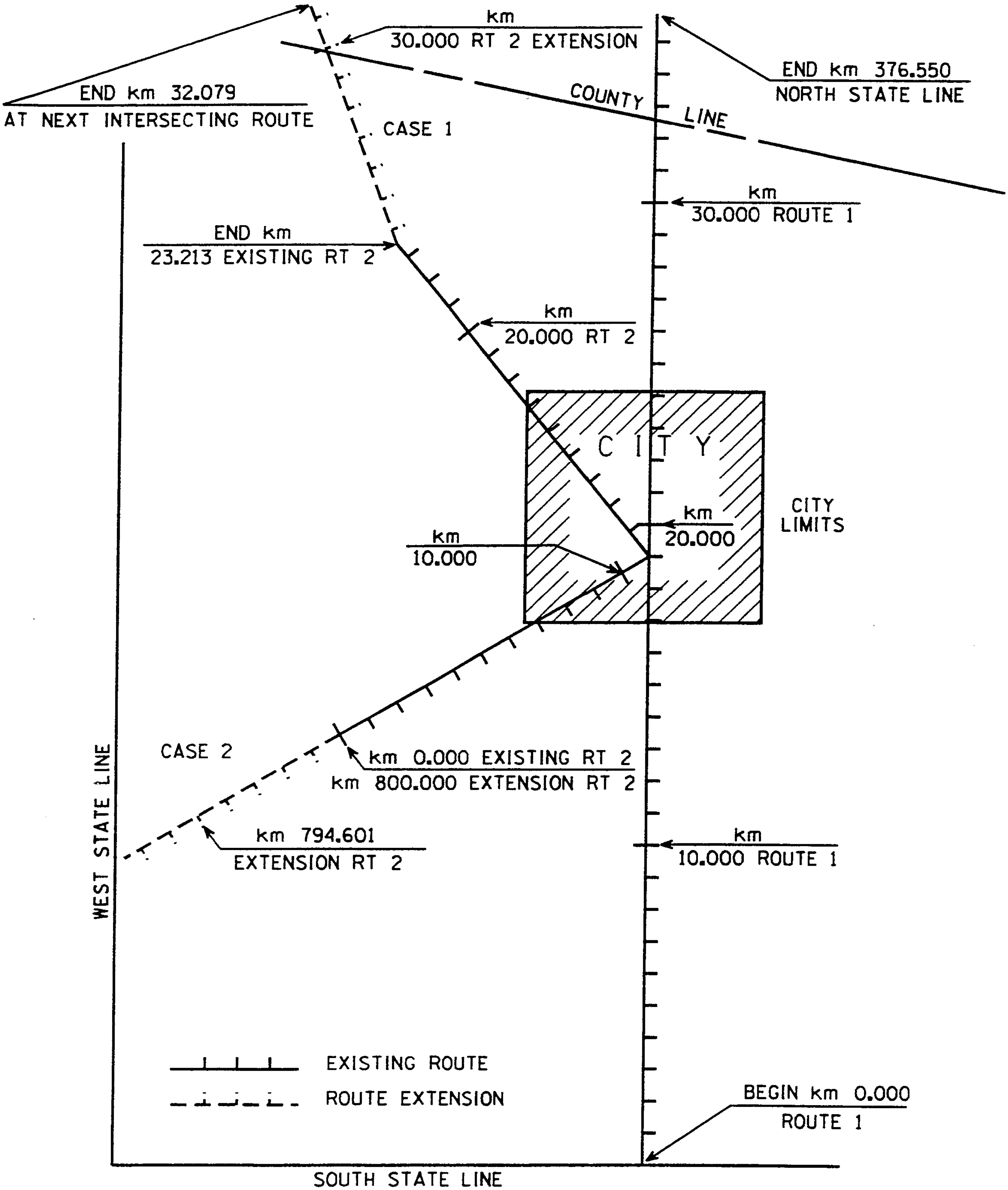
RECOMMENDED FOR APPROVAL: George Kay
BUREAU CHIEF/DIVISION ENGINEER

