Improvements to Utah's Location Referencing System To Allow Data Integration

Richard A. Deighton, *Deighton Associates Limited, Canada*
David G. Blake, *Utah Department of Transportation*

A location reference *system* and a location reference *method* are distinguished by listing options available for location reference methods and explaining the importance of a standardized system to facilitate integrating data from more than one source. The conclusion describes necessary changes to Utah's method and the implementation procedures necessary to stabilize and improve Utah's system to meet the objective of data integration. Both linear and spatial approaches to location referencing are discussed. However, the focus is on explaining the details of the four basic linear methods, including advantages and disadvantages of each. Issues the Utah Department of Transportation needed to address when it selected its approach to location referencing are presented, including balance between system and method, stability of addresses, procedures to accommodate address changes, ability to replace one unit of measure with another, institutional issues, and training requirements.

The question most often asked in a highway agency is, "Where is it?" Keeping track of where events and objects are on roads is called *location referencing*. Since terminology is important in location referencing, Table 1 gives definitions of the terms used.

Location Referencing

The most important issue regarding location referencing is to make a clear distinction between a location reference system and a location reference method. National Cooperative Highway Research Program (NCHRP) *Synthesis of Highway Practice 21* (*1*) defines the difference between system and method:

> There is a definite distinction between a highway location reference system and a highway location reference method, the former being a larger set of office and field procedures that includes the latter. The method is seen by the user in the field as a way to identify a single location; i.e., to reference a specific position with respect to a known point. The system is seen as the procedures that relate all locations to each other. It includes techniques for storing, maintaining, and retrieving location information.

Location Reference Systems

To manage location referencing a highway agency must have one, and only one, location reference system. A location reference system, like all information systems, requires separate components to acquire, store, manipulate, retrieve, and distribute information. Typical location reference systems are a mixture of manual procedures for data acquisition and distribution and computerized procedures for data storage, manipulation, and retrieval.

Unlike other information systems, location reference systems depend on the manual components of acquisition and distribution. The manual functions are carried out by employees in the agency who communicate the

TABLE 1 Definitions

Term	Definition
Address	Sequence of numbers and characters to represent the location of a point, specific to a location reference method
Offset	Linear distance along the route to relate a point to a known point
Location	Particular position on a route, identified by address(es) [a]
Primary direction	The direction in which a route is said to "run"
Positive direction	Undivided highways: the primary direction Divided highways: the direction of travel on each side
Negative direction	Opposite to the positive direction
Mile point	Distance in miles from the beginning of the road in the primary direction
Mile post	Post placed along the road, with a number representing the mile point of the post
Reference post	Post placed along the road, with an identification number
Reference point	Point on the road which can be easily identified and whose identification number and location is known
Location reference method	Set of procedures used in the field to identify the address of any point
Location reference system	Set of procedures used in an agency to manage all aspects of location referencing

[a] A point location is identified with one address, a section location with two addresses

addresses of points among one another and with the system. Since consistency in this communication is paramount to success, managing the manual component is a large part of managing the entire system. One way to ease this burden is to enforce a well-conceived location reference method.

Unfortunately, many agencies regard the location reference system as unnecessary. Hence, training courses to show people how the system and the method works are often neglected. Today, few highway agencies make location reference training a requirement for all employees. In fact, few states even publish a location reference users' manual. An example of such a manual is the *Roadway Reference System Users Manual* of the Indiana Department of Transportation (DOT) (*2*).

Location Reference Methods

A location reference method consists of a mechanism to find and state the address of a point by referencing it to a known point. Its purpose is to communicate the location of a point through an address.

The method must be viewed as part of a larger system and should be developed within that context. The method must be easy to use in the field. It must also have characteristics that support the system. The balance between these two requirements provides the key to success for any location reference system. The NCHRP Synthesis (*1*) states that the objectives for a location reference method are to provide a means for

1. Designating and recording the geographic position of specific locations on a highway,
2. Using the designations as a key to stored information about locations, and
3. Uniformity in application of procedures through which various highway-related data observations are located.

Listing "uniformity" as an objective explicitly highlights the desirability for an agency to either use only one

location reference method or provide a location reference system that can accommodate many methods at once. This also shows that designating a location should be independent of the viewpoint of various organizational units making observations.

