AN ALTERNATE KEY FOR A STATEWIDE HIGHWAY INFORMATION RETRIEVAL SYSTEM FOR THE STATE OF TEXAS

by

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Dear Professor Greer:

I have the pleasure to submit my report, "An Alternate Key For a Statewide Highway Information Retrieval System For the State of Texas," as a partial requirement for CE 391G. This report outlines the procedure for the development of an alternate common base of reference for a statewide information retrieval system.

Your list of suggested term paper topics contains many unsolved problems related to highway administration and finance. My chosen topic is unique in that it is an attempt to solve a problem confronting the Texas Highway Department in connection with the development of a statewide information retrieval system, a problem that has plagued many state highway agencies in similar circumstances.

I appreciate the opportunity of undertaking a project of this nature and trust that the findings and guidelines of this report will be of some value to the Texas Highway Department.

Respectfully submitted,

Francis Yu

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FOREWORD

The Planning Survey Division of the Texas Highway Division, in coordination with Districts and other Divisions, is now seeking a common base of reference for use in data management in anticipation of the development of a data file system. The Center for Highway Research is interested in such a common reference base as a direct consequence of involvement with the pavement feedback data system (PFDS).

In a similar situation, development of the highway information system (HIS) for the state of Montana which is now fully operational in a direct-access environment, a systems analyst now at the Center created a fictitious milepost system to reference data in a record. Adoption of a similar concept as an approach to development of an alternate common base of reference for use by the Texas Highway Department is considered desirable.

This proposal is written for perusal by management, and generally, technical details are omitted. The cooperation of and the supplying of relevant information by the Planning Survey, Maintenance, Design, and Finance Divisions are gratefully acknowledged.

INTRODUCTION

An all-purpose and unique common base of reference for accessing files is of interest to many state highway agencies because of changing methods of data coding and storage. Over the years data storage modes have changed from unit record to card and from card to magnetic tape, and now the trend is from magnetic tape to direct storage access devices (DASD), such as a disk, drum, and data cell. With the change of storage mode a corresponding modification of referencing data is made to utilize the new device better in terms of access and efficiency. Transitions to new data coding methods are troublesome, and development and adoption of a uniform method for coding a common reference base for use by all Texas Highway Department Divisions is of primary importance.

Most Planning Survey Division (D-10) files, which are the main source of Texas highway information, are sequential files on tapes. To convert these files and others, such as those of Maintenance (D-18), Design (D-8), and Finance (D-3), to direct access files in order to form a statewide coordinated information retrieval system would require a common base of reference for inter-referral. A search for such a common base is now underway within the Department.

This proposal outlines an alternate common reference base for consideration by the Texas Highway Department.

A long-range, rapid-access information retrieval environment has been considered, and simplicity and ease of implementation are emphasized. This common base of reference is an important tool for tying together decentralized data files, such as those in the THD, and this is an important factor in management control.

DATA MANAGEMENT

Generally, highway data, which are varied and extensive, can be classified as

(1) physical data, such as locations of bridges, interchanges, culverts, and railroad crossings; pavement types and materials; thicknesses; and median width;

(2) areal data, i.e., geographical and judicial boundaries of an area such as a city or a county;

(3) administrative and cost data, i.e., federal aid codes and construction and maintenance costs associated with the highways; and

(4) event data, such as average daily traffic, service volumes, and classification of accidents.

Along a highway, the points at which data characteristics change (Fig 1), must be recorded relative to one another. These breaks, and the lengths between them, are not the same for all classes of data or for all users. Each break is a record in data processing, and a collection of records is a file. In a coordinated file system, all files are equal in rank or order and represent various classes of highway data.

Files currently maintained by D-10 are

(1) State Highway System (RI-2),

(2) County Road System (RI-6),

(3) Bridge Log,

(4) Traffic Log,

(5) Accident Data,

(6) Road Life,

(7) Railroad Crossing Data, and

(8) City Street Mileage Summary.

Other files, such as Maintenance, from D-18; Skid Resistance, from D-8; Cost Items, from D-3; are also distinctly different.

For inter-referral purposes, i.e., for one file to access one or more other files, it is necessary to be able to tie the separate files together.