APPROVAL: Ray W. Barr
CHIEF ENGINEER

APPROVAL: Guy Bath
TRANSPORTATION DIRECTOR

12/19/96
DATE

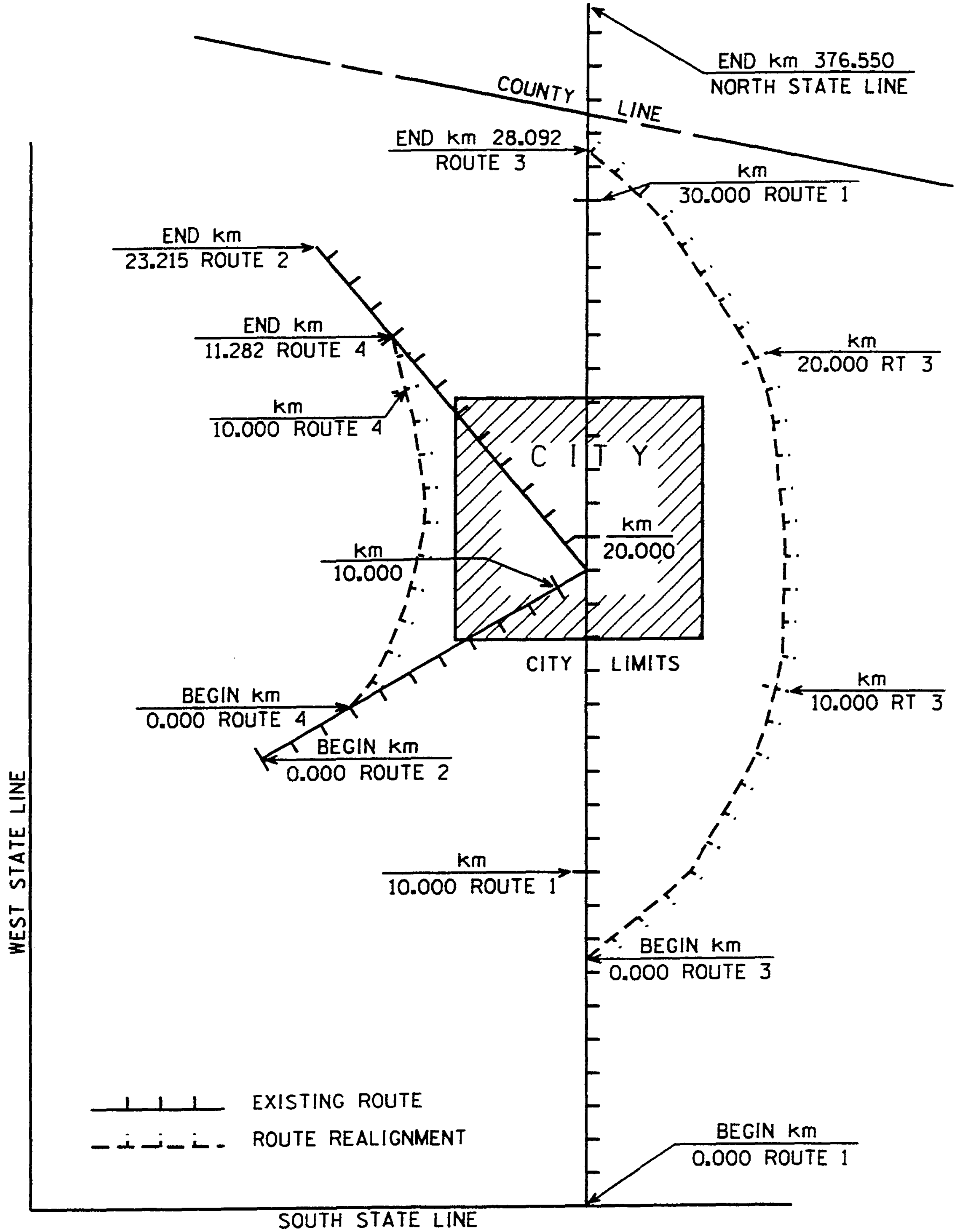
EXHIBIT "A"