There are two quite different approaches to location reference methods, commonly classified as either "linear" or "spatial." Linear location reference methods express the address in terms of a linear displacement along a highway. Spatial location reference methods express the address in terms of three-dimensional coordinates.

Although much work is being done in the field of spatial methods, the authors are unaware of any highway agency that has abandoned a linear method in favor of a spatial method.

Spatial Methods

Spatial methods use a set of coordinates to identify the location of a point. These "geocoordinates," as they are often called, are commonly expressed either in longitude, latitude, and elevation or in state plane coordinates and elevation. The driving force behind using geocoordinates seems to be a desire to use Geographic Information System (GIS) technology.

Advantages

The advantages of spatial methods are as follows:

- No physical marking is required in the field,
- Coordinates can be obtained electronically with a Global Positioning System (GPS) receiver,
- Any address given in terms of coordinates is permanent since the location in a three-dimensional space never changes,
- Any point can be automatically displayed on an electronic map, and
- Addresses can be given for data that are outside the right-of-way using the same method.

Disadvantages

The following are disadvantages of spatial methods:

- It is difficult to assign the topological relationships between highway segments in a three-dimensional manner,
- It is difficult to detect measurement errors in the field,
- Communicating the location of a point is impossible without a map or without a linear location reference method,
- The motoring public will not be able to use location referencing to chart their progress along a route,
- Calculating a distance between two points requires complicated three-dimensional geometry,
- Users in the field must have a GPS receiver,
- GPS receivers do not work when there is overhead cover such as trees and bridges, and
- Accuracy requirements are significantly greater than for any linear method, because small errors can result in the identification of a point on an entirely different facility.

Linear Methods

The manner of identifying a known point, generally called a reference point, usually distinguishes one linear location reference method from another. Existing implementations of linear location reference methods can be described using one or more of the following fundamental methods:

- Mile point,
- Mile post,
- Reference point, and
- Reference post.

Even though there are many different names, all linear location reference methods are fundamentally the same. The NCHRP Synthesis (*1*) addresses this issue in its conclusion:

> To the casual user of a highway location reference method, there appear to be many widely different methods in use today. There is a tendency to "see" significant differences between methods on the basis of different names. To make matters more confusing, terms such as "straight-line diagram", "route log", "coordinates", "milepoint", and even "milepost" and "reference post", are used rather loosely in connection with location reference methods. . . . There really is not a great deal of difference between the several most commonly used methods.

Mile Points

The mile (or kilometer) point method is the most fundamental method. Most location reference systems employ the mile point method in some manner. The more successful systems use the mile point method internally to relate locations to one another.

This method assumes that each road has one reference point located at its beginning. The address of any point along the road is the numerical value of the distance of the point from the beginning of the road. Mile points are not physically identified in the field.

Mile point addresses are communicated with a format of "NNNN 999.999", where NNNN is the route number and 999.999 is the mile point. Figure 1 shows a typical road that is 8.7 mi long and has five "incidents": a start, a bridge, a T-intersection, a culvert, and an end.

Advantages

The advantages of the mile point method are as follows:

- The distance between any two points on the same road is equal to the difference between the "to" and the "from" addresses,
- Special posts are not required, and
- Mile point systems are easy to understand.