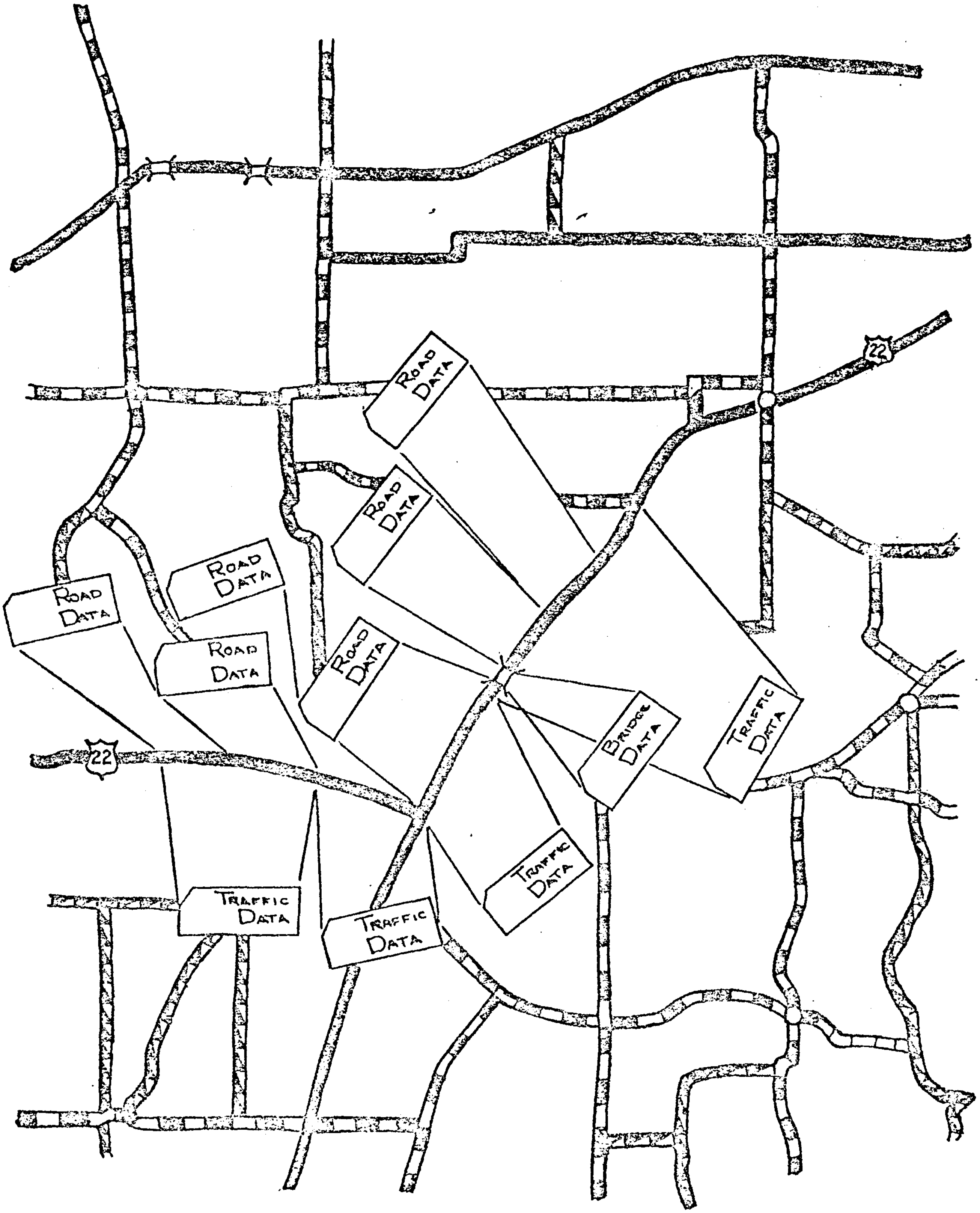


Fig 1. Storing Roadway Information as it Exists (After Blessing, Ref 2).

This can be done easily by relating all data records to a common base of reference. This is known as a key, which is a concatenation of the variables that uniquely define a record. A record contains all the data associated with a particular key. In a direct access file each record is identified by a key and the file is resident on a direct access storage device (DASD). In a DASD, each physical record has a discrete location and a unique address. Records are stored in such a way that any record can be accessed directly instead of serially as in sequential files files on tape. This concept of storing and retrieving is very adaptable to a coordinated information retrieval system, which many divisions of the THD, including D-10, are considering for use in the near future.

The THD is currently using two fast and large IBM 370/155 computers and will replace the 2314's with 3330's DASD. The THD programming staff is among the most capable of any highway department. Converting the sequential files into direct access files is a minor process, but adopting a uniform coding procedure for the key will require tremendous coordination. D-10 has developed a workable coding method and is coordinating with other Divisions to achieve its adoption. This method is reviewed here and an alternate method is suggested.

PROPOSED D-10 KEY

Wright (Ref 1) suggested that the common base of reference for a statewide data base in Texas include the county, control section number, and beginning and ending milepoints. The key would be a concatenation of these variables to form a unique string to define a record.

In an indexed sequential access method (ISAM), the records in a file are organized on the basis of a collating sequence determined by the keys that precede each record. An ISAM file exists in space allocated on a DASD as the prime area, the index area, and the overflow area. In the prime area, records are written when the file is created or reorganized, and the keys are imbedded in the records. The index gives the location of a record, and the index area is created and written by the operating system of the computer when the file is created or reorganized. The overflow area provides additional storage for use when the prime area becomes full.

ISAM, because of its ability to refer to indexes associated with the file, makes it possible to quickly locate individual records for random data processing. In updating, the system locates the proper position in the file for a new record and makes all necessary adjustments to the indexes. ISAM is very suitable for the information retrieval type of application.

Records from RI-2 are shown in Fig 2.

The D-10 method is an extension of the Texas Highway Control Section Numbering System, which was inaugurated in 1935. It is primarily a system of recording highway expenditures pertaining construction and operation of highway facilities. It includes:

(1) Control numbers, which define specific sections of highway with well-defined geographic termini; and

(2) Control sections, which define portions of a control number with well-defined geographic termini within the established limits of the control number.

Originally, the controls and sections were set up in numerical sequence from west to east and from north to south. Control section termini were established at the beginning and ending points of previously designated state and

District Number, County Number, Control, Section Number, Beginning Milepoint, Ending Milepoint, Highway Status, Administrative System, Federal Aid System, In Federal Reservation, City Number, Right of Way Width, Road Bed Width, Surface Width, Base Type, Shoulder Type, Surface Type, Etc.

10	0013019010000001619	10102000000001000280204095 10102	
10	0013019010161902415	10102000000001000280204095 10102	0102
10	0013019010241503352	10102000000001000280204095 10102	0102
10	0013019010335204892	10102000000001000280204095 10102	
10	0013152010000000831	10108000000001200380244015 10102	
10	0013152010083100866	10208003165001200380244015 10102	
10	0013152010086601394	10108000000001200380244015 10102	0101
10	0013152010139401559	10208003165001200380244015 10102	
10	0013152010155901743	10208003165000700480484095 10102	
10	0013199010000001639	10100000000001000280204095 10102	
10	0013199010163902133	10100000000001000280204095 10102	
10	0013199010213302913	10100000000001000280204095 10102	
10	0013199010291303448	10100000000001000280204095 10102	0103

Fig 2. Listing of records from RI-2.