EXAMPLES OF ROUTE EXTENSIONS

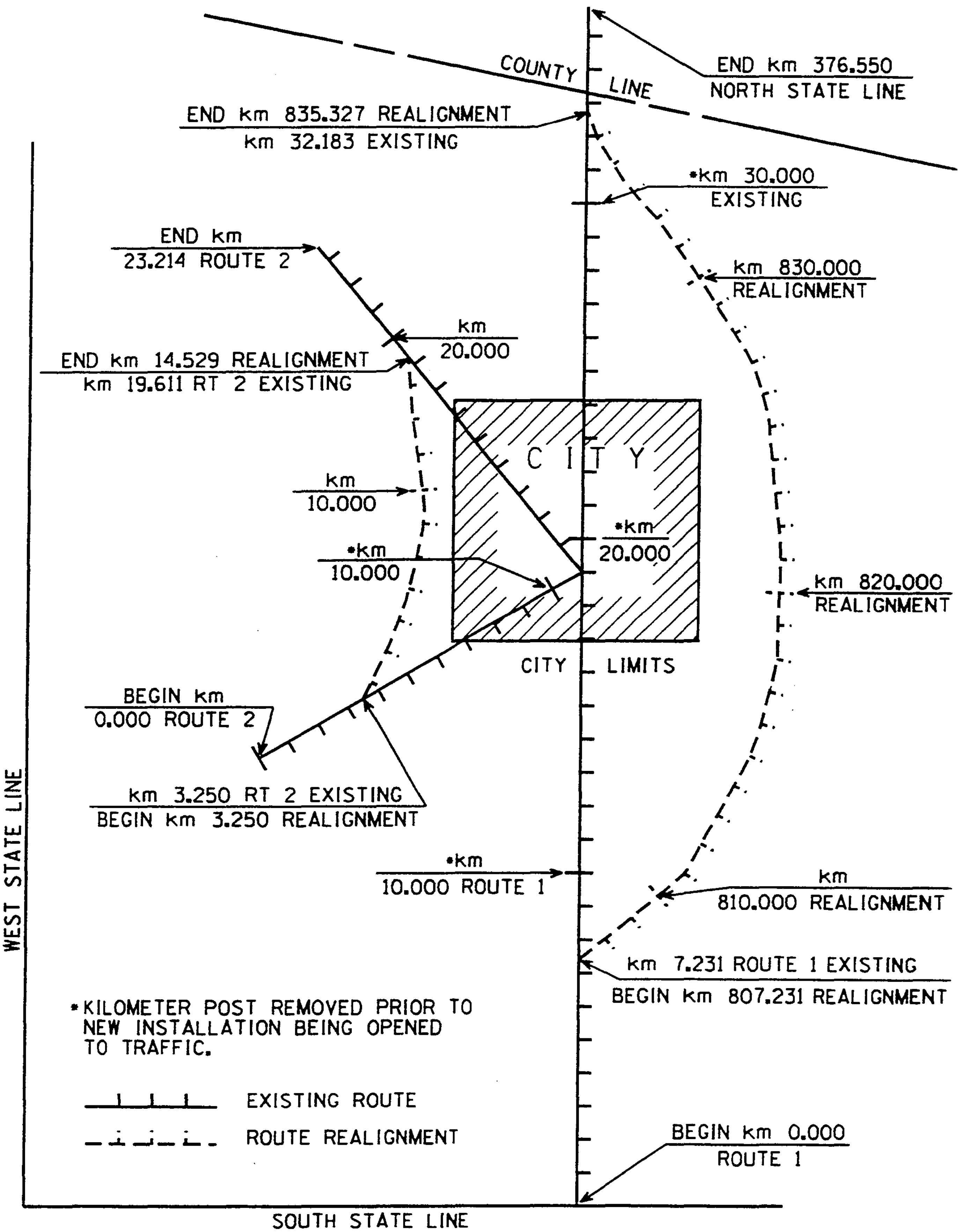
2.4.5

EXHIBIT "B"



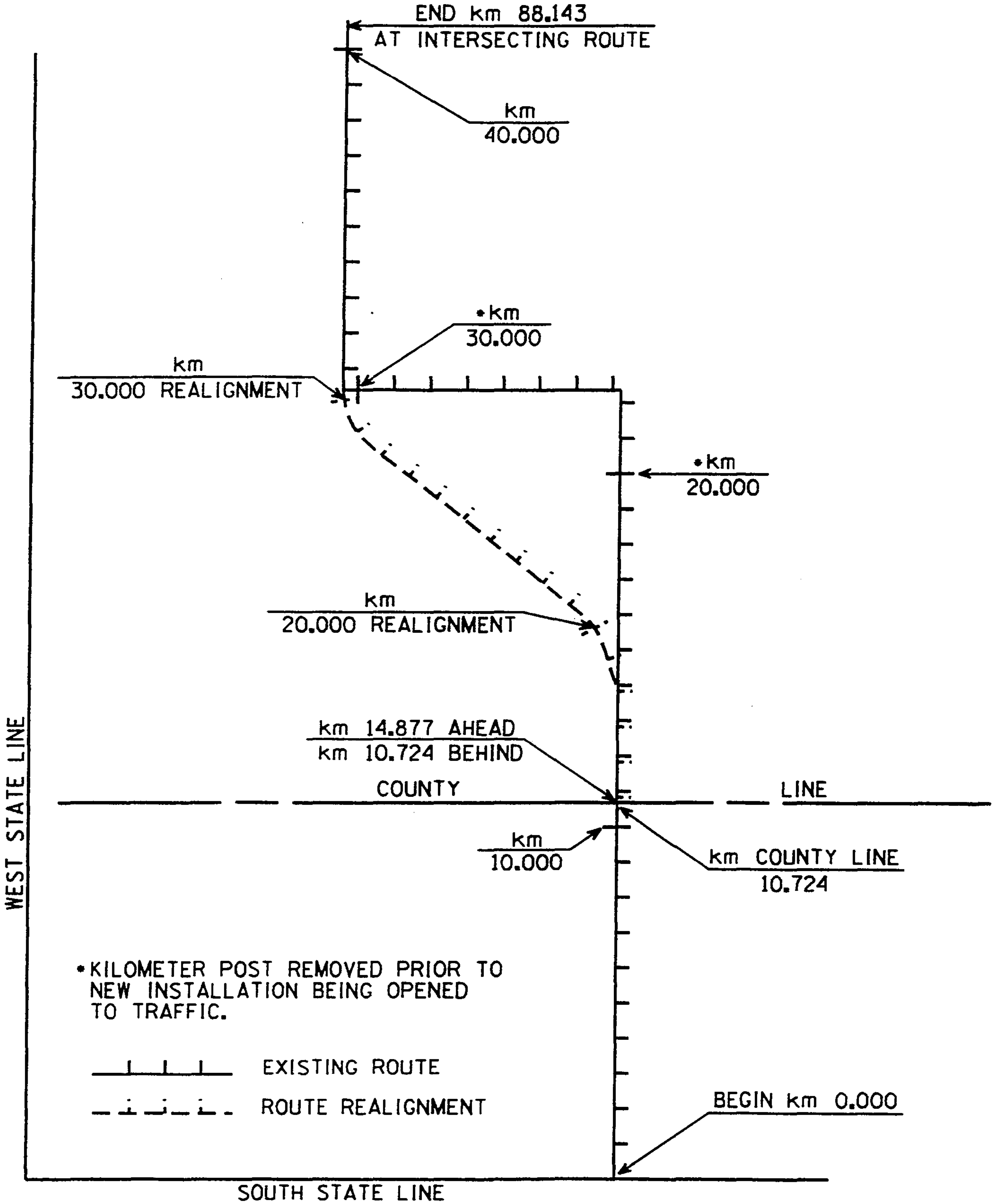

EXAMPLES OF ROUTE REALIGNMENT
WITH NO LOCAL TAKEOVER OF FORMER ROUTE

EXHIBIT "C"