Disadvantages

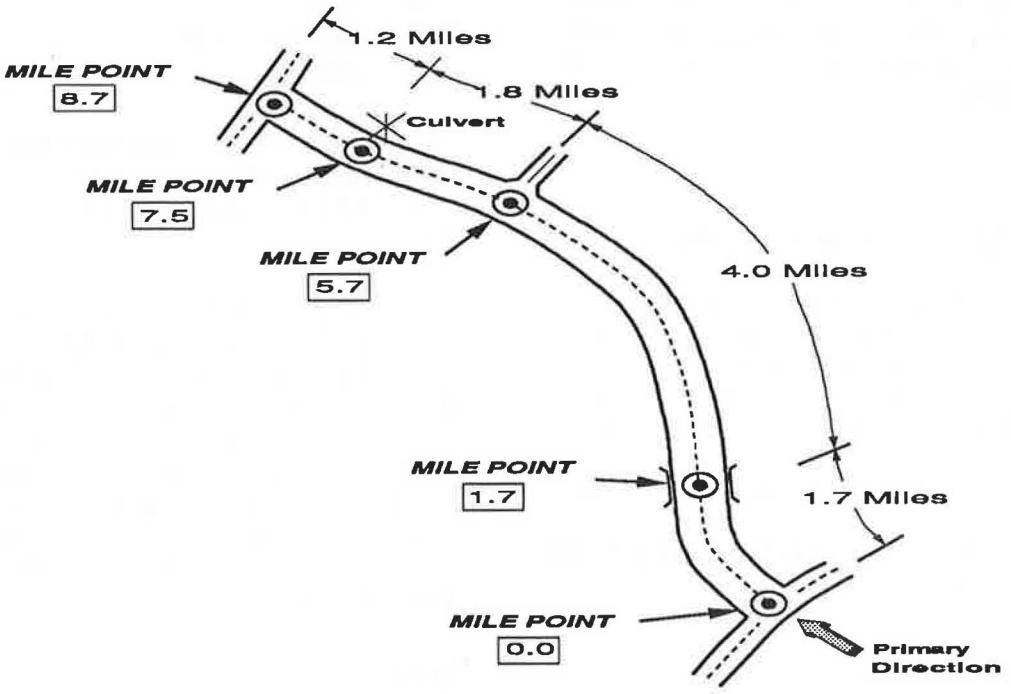
The disadvantages of the mile point method are as follows:

- A user in the field must start to measure at the beginning of the road each time to get an address,
- Addresses are unstable because mile points change whenever the length of the road changes, and
- Whenever mile points change on a road, the location reference system must go to all files, including historical records, and renumber the addresses for all points on the road.

Mile Posts

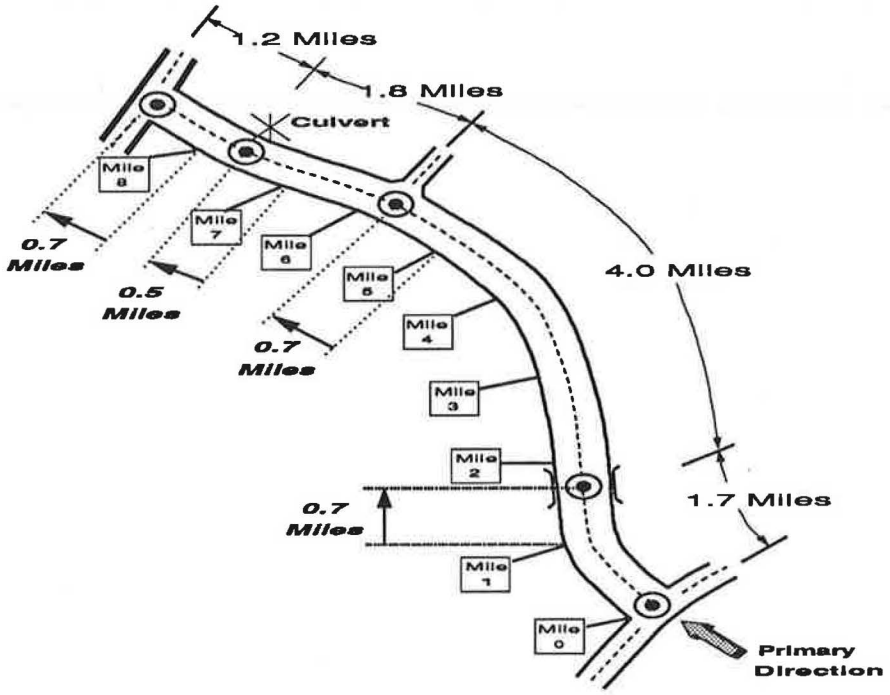
The theoretical difference between the mile post and the mile point methods is in the physical placement of posts at even mile points along a road. Each mile post must be labeled with a number that represents the true mile point at the post. The address of any point, then, is given by adding or subtracting the distance traveled from any post to the point in question.

The format for communicating the address of a point is "NNNN 999.999," as for the mile point. Figure 2



DESCRIPTION	ADDRESS
Start of road	000.000
Bridge	001.700
"T" Intersection	005.700
Culvert	007.500
End of road	008.700

FIGURE 1 Mile point location reference method.