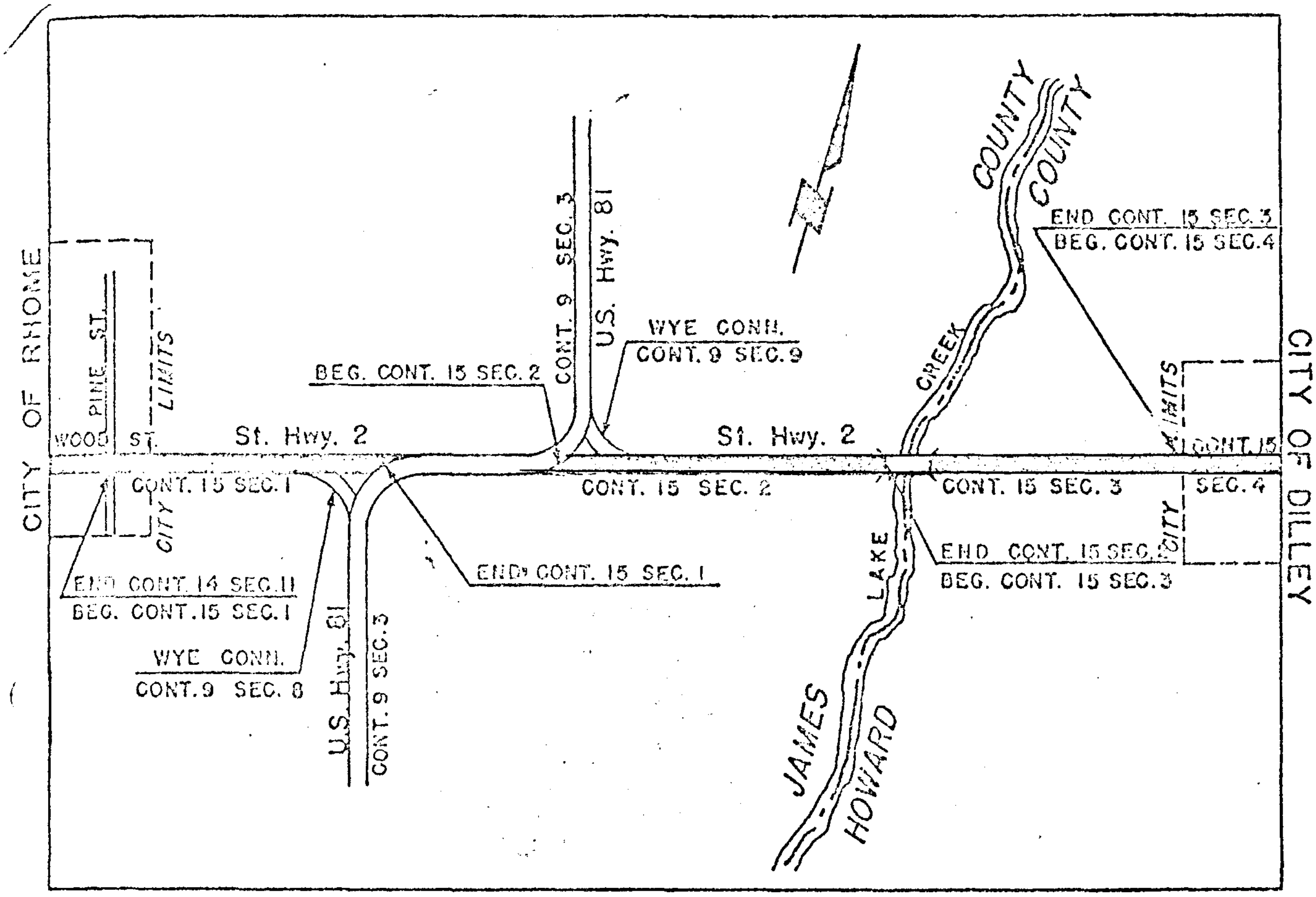


Fig 3. Control numbering system for highways in Texas.

federal project limits, at county lines, intersecting routines, major stream crossings, city limits, city street intersections, etc. (Fig 3).

At present, controls and sections are added to the system as needed to cover new highway designations, as proposed in the various programs of work. There is no longer a numerical sequence of control sections, because different periods of construction were used for different sections of highway.

The D-10 key is prefixed by a county number and suffixed by the beginning and ending milepoints. These milepoints are correlated between existing data records and straight-line diagrams; milepoints start at the state line or the starting points of the routes. These milepoints are not to be confused with the mileposts seen on most Texas highways, which are actual wooden posts or metal plates mounted on standard delineator posts to assist drivers in estimating progress and in orienting themselves, to provide means for identifying the location of emergency incidents, and generally to aid in the operation of the highway. Actual locations of mileposts are shown on straightline diagrams, as in Fig 4.

The D-10 method of coding the key is syntactically sound; keys in an ISAM file are arranged in collating sequence and are left-justified, i.e., they are collated from left to right. Therefore, the coupling of the beginning and ending milepoints as part of the key is redundant. Under the present coding system, the beginning milepoint of a given section is not necessarily the ending milepoint of the previous sections, e.g., when a milepoint is zero at the start of a new section, but in terms of collating sequence, the beginning milepoint is sufficient to identify a record. The ending milepoint can be included in the data in the record. A key should be kept as simple as possible.

Using this scheme to determine the total length of highway with pavement thickness less than 7 inches between Austin and Giddings on U. S. 290, it is necessary to know the keys (county, control section number, and beginning and ending milepoints) of the two city limits to start scanning the RI-2 file. The Travis County Numbers involved are 227, Bastrop, 11, and Lee, 144, which are not in numerical order as far as U. S. 290 is concerned. Because of this constraint, the computer will scan Bastrop County first, Lee next, and Travis last, and this will require three separate keys (instructions) as to where to stop and where to branch out in searching. To an average user, who is not familiar with the control numbers and section numbers, communicating with the computer will be quite a task.