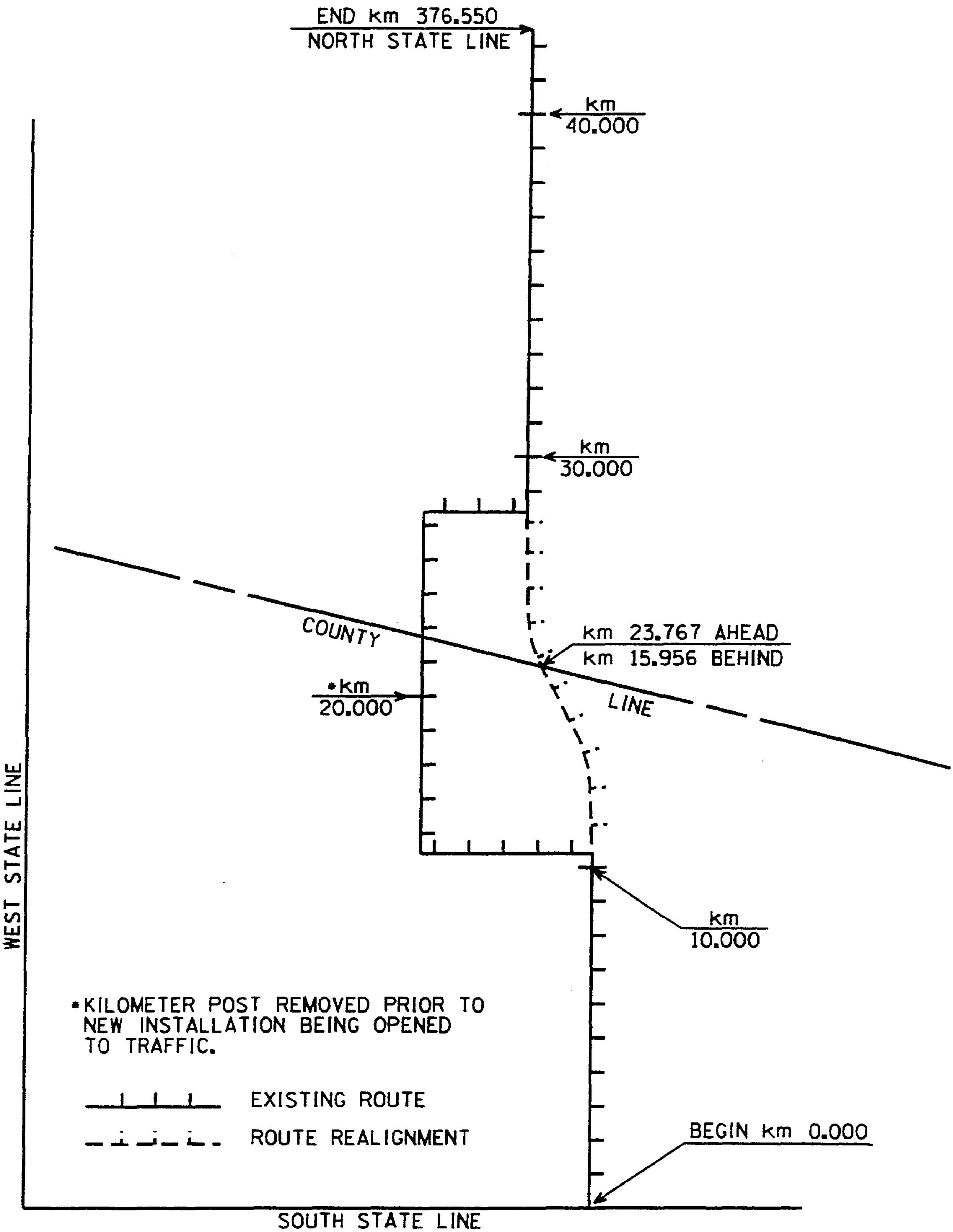

EXAMPLES OF ROUTE REALIGNMENT
WITH LOCAL TAKEOVER OF FORMER ROUTE

EXHIBIT "D"