DESCRIPTION	ADDRESS
Start of road	000.000
Bridge	001.700
"T" Intersection	005.700
Culvert	007.500
End of road	008.700

FIGURE 2 Mile post location reference method.

shows the same road as that in Figure 1, this time with the mile posts.

Advantages

The mile post method has these advantages:

- It is easy to use in the field,
- Motorists can use the posts to chart their progress along the road,
- A user has to travel at most 0.5 mi to find the nearest post,
- Numerical sequencing of the signs provides users with easy orientation, and
- A user can calculate the distance between any two points by subtracting the "from" address from the "to" address.

Disadvantages

The mile post method has these disadvantages:

- Maintenance forces must place, maintain, and work around posts;
- Posts must be replaced whenever the length of a road or the unit of measure changes;
- If the posts ever become out of date, the method can no longer be a mile post method; it becomes a reference post method and all the requirements of using a reference post method must be practiced; and
- Mile posts can be confusing on concurrent routes (the numbers on the posts represent the mile point for only one route, or there is a set of posts for each route).

Reference Posts

The reference post method uses posts physically placed at various increments along the road. Each post has a reference number. In this method the reference point is identified by the number on the post. The address of any point is stated by giving the route number, the distance traveled from any reference post to the point in question, and the direction.

To calculate the distance between any two points, all reference numbers must be related to a mile point. Although a reference post number never changes, the mile point associated with a reference post number may change. Maintaining the relationship between reference post number and mile point is the key to success. The distance between any two consecutive posts is maintained in a file. Any user or information system that wants to calculate the distance between any two points must use this file.

The format for communicating the address of a point using the reference post method is "NNNN XXX ± 99.999", where NNNN is the route number; XXX is the reference number on the post; + or − indicates a positive or negative direction, respectively; and 99.999 is the distance from that post.

Figure 3 shows the same road as that in Figures 1 and 2, this time, with reference posts added.

Advantages

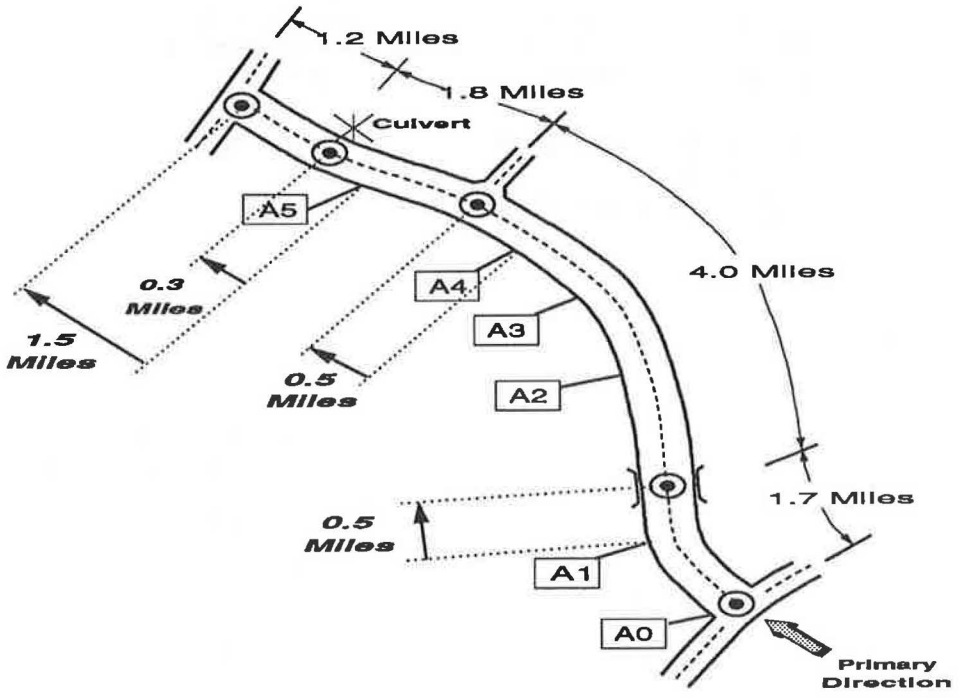
The reference post method has these advantages:

- It is easy to use in the field,
- Addresses are stable and changes in route lengths or in the unit of measure for distances do not affect the physical location of the posts or the validity of the post reference numbers,
- On concurrent routes a single set of posts applies to all routes, and
- The distance between posts is usually small enough so users need not travel a long distance to find one.