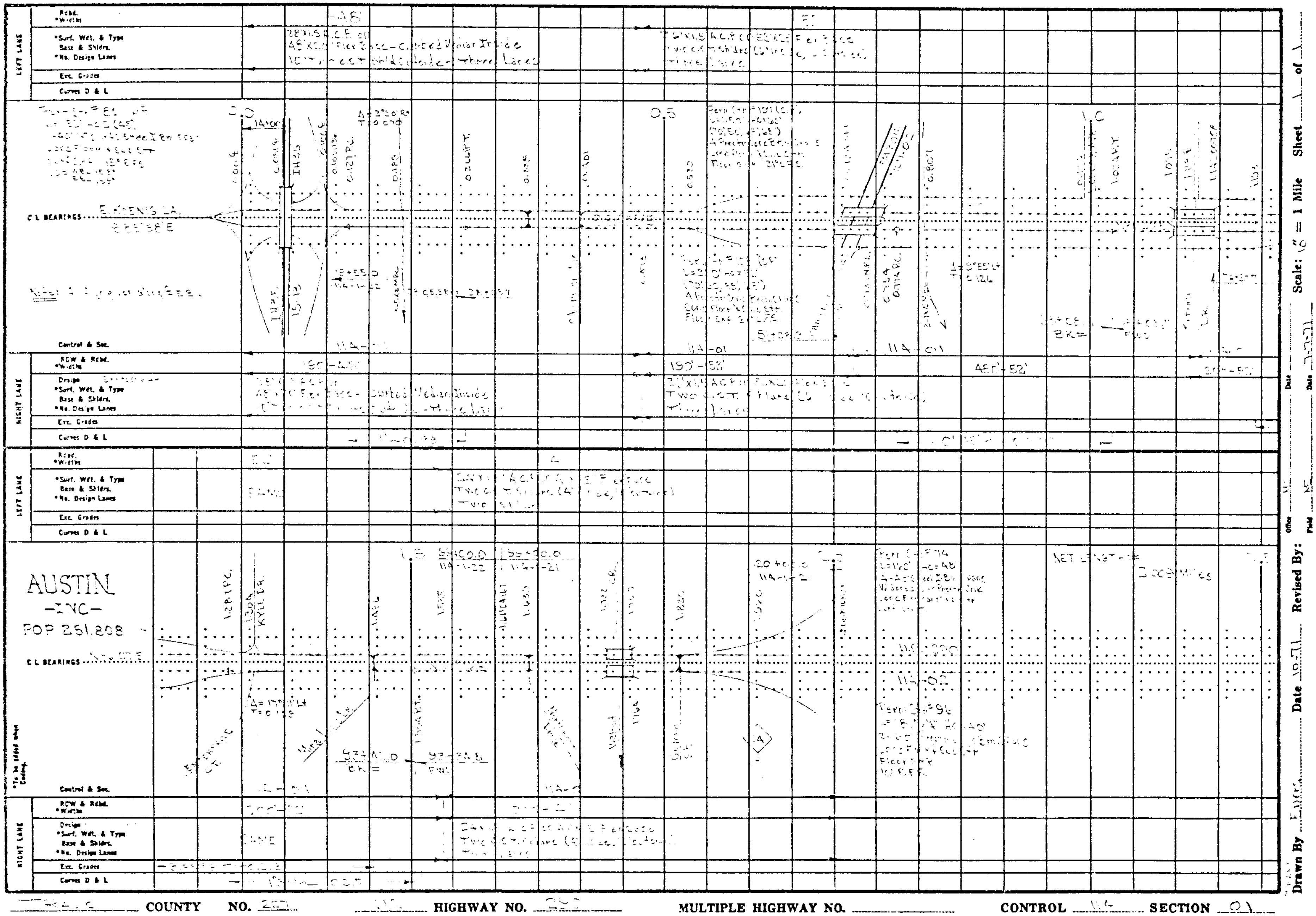


Fig 4. Straightline diagram showing actual locations of mileposts.

PROPOSED ALTERNATE KEY

Attributes desirable in a reference system are that it

(1) be simple to use in both the office and field,

(2) have a relatively short code,

(3) have a meaningful code without elaborate references,

(4) be absolutely unique for each piece of roadway,

(5) be readily compensating for changes in route identification and length, and

(6) be constructed from a rational sequence or progression.

The key proposed as an alternate is a concatenation of three variables that will uniquely define any section of highway. They are

(1) the highway system,

(2) the highway administrative number, and

(3) a reference milepoint.

Presently there are ten highway systems. Their codes are

(1) U. S. Highway,

(2) State Highway,

(3) State Loop or Spur,

(4) Park Roads,

(5) Farm or Ranch to Market,

(6) U. S. Alternate,

(7) State Alternate or Temporary Route,

(8) Interstate Highway,

(9) Farm or Ranch to Market Spur, and

(0) U. S. Highway Spur.

The proposed key does not preclude any code number, e.g., an urban highway could have a code of 11.

It is understood that with the control and section numbering system used in the D-10 key, there is no need for such a hierarchy of highway systems because the control number for a section of highway is unique.

The concept of a coordinated file system prohibits unnecessary duplication of data. For a coincident section, there will be a question as to which route will carry the data, and this necessitates a hierarchical arrangement of highway systems. An arbitrary but logical arrangement is

(1) Interstate,

(2) U. S.,

(3) Texas, etc.

In the event of a coincidence between two highways of the same system, a lower numbered route can be arbitrarily given priority over a higher numbered route; e.g., if U. S. 10 is coincident with U. S. 29 over a certain section of the highway, data will be found in U. S. 10. This can be done with a flagging technique in computer programming.

The changing of highway numbers may cause unforeseen trouble in updating. One possible solution is to maintain the normal highway numbering system. Reorganize the entire file once a year, but prior to annual updating, reserve a copy of the file on tape as a historical record. With ISAM, frequent updating will lead to inefficient access of files. The THD now has a package called AMIGOS which is intended to functionally replace ISAM and carries out the updating procedures more efficiently.

A second solution to the problem of changing highway numbers is to establish a basic number for each highway. This number could be used internally in a program or externally in the office if it proves to be efficient. In Montana, a federal aid number is associated with each highway. In Missouri, corridors across the state, formed using latitudinal and longitudinal coordinates, are given numbers. The number of the corridor where a route begins in the state is used to get a basic route number. Certain reference milepoints along the route are associated with the basic route number in a control file. These points are equated with the current route number and the current milepoints for those points. Initially, the milepoints for both basic and current numbers on the same route are the same. As changes are made in the length of a route, the basic milepoints will equal a different current milepoint. The same kind of equality occurs with the basic and current route numbers.

A record is coded for entry into a data file by identifying current route number and current milepoints. The updating program converts this identification into the basic route number and basic milepoints from the control file and enters the record into the data file with basic identification. Data are retrieved from the file in the same manner.

The advantages of the Missouri method are

(1) Only one file is to be updated with changes in route lengths and numbers.

(2) Regardless of current milepoints and route designation changes over the years, data are stored and retrieved for the same section of a roadway. This is illustrated in Fig 5.

The Reference Milepost

The reference milepost can be considered as a modification of the existing milepost system currently used by the THD. Unlike the existing milepost, which starts at every county line, this reference milepost would start at the beginning of each route, and continuity would be maintained in a south-to-north or a west-to-east direction.

These reference mileposts would be erected at intervals of 2 miles, except on Interstate highways which are mileposted at 1-mile intervals. These posts would not necessarily be exactly 2 miles apart. Associated with each erected milepost along a highway would be the accumulated mileage to that point from the beginning of the route (see Fig 6). In effect, the new procedure would convert the as-built milepost system to a reference milepost system without physically relocating the present mileposts.

A table of integer mileposts with their corresponding accumulated mileages could be generated and stored as an auxiliary file for computing distances between two reference mileposts.

Integer Mileposts	Accumulated Mileages
0	0.000
1	1.000
2	2.000
3	3.000
4	4.000
5	5.000
6	6.000
7	7.000'
8	7.821
9	8.821
10	9.821
11	10.821
12	11.821
:	:
18	17.821