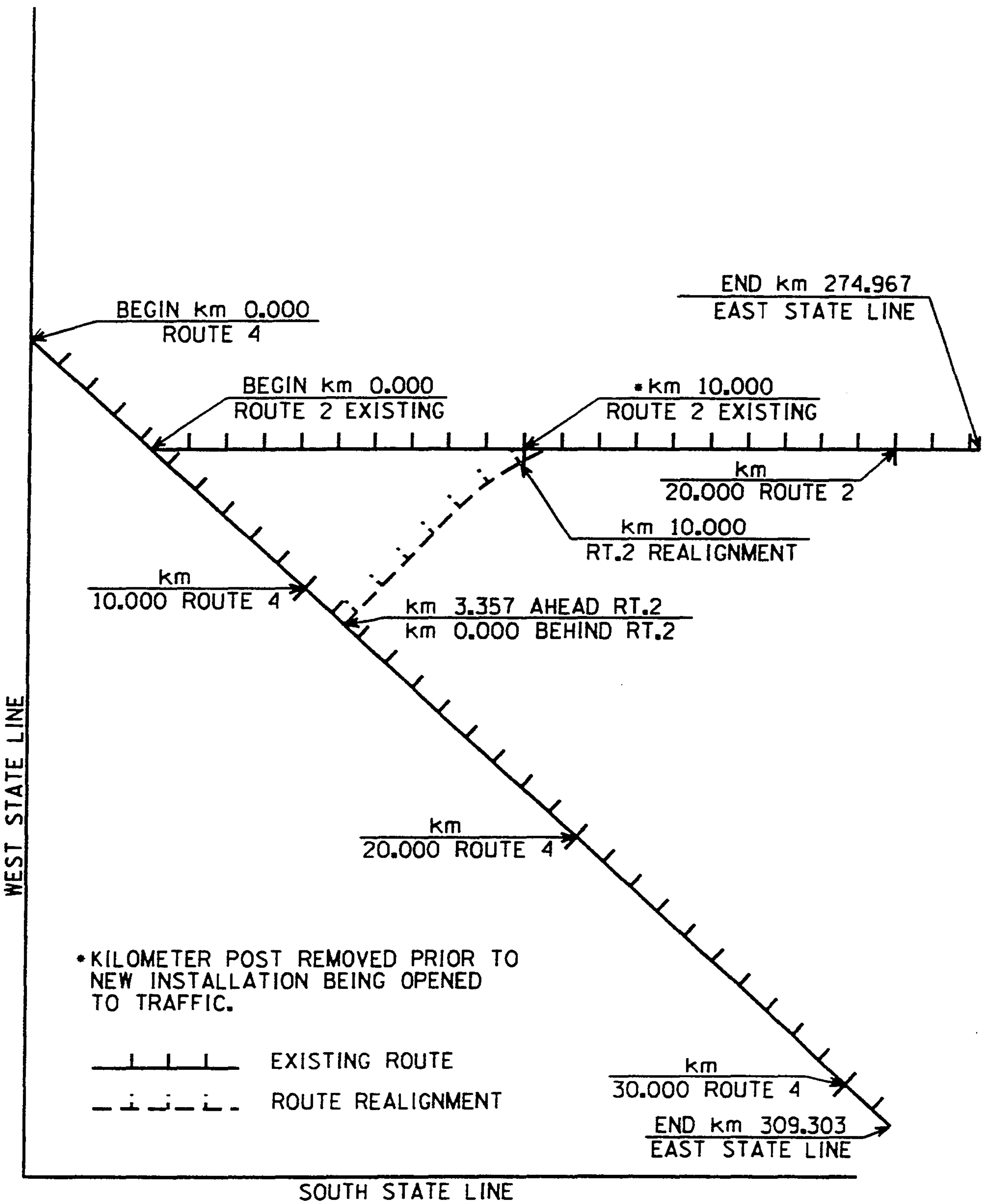

EXAMPLES OF EQUATION PLACEMENT FOR ROUTE REALIGNMENT
WITH LOCAL TAKEOVER OF FORMER ROUTE

EXHIBIT "E"




EXAMPLE OF EQUATION PLACEMENT FOR ROUTE REALIGNMENT WITH LOCAL TAKEOVER OF FORMER ROUTE

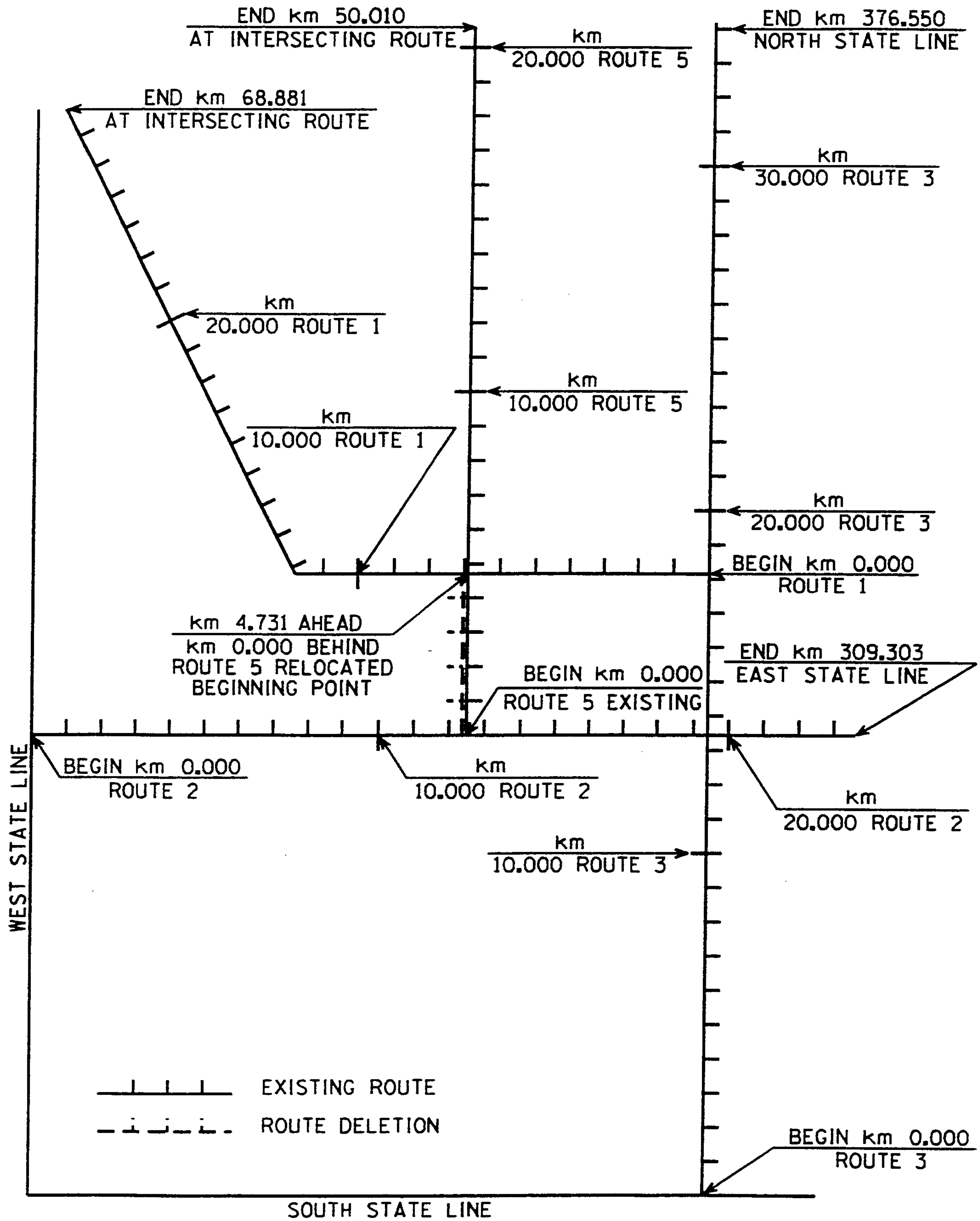
EXHIBIT 'F'