Disadvantages

The reference post method has these disadvantages:

- Motorists may not be able to chart their progress along a route,
- Maintenance forces must place and maintain the posts and work around them,
- Users and information systems must use a list to calculate distance between any two points, and
- It is difficult to maintain and distribute the list of mile points for all reference posts.



DESCRIPTION	ADDRESS
Start of road	A0 + 00.000
Bridge	A1 + 00.500
"T" Intersection	A4 + 00.500
Culvert	A5 + 00.300
End of road	A5 + 01.500

FIGURE 3 Reference post location method.

Reference Points

The difference between the reference post and the reference point methods is the physical placement of the posts in the field. The reference point method relies on assigning reference numbers to easily identifiable physical features such as bridges and intersections. The reference point is identified by a number on a list. Distance between any two consecutive points is given on the same list. The list is required in the field to find the number for any reference point.

The format to communicate the address of a point using the reference point method is identical to that in the reference post method: "NNNN XXX ± 99.999."

Figure 4 shows the same road as that in Figures 1–3, this time with reference points.

Advantages

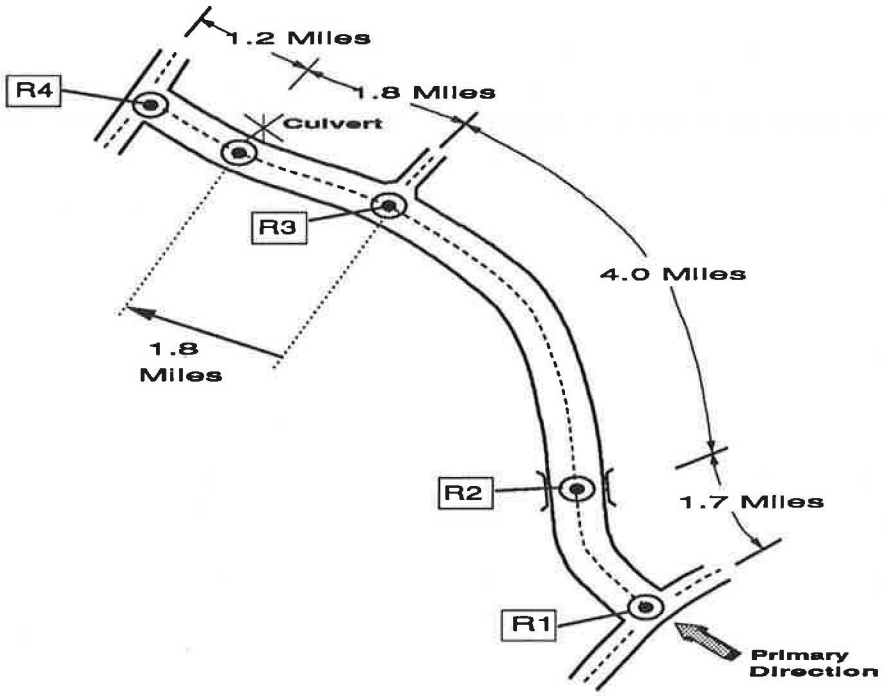
The reference point method has these advantages:

- Special posts are not needed,
- Addresses are stable and changes in route lengths or in the unit of measure for distances do not affect the validity of the numbers for the reference points, and
- On concurrent routes the reference points apply to all routes.

Disadvantages

The following are disadvantages of the reference point method:

- It is cumbersome to use in the field,
- Reference points can often be located only at impractical distances apart on rural roadways,
- Motorists are not able to chart their progress along the route,
- User and information systems must employ a list to calculate distance between any two points, and
- Maintaining and distributing the list of mile points for all reference points is difficult.



DESCRIPTION	ADDRESS
Start of road	R1 + 00.000
Bridge	R2 + 00.000
"T" Intersection	R3 + 00.000
Culvert	R3 + 01.800
End of road	R4 + 00.000

FIGURE 4 Reference point location method.