Key for county line is US0290007821
Key for A-A is US0290010751

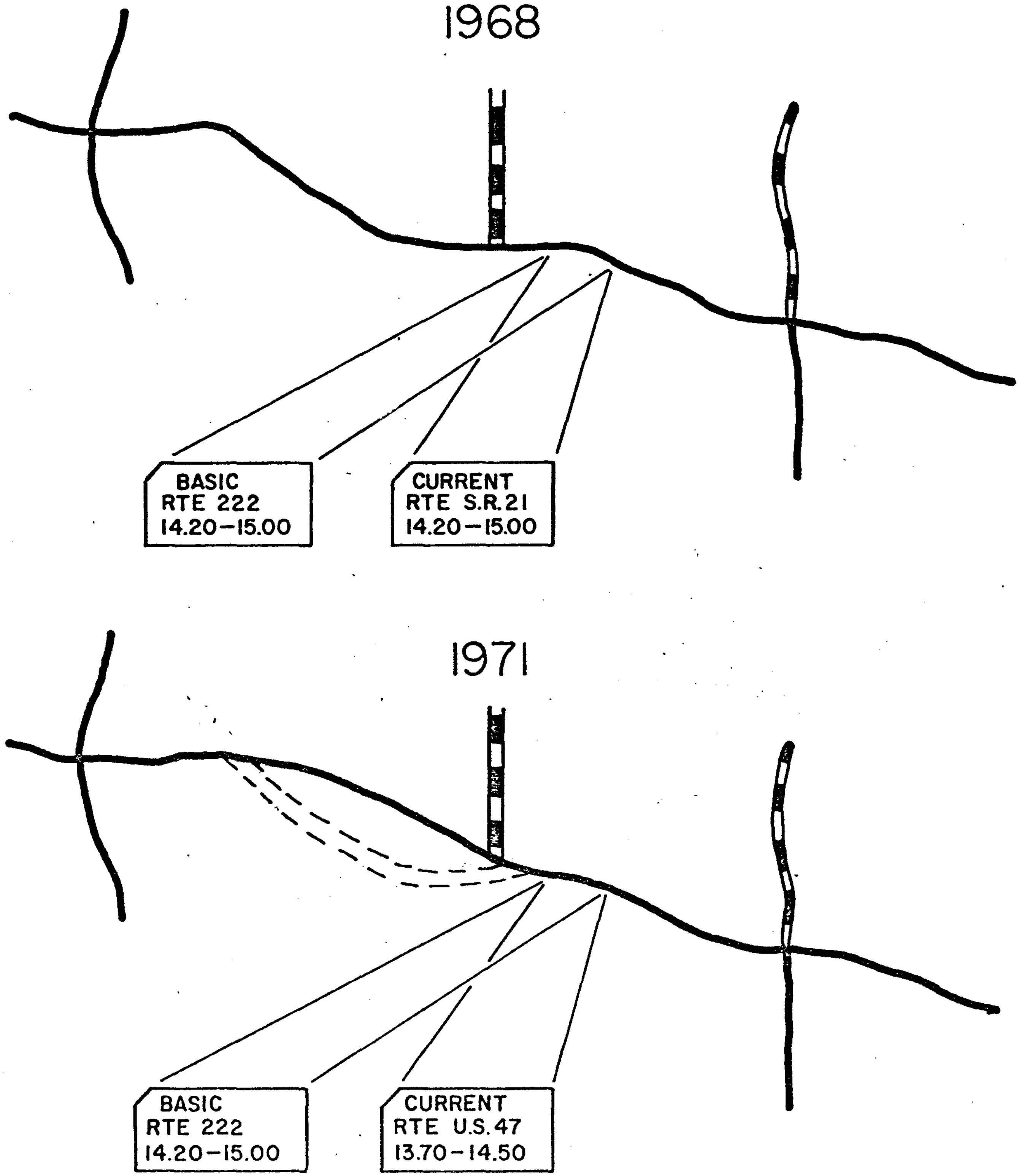


Fig 5. Basic and current identification before and after route and construction changes.

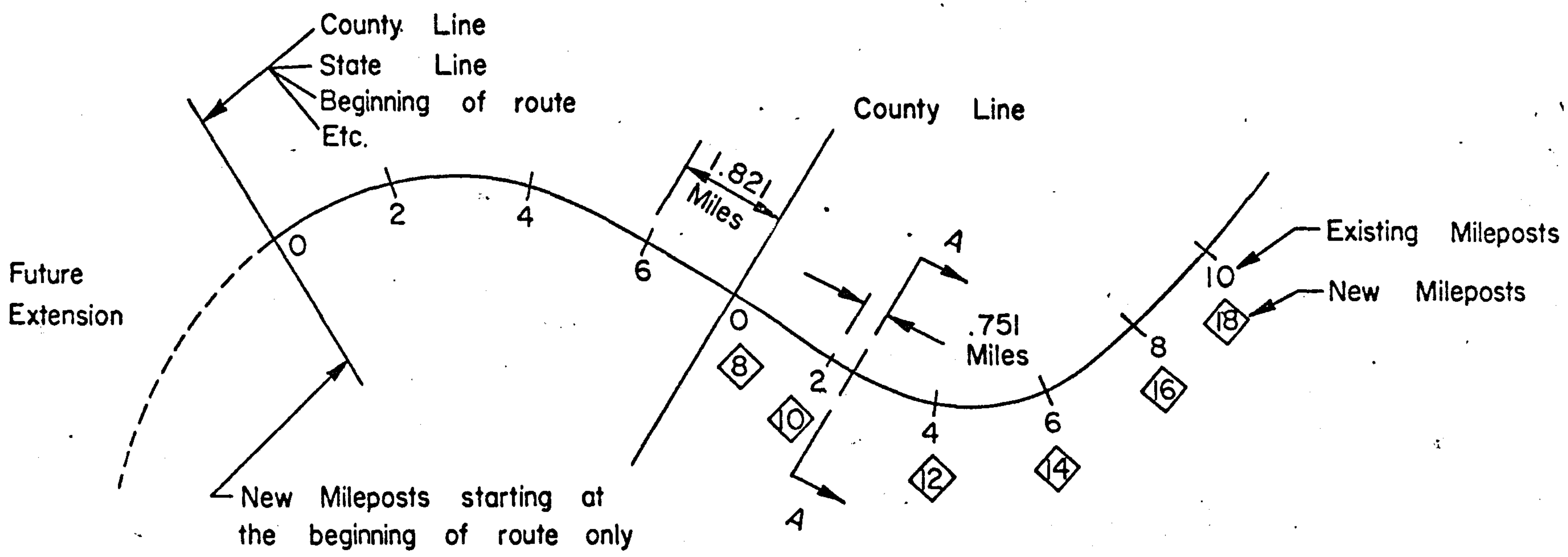


Fig 6. The proposed reference milepoint system.

Internal conversion table by program:

Reference milepost	7		7.000
Fraction	.821	=	.821
Accumulated mileage	7.821	=	7.821
Reference milepost	10	=	9.821
Fraction	.751	=	.751
Accumulated mileage	10.751	=	10.572
Less			7.821
Difference			2.751

Shortening or Lengthening of an Alignment. Figure 7 shows shortening of an alignment .247 mile long. The section starts at reference milepoint (RMP) 2.213 and ends at RMP 3.781. The RMP for point A located at .800 mile from RMP 2.213 along the shortened alignment is needed. The procedures are shown below.

The adjusted accumulated mileages:

Integer Mileposts	Accumulated Mileages	
0	0.000	
1	1.000	
2	2.000	
3	2.753	= 3 - .247
4	3.753	

Again, the program will convert the reference milepost to the true length:

Reference milepost	2		2.000
Fraction	.213	=	.213
Accumulated mileage	2.213	=	2.213
Reference milepost	3	=	2.753
Fraction	.781	=	.781
Accumulated mileage	3.781	=	3.534
Less			2.213
Difference			1.321

which is true length of the newly aligned section.