EXAMPLE OF EQUATION PLACEMENT FOR ROUTE REALIGNMENT
WITH LOCAL TAKEOVER OF FORMER ROUTE

2-4-10

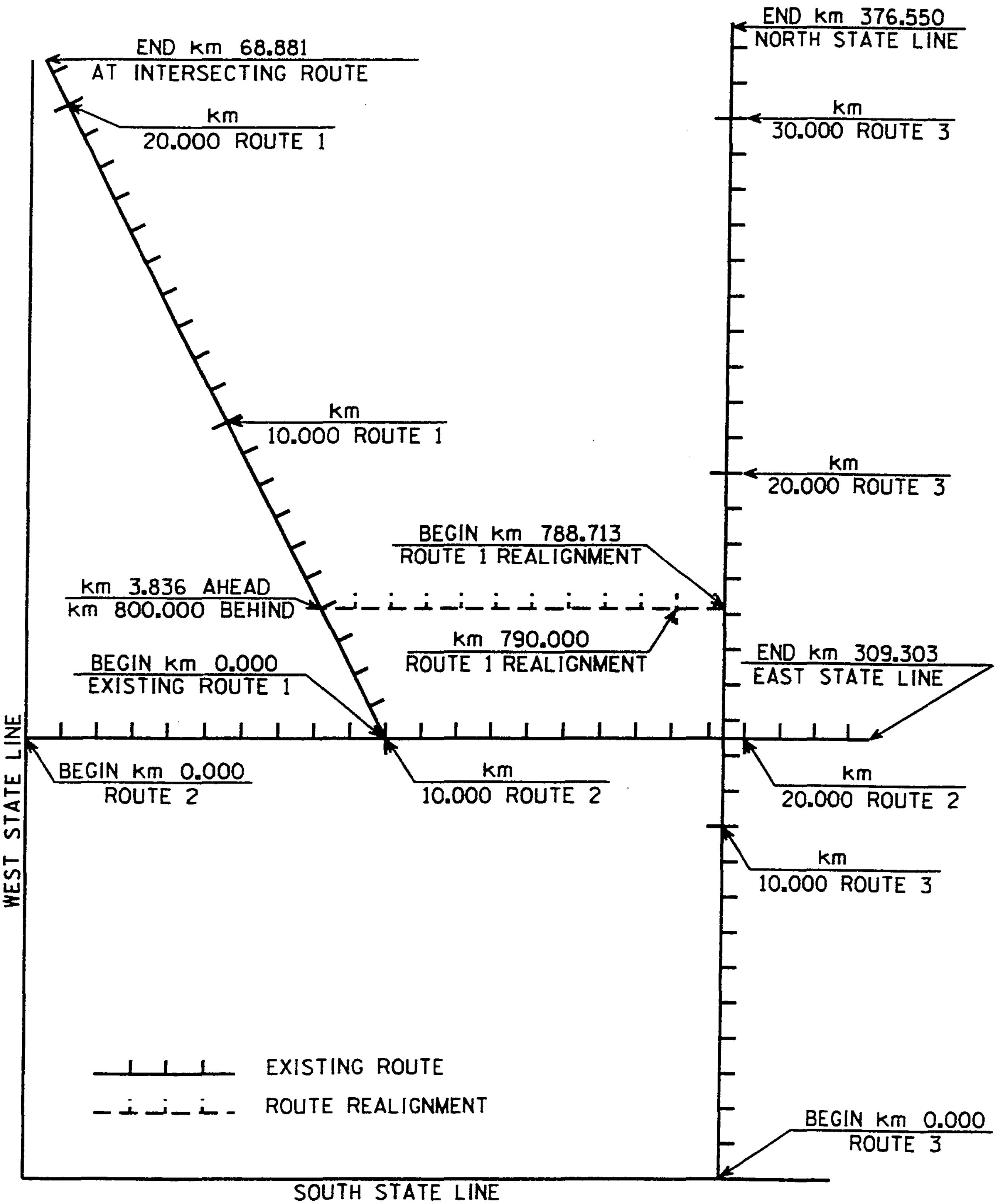
EXHIBIT "G"