Issues in Selecting a Method

In presenting issues that an agency should address in the selection of an approach to location referencing, the relationship between system and method is discussed from five different perspectives: balance between method and system, experience of some DOTs, stability of addresses, institutional issues, and the act of replacing one unit of measure with another.

Balancing Method Against System

In general, two aspects must be balanced when the appropriate method for an agency is selected. The method must be easy to use in the field, and the supporting system must provide a mechanism to accommodate changes in addresses. It is desirable to reduce the impact of address changes so that separate files, including historical files, can be easily integrated. Creating an appropriate balance between these two aspects is confusing because one is only achieved at the expense of the other. This is why mile point and mile post methods are unattractive; ease of use comes at the expense of address stability.

Three principles have been observed by the authors. First, systems based on a single method are generally more successful than those involving many methods. Second, systems based on post methods are generally easiest to use in the field. Finally, systems that require a list to be used in the field are generally more difficult to use and maintain.

Experience of Some DOTs

A true mile post system must have a procedure in place to ensure that the posts are always located at exact mile points. All posts beyond an affected point must be removed and replaced whenever a realignment activity occurs. Since this removal and replacement is seldom done, many agencies that started with a mile post method ended up with a reference post method. Yet, these agencies still called their method a mile post method and did not have a system in place to manage either. Mislabeling the method and lack of system procedures have resulted in much confusion.

Agencies still using these mislabeled mile post systems are trying to force some procedures of a mile post system to perform like those of a reference post system while still employing the main characteristics of a mile post method. When a road's length changes, an "adjustment equation" is introduced in the system. Because of post placement errors, some agencies have "short miles" and "long miles," also accounted for by adjustment equations in the list.

Stability of Addresses

The impact of address changes is also a system issue. The system must have procedures to accommodate changes in addresses swiftly and thoroughly. Since few agencies have integrated data bases in place, it is difficult to communicate address changes to all existing information systems automatically. Usually these matters are left to manual procedures, and manual procedures are notorious for not being applied properly, especially without documentation or formal training in their application.

Therefore, an agency has two choices: automate procedures or minimize address changes. Since providing the system with automated procedures requires an expensive integrated data base, it is usually better to focus on education and address stability. Minimizing address changes is a methods issue.

Institutional Issues

Location referencing has a tremendous influence on virtually all areas of business in a DOT. Anyone involved with DOT data must be familiar with various parts of the location reference system, and all must be familiar with the method.

Whenever any change is recommended, it is most often greeted with resistance. People, particularly those intimately familiar with the nuances of the current method, tend to resist change. If an agency wants to change its method, this resistance must be considered, planned for, and accommodated. In the Utah Department of Transportation (UDOT), this was accomplished through education seminars and by forming a joint task force consisting of all major players, including the police.

Changing Units

Changing the unit of measure for distances to the International System of Units (SI) will definitely have an impact on the location reference system. The size of this impact can be linked to how easily the location reference method can handle the change.

The conversion can be simple. In the reference post method, for example, all distances in all files can be converted from miles to kilometers through a simple program. Then those in the field must start reporting all distances in kilometers instead of miles.

However, the conversion can be complicated. For example, agencies using any form of the mile post method, mislabeled or not, must either remove and replace all posts or convert their method to a reference post method. The agency must then make the same modifications in reporting distances mentioned above for the reference post method.

UDOT Location Reference System

System Review and Recommendations

The key to sharing information gathered and maintained by different divisions within the department was to relate all information pertaining to a specific location to a common address on the highway system. For 15 years UDOT had used a Highway Reference System (HRS) to establish and report common addresses for points along the highways. In 1992, UDOT requested proposals for an engineering data base to develop a capability to provide complete and easily usable information to district field personnel and department decision makers. As part of this request, UDOT specified that the data base provide an automated capability to store, maintain, retrieve, and report information by location, using the HRS. UDOT also requested a review of HRS to determine what adjustments would be needed to make the system compatible with the automated system.

The consultant review and evaluation of HRS revealed major discrepancies between the desired capability and what was actually provided by the present system. HRS did not have documented procedures, and the operating methods were unclear. Over the 15 years since system implementation, changes in data collection and reporting procedures and individual, informal changes to meet individual user's needs had rendered the system ineffective.