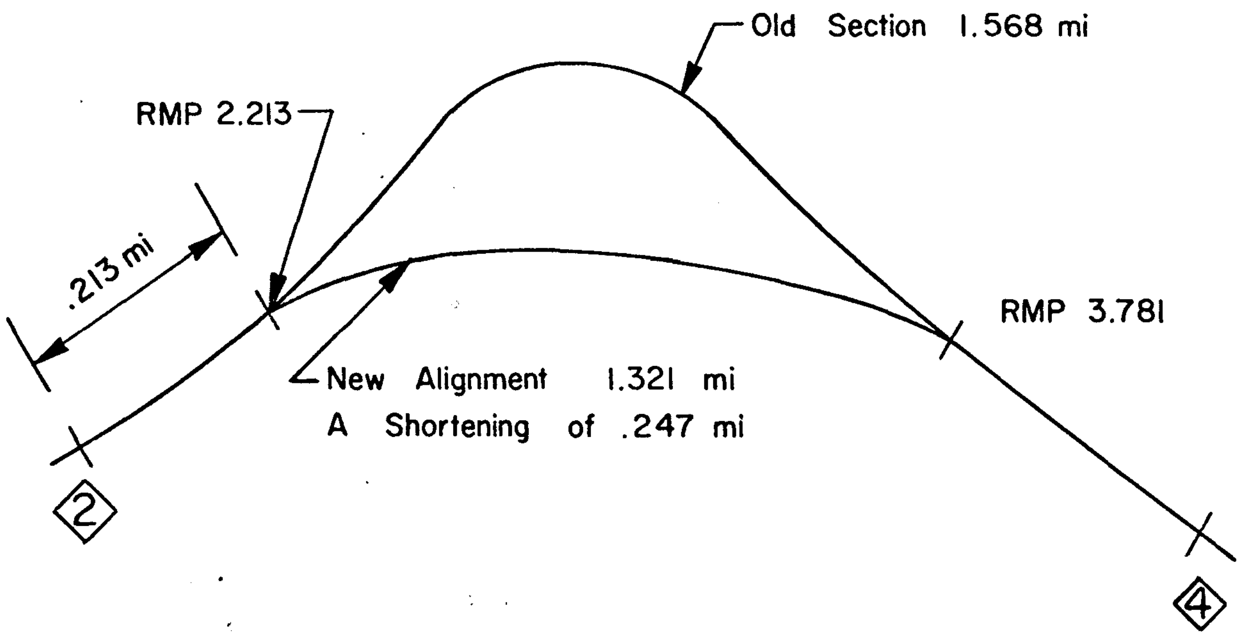


Fig 7. Old alignment.

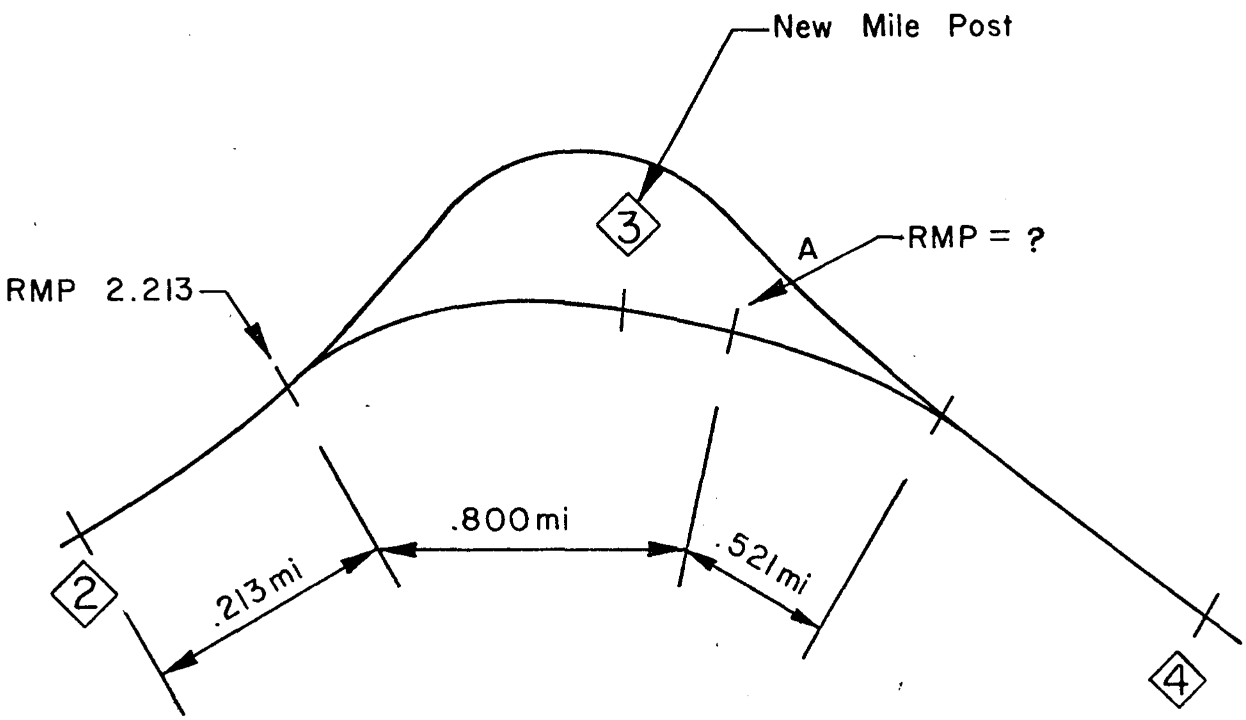


Fig 8. New alignment.

Although the present mileposts are spaced at even-mile intervals, an intermediate odd milepost is needed to prevent "over" referencing. This problem is illustrated in Fig 8.

If the odd milepost is not erected, the break according to the odometer is .213 + .800 or 1.013 miles from milepost 2; using the convention described, will give point A reference milepoint 3.013.

Repeating the table conversion program:

Reference milepost	3		2.753
Fraction	.013	=	.013
Accumulated mileage	3.013	=	2.766
Reference milepost	3	=	2.753
Fraction	.781	=	.781
Accumulated mileage	3.781	=	3.534
Less			2.766
Difference			.468 ≠ .521, as shown.

If milepost 3 is to be erected .753 miles from milepost 2, then point A will be at reference milepoint 3.260.

Reference milepost	3	=	2.753	
Fraction	.260	=	-.260	
Accumulated mileage	3.260	=	3.013	
Reference milepost	3	=	2.753	
Fraction	.781	=	.781	Check
Accumulated mileage	3.781	=	3.534	.800
Less			3.013	.521
Difference			.521	1.321

The reverse is true for lengthening of the alignment, which rarely happens.

Note that this method is only applicable to mileposts spaced 2 miles apart. In the interstate system where the mileposts are spaced at 1-mile intervals, shortening or lengthening of the roadway can best be done by reorganization of the internal accumulated mileage program.