EXAMPLE OF EQUATION PLACEMENT
FOR ROUTE SHORTENED AT BEGINNING

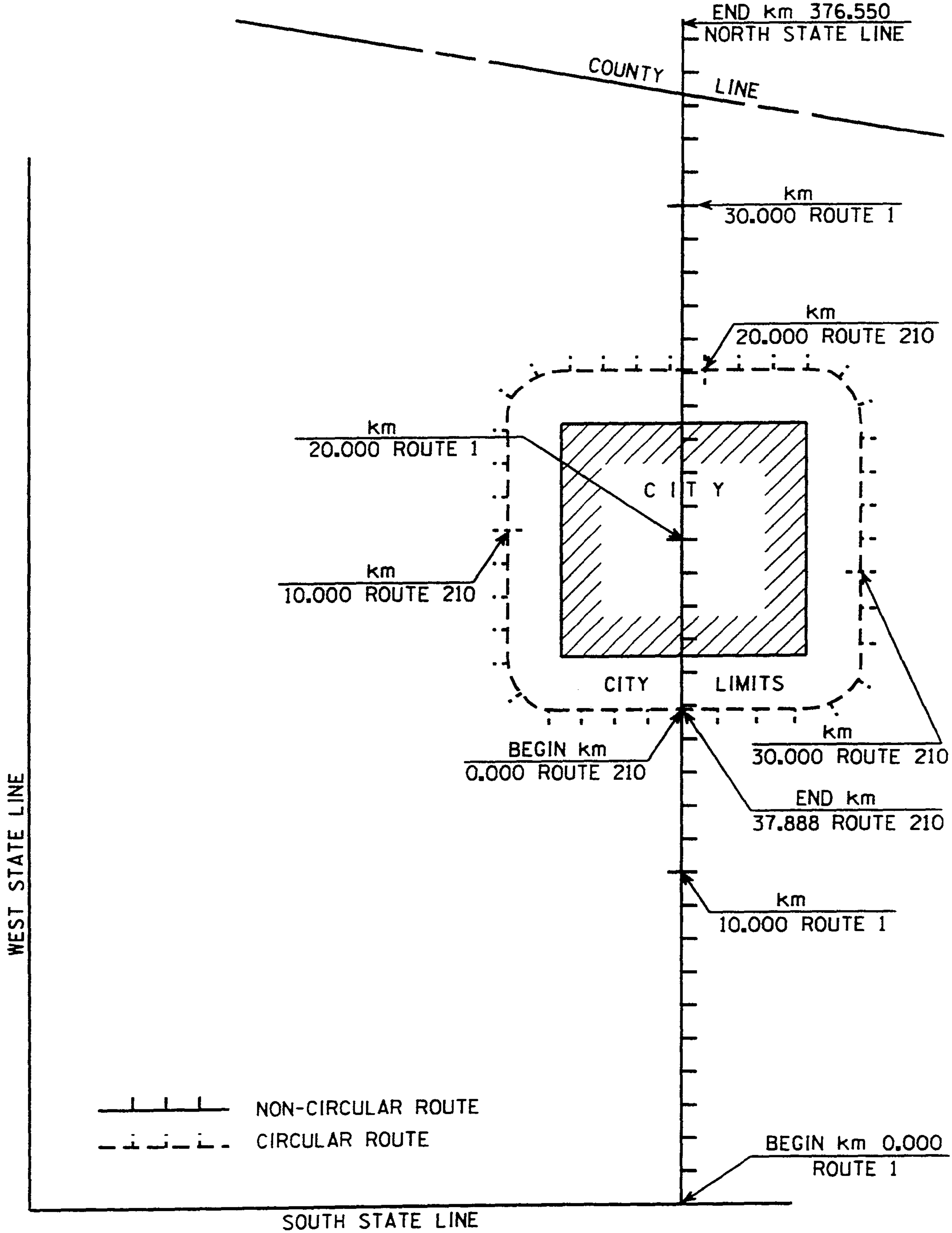
2-4-11

EXHIBIT "H"