UDOT's selected engineering data base provided the capability for the automated portion of a usable location reference system. It could concurrently support several reference methods. In addition to the automated capabilities of the engineering data base, the consultant made several recommendations for actions to implement an adequate location reference system, calling for UDOT to develop

- A manual explaining UDOT's location reference system and giving examples of its use,
- A formal location referencing training course for all employees who are involved with the HRS,
- A policy designating one office as responsible to maintain all aspects of the HRS including effective distribution of the address list,
- A procedure by which the location reference office annually freezes address data for a period of 1 year so all data collected during that year are referenced to the same addresses,
- A formal computerized and manual system to cover all aspects of location referencing,
- A procedure to make cascading changes to addresses in all current and historical files to allow comparison of data collected when other addresses were used,
- A procedure to make the location reference method as easy to use in the field as possible, and
- A strategy to implement metric measurement notation.

Necessary location reference method changes basically combined the best features of the reference post method with the reference point method. Recommended changes were as follows:

1. Leave existing posts in the field where they are. Costs to remove and replace the posts would be high, and the posts can be used as reference posts in the upgraded referencing system after "freezing" their locations to provide consistency.
2. The fact that mile points are fundamentally different from existing mile posts must be communicated effectively. The best place to start would be to officially change the name "mile post" to "reference post." This would help eliminate the mistaken belief that posts are always 1 mi apart and would also help in the transition from miles to kilometers when none of the posts will be 1 km apart.
3. Change the format of the address used by the HRS to the format shown below. This format must be used by all systems in the agency.

$$\text{NNNND FFF} + 9.99\ \text{TTT} + 9.99$$

where

NNNN = route number designator with leading zeros;
D = direction of roadway lanes, for example, P, primary direction, used on the set of lanes that runs in the primary direction on divided highways; B, primary direction, used to indicate an undivided highway; N, opposite direction for the set of lanes on divided highways that runs opposite to the primary direction; R, ramp in the primary direction; and S, ramp in the negative direction;
FFF = identifier on the closest reference post in the negative direction from the address;
9.99 = distance from FFF to the address in the positive direction;
TTT = identifier on the closest reference post in the negative direction from the address of the "to" point (only for sections); and
9.99 = distance from TTT to the address in the positive direction (only for sections).

4. Change all existing systems in UDOT to accommodate the new address. If data from existing systems are to be integrated with new data, all must use the same addresses.
5. Maintain and distribute the following four lists to users in both paper and electronic format.

- Route list, showing route identifier, positive direction, and a description of each route in the location reference system;

- Reference post list, showing route identifier, reference post identifier, mile (kilometer) point, distance from the next preceding reference post, and unit of measure for distance;
- Reference point list, showing address and a description of major physical features along each route; and
- Concurrent highway list, showing the addresses of concurrent highway sections

6. Change the method used to acquire addresses.

Institutional Issues

A Highway Location Reference System Group was formed to deal with the multitude of institutional issues that arose. Group membership included representatives from all UDOT users and a representative from the Utah Highway Patrol to represent the views of law enforcement users, both state and local, who report accidents and other information using location references. Identification of all of the varied user requirements and providing a capability to satisfy them was key to implementing both the system and method. In some cases this dictated compromises, which led to some users' functions not being optimized. Thanks to the Location Reference System Group's expertise and professionalism, these areas were identified and accommodated.

Pros and cons regarding extensive modification of UDOT's existing system were considered. Major points in favor of the new system were that it would provide

- Easily communicated, exact location information from a wide variety of inputs and to any connected users;
- Unification and integration of data from diverse data collection systems; and
- Increased location referencing accuracy.

However, the new system would require

- A major effort to implement, and
- Extensive computer program changes for all data-gathering activities.

Several major departmental decisions were made affecting UDOT's location referencing system. A single, departmentwide location referencing system is essential to allow multiple users to share data. The automated portion of the system will be provided by the engineering data base program. Finding locations and identifying relationships among various combinations of data at and between specific locations is a repeated requirement, essential to ensure that information and analyses from diverse data areas reflect true conditions in the field.

For example, investigating police officers usually drive from the scene of an accident to the next reference post to establish the reference post location and the distance from it. However, data collection is usually conducted in a primary direction along a route over an area spanning several reference posts.

