A Business-driven Approach to Linear Network Management for Roads

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Introduction

A linear referencing solution (LRS) brings many benefits to an organization, often becoming the foundation of its transportation asset management processes. To achieve this the LRS needs to meet regional standards and provide certain asset management functionally, such as the asset register. This paper proposes that the LRS and asset register should be integrated to provide the best possible foundation for an organization's asset management needs.

This paper also discusses:

- Features an LRS needs to provide to meet the organization's corporate asset management requirements.
- Business requirements an organization should consider to ensure that the right decisions are made during the implementation of an LRS.

What is an LRS?

Regardless of what constitutes a linear referencing solution, it is imperative to fully consider the business processes the linear referencing solution needs to support. This will make clear why a linear referencing solution is important and what functionality it needs to provide. It will also make clear that the LRS should be driven by the business and not the technology.

Asset management means different things to different people. To maintenance engineers it is a condition monitoring and work management solution. To accountants, it is a valuation and budgetary management solution. And, to executives, it is a reporting tool that details how the organization's assets are performing. In short, asset management is an all-encompassing term that can refer to any part of the asset management lifecycle process.

Is this also the case with linear referencing solutions? Initially, the answer might be 'No.' After all, a linear referencing solution is simply a network modeling tool used to identify the road network and edit it as changes to the network occur over time. But, is that all a linear referencing solution is? What about the features of that network, such as the number of lanes it provides and its pavement structure? What about the assets located along the network, such as signs and safety barriers? Some might say the assets are business data and are a separate discussion because they are not part of the linear referencing solution itself. This might