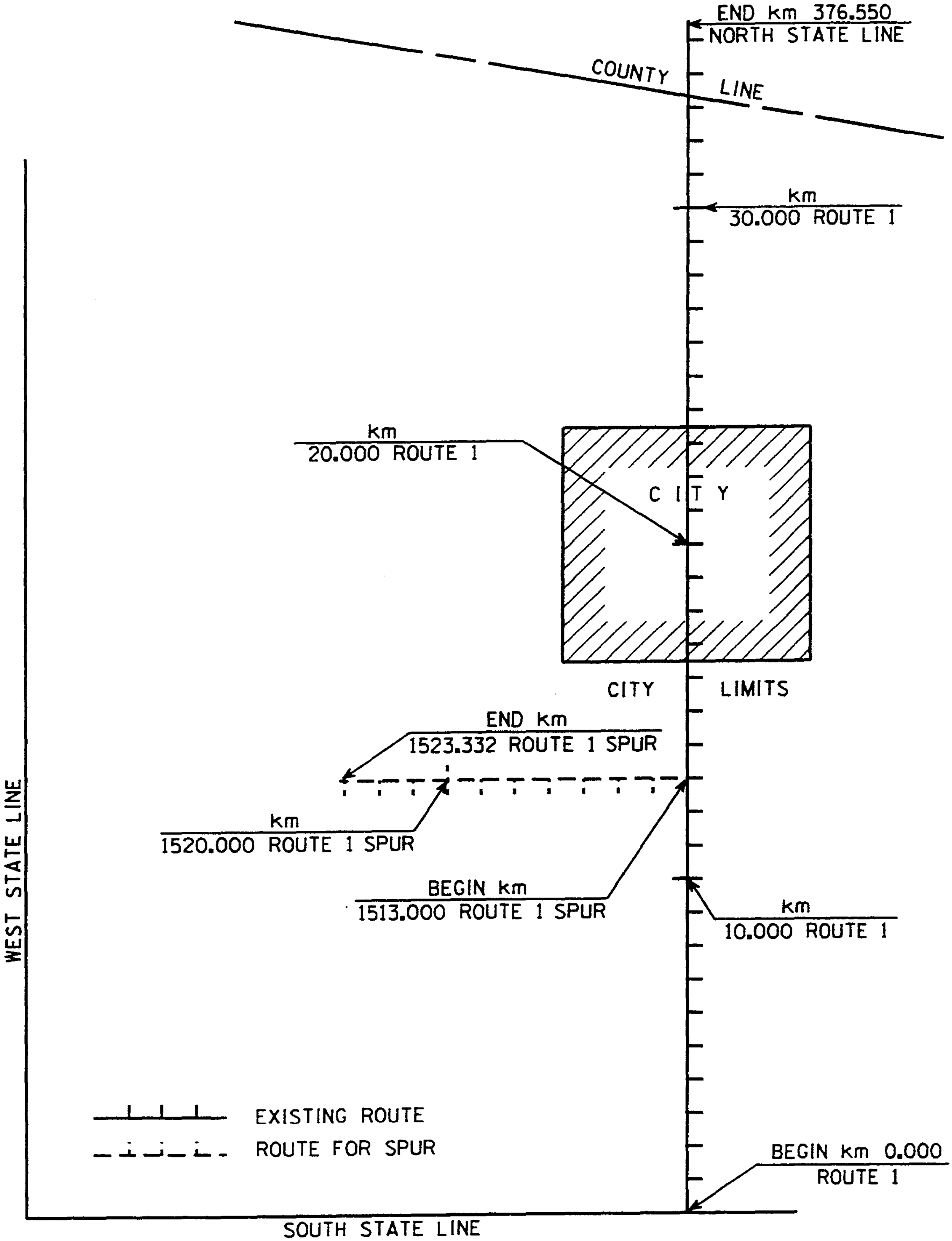

EXAMPLE OF EQUATION PLACEMENT FOR ROUTE REALIGNMENT WITH LOCAL TAKEOVER OF FORMER ROUTE

EXHIBIT "I"



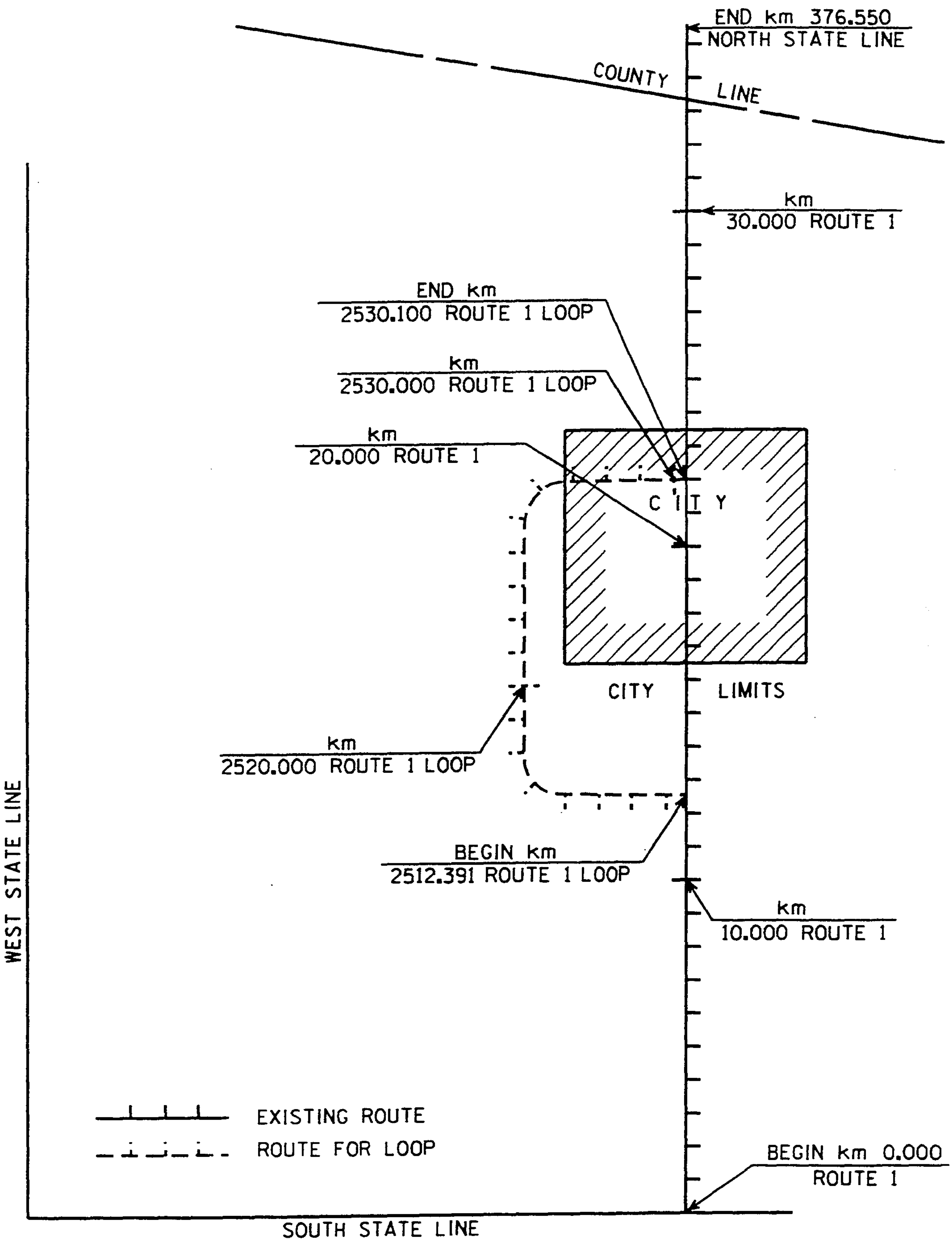

EXAMPLE OF CIRCULAR ROUTES

EXHIBIT "J"




EXAMPLE OF ROUTE SPURS

EXHIBIT "K"




EXAMPLE OF ROUTE LOOPS