Future Extension of Highway. Occasionally, a future extension is added to the beginning of a highway which has already been mileposted zero. This extension will create confusion with what is commonly known as the "negative milepost" dilemma. There are two practical solutions to this problem, depending on the circumstances:

(1) For an unposted route, designate the first milepost of the beginning of the existing highway to be an adequately large even integer to allow for future extension; e.g., if the future extension is to be 5.145 miles, then designate the milepost 0 as 6.

It is feasible, though not practical, to create negative mileposts both physically in the field and internally in a computer. This effort would only add confusion.

Flexibility of the Key

Currently the lengths of Y connections, ramps, and loops are not included in RI-2 file. The proposed alternate key offers great flexibility for inclusion of these items, if ever required, by a simple concatenation of an extra field to the key. Figure 9 is a Parclo-A (4-Quad) and a Y connection. The expanded keys are compiled as shown in Table 1. These keys are self-explanatory and are arranged in collating sequence, fully compatible with ISAM requirements. Using this concept the key can be extended in any logical fashion provided the variables to be concatenated are meaningful without overburdening the function of the key. The key should always be kept as simple as possible. The district number and the control section number are examples of potential variables.

Application

In a multiple file environment, inter-referral of data is possible only if a common base of reference is established in each file. Using the example considered for the D-10 key, between Austin and Giddings on U. S. 290, find the length of highway with pavement thickness less than 7 inches. From the straight-line diagram, the starting key (Austin city limit) is US0290024000, and the ending key is US0290076123. The computer can scan the RI-2 file from the record with key US0290024000 to record with key US0290076123 to extract the necessary information, as shown in Fig 10.

If a maintenance worker wants to know the geometrics of certain curves about .160 mile from milepost 58 on U. S. 290, he only needs to enter key US0290058160. It is feasible to program the computer so that if a key is not

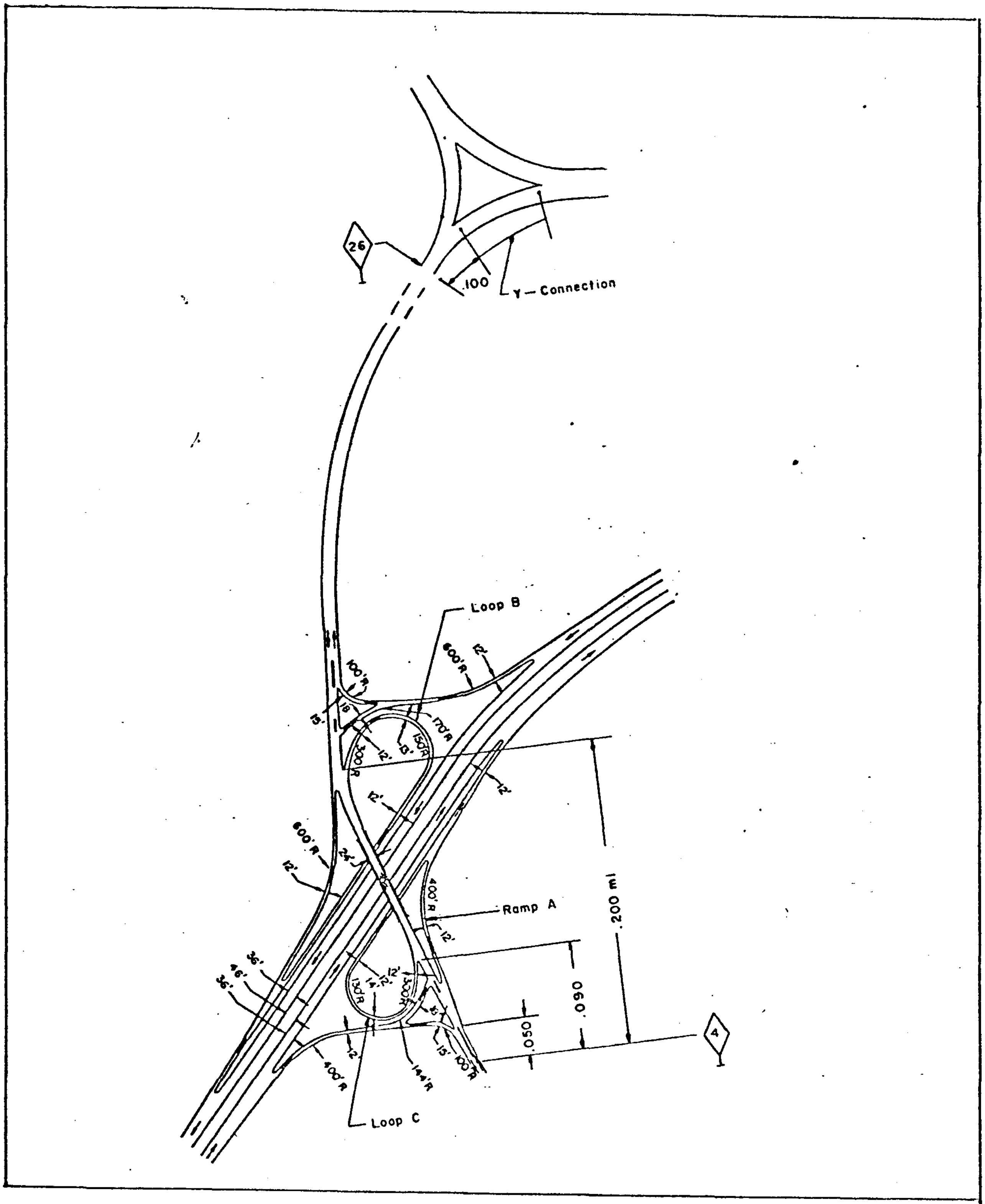


Fig 9. Layout of a Parclo-A (4-Quad) and a Y connection.

TABLE 1

Element	Length (miles)	Location (miles)
Ramp A	.250	.050 from Milepost 4
Loop C	.175	.090 from Milepost 4
Loop B	.175	.200 from Milepost 4
Y connection	.200	.100 from Milepost 26

Extended Key	Section Length	Remarks
US0999000000b̸		Start of US0999
US0999004050b̸		Normal key
US0999004050R	0300	Key for start of Ramp A
US0999004090L	0265	Key for start of Loop C
US0999004200L	0375	Key for start of Loop B
US0999026100b̸		Normal key
US0999026100Y	0200	Key for start of Y connection