To accommodate the varied needs of data collectors, the system allows locations to be identified using any valid address. However, to ensure easy communication with all users and uniformity, the system converts input addresses to a standard address that is stored, retrieved, manipulated, and used for all reporting. This leads to two types of addresses:

1. To identify an address where data are collected, a "UDOT address" may be used. This address is expressed by a route number, direction indicator, reference post number, and an offset, which may be any distance (e.g., 0015P 321 + 4.63).
2. To provide the most stable and predictable way to identify a location for a wide variety of users over time, it was decided to establish a "UDOT standard address." A standard address ensures one, and only one, address for each location or event. The UDOT standard address uses route number, direction indicator, the number of the reference post immediately preceding the location, and an offset in the positive direction, which is less than the distance to the next reference post (e.g., 0015P 325 + 0.63). This address is the one under which all data pertaining to a particular location are stored, retrieved, manipulated, and reported.

Data will be gathered and stored as separate roadways for each direction of travel on divided highways.

Address reporting formats will be multiple and varied to meet the needs of individual users. For example, one user may need a report on all routes within a single UDOT district, and another may need to use standard addresses to locate individual pavement sections or points along a route or routes. Other users will have their own unique requirements.

To provide stability, accuracy, and repeatability, a unit within the Transportation Planning Division was designated to manage, operate, and maintain the location referencing system. Maintenance Division and district maintenance personnel were designated as responsible to replace missing or damaged posts in locations designated by the system manager.

Within UDOT's system a single reference method was desirable to communicate location more easily and to provide more consistent data for use. A single method throughout UDOT will allow easier, more accurate data communication and integration. To meet these requirements UDOT selected the reference post method for location referencing. Several decisions were required to implement this method:

- Existing mileposts were redesignated "reference posts" and remained in their original locations. Missing or damaged posts were replaced and maintained at their original locations.
- Each route had a zero reference post placed at its point of beginning and an ending reference post marking the end of the route.
- Route designations and cardinal direction signs were placed on every fifth reference post, along with the post number.

As currently constituted, the system provides several essential capabilities:

- To accept any reported address, convert it to a UDOT standard address, and store, retrieve, manipulate, and report it in UDOT standard address format;
- To identify linear segments in a standard manner by converting beginning and ending addresses to UDOT standard addresses;
- To recover the distance attribute between two addresses and to report the UDOT standard address of a point from any address when provided with a distance and a direction;
- To provide standard addresses for selected data elements without displaying addresses for any other undesired items;
- To be easily convertible to metric measurement units; and
- To treat divided highways as separate roadways.

Within the system the method

- Contains minimum perceived changes for field personnel,
- Uses existing mileposts as they were previously installed,
- Is easy to learn and use in the field,
- Has flexibility to meet varied user needs for location identification, and
- Provides stable addresses over time

Implementation

There were several implementation impacts. Full implementation of the revised UDOT location reference system and method required about 1 calendar year and 3 to 5 person-years of effort. Implementation required

- Complete inventory of mileposts along the highway system to establish precedence, succession, distance, and condition of existing mileposts for their conversion to reference posts;
- Full inventory on opposing roadways for divided highways;
- Modification of all existing data collection systems to use the new location reference method and format; and
- A manual interface for each data area to translate between old and new method addresses.

Finally, all potential users must be educated in using the system and to realize that optimizing the system is not the same as optimizing each individual area. Users in the UDOT Central Office must be aware of the reference method used in the field and know system capabilities for data retrieval, manipulation, and report generation. In the field, personnel must be familiar with the method used to report and find locations and be aware of the system capabilities. In all areas, individual users must understand that they may be required to give up some desirable features to allow the system to best serve overall department needs.

SUMMARY

UDOT adopted the reference post method of location referencing. This method allows data gathered by various department divisions to be related to specific locations along the highway system. Used with the management system provided by the engineering data base, this method provides the key to sharing information among UDOT's many separate activities.

REFERENCES

1. NCHRP *Synthesis of Highway Practice 21: Highway Location Reference Methods.* TRB, National Research Council, Washington, D.C., 1974.
2. *Roadway Reference System User Manual.* Roadway Management Office, Indiana Department of Transportation, April 1991.