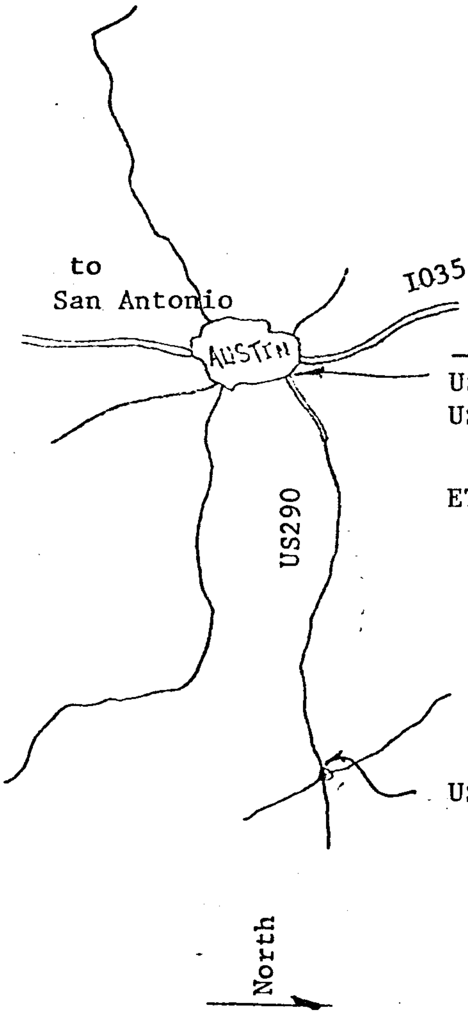
Where

b̸ = blank

R = Ramp

L = Loop

Y = Y connection



Key	Highway Status / Administrative System / Federal Aid System / In Federal Reservation / City Number / Right of Way Width / Road Bed Width / Surface Width / Base Type / Shoulder Type / Surface Type / Etc.
US0290024000	1010200000000100028020409510102
US0290026789	1010200000000100028020409510102
	1010200000000100028020409510102
	1010200000000100028020409510102
ETC.	1010800000000120038024401510102
	1020800316500120038024401510102
	1010800000000120038024401510102
	1020800316500120038024401510102
	1020800316500070048048409510102
	1010000000000100028020409510102
	1010000000000100028020409510102
	1010000000000100028020409510102
US0290076123	1010000000000100028020409510102

Fig 10. Listing of RI-2 record using the new key.

found, the computer will search either the next lower or upper record and display the data on a cathode ray tube or any other on-line access device for rapid retrieval.

Advantages

The advantages of this proposed key system are

(1) It provides a direct common base of reference to inter-access files at random within THD and also a common means for outside agencies such as the Center for Highway Research at The University of Texas at Austin, or Texas Transportation Institute at Texas A&M University to access highway information on common research interests.

(2) The coding system is extremely simple to use. Both THD employees and the public are familiar with highway systems and highway numbers from reading roadway signs.

(3) The method uses current operating conditions. The as-built mileposts will not be relocated except for reassigning. The cost involved therefore will be minimal.

(4) The system provides the management and the public, who are generally not conversant with the highway internal coding system variables such as the control section number, easy comprehension of the location of highways in reading highway reports.

(5) The continuity of this milepost numbering system, without interruption at the county line, etc., helps the motoring public to better understand travel information.

(6) Except for physical renumbering of mileposts, the conversions are done internally by computer programming.

(7) District and other divisional offices can code their own keys without going through the tedious process of checking the straight-line diagram and consulting D-10.

(8) Apart from agreement on using a common key, the total involvement of districts and divisions at data-conversion level is minimal. Each file is maintained by its own staff, as before. The enhancement of inter-referral of file facilities may bring THD personnel one step closer to standardization of data coding.

(9) It makes it easy to efficiently turn over records when a change of personnel occurs.

(10) The straight-line diagrams (SLD) which have hitherto been prepared manually can now be digitized and can be retrieved in graphical form. Alternatively, the present SLD can be stored in a Mosler 400, a microfilming storage device, and can be retrieved by referencing to this new key in an indexing system linked to an IBM 360 machine.

(11) The new system eliminates the ending mileposts of each record. It therefore simplifies the coding process.

(12) This keying system provides a more overall economical means of data storage since duplication of data will be reduced to a minimum in a coordinated file system; e.g., geometrics and administrative data can be retrieved from the RI-2 file.

Disadvantages

(1) Costs will be involved in coding and converting of data and reassigning of mileposts.

(2) It causes confusion to the widely used SLD, since the latter is based on the control section numbering system and the milepoint system.

(3) In the process of converting data from one system to the other, valuable historic records may be lost.

Implementation

It is recommended that the position of state highway mileage controller be established in THD. Logically, this should be set up within D-10 since it will be responsible for the state mileage beginning in 1972 and is the main source of highway design information in the THD.

The state highway mileage controller would

(1) coordinate with Divisions or Districts on all matters concerning the keys,

(2) obtain information from the Commissioner's office on all approved or proposed projects,

(3) inventory the existing milepost system,

(4) reassign milepost numbers and erect new mileposts wherever necessary,

(5) create internal tables for accumulated mileages from field data and interpolation,

(6) develop computer programs for general coding conversion,

(7) supervise a field crew for milepost maintenance and construction,

(8) establish standard coding procedures and documentation for all file contents (data items in each record and their attributes) for inter-referral use, and

(9) conduct user education.

Prefereably the state highway mileage controller would be a graduate civil engineer with varied highway and data processing experience. To function efficiently, he would need a staff of two, one familiar with field experience and the other with considerable computer programming knowledge.

The state highway controller is a coordinating agent whose primary function is to implement this proposal and to provide services to other divisions or departments in terms of inter-referral of file managements.

CONCLUSION

This proposal considers a statewide highway information retrieval system. Specifically, it is written for management perusal and emphasizes simplicity and ease of implementation to help in making a rational decision from among all alternatives, including those not considered here. The proposed key is self-explanatory, rudimentary in construction, and requires relatively low expenditure for implementation. The control section numbering system that is so widely used for accounting purposes seems to be outdated because of its limited scope. The proposed alternate key is a compromise between the existing milepost and milepoint systems. The majority of the data conversion required will be done by computer program means. The proposed key requires no relocation of mileposts except for reassignment of integer numbers. If the position of state mileage controller is created, the involvement of THD personnel will be reduced to a minimum. The transition from the existing way of referencing data using the straight-line diagram to the use of this proposed key will be almost unnoticeable. While the inconvenience of abandoning the control section numbering system may be felt by the relatively few who are familiar with the system, the advantage to be gained in adopting a new key system seems to far outweigh the other in terms of ultimate use and application.

The proposed alternate key presented here is still in an embryolic state. It must be subjected to rigorous tests for its suitability before being adopted by THD, and constructive comments are solicited.

REFERENCES

1. Wright, J. E., "Developing a State-Wide Data Base in Texas," Highway Research Board 4th Summer Meeting, Austin, Texas, August 1971.

2. Blessing, W. E., "Coordinated Data System for Highway Planning," Highway Planning Technical Report No. 7, Federal Highway Administration, May 1968.

3. Yu, F. C. F., "Design of a Computer-Based Information Retrieval System for Highway Planning," Master's Thesis, Civil Engineering and Engineering Mechanics Department, Montana State University, December 1970.

4. Texas Highway Department, Plan Preparation Book I, December 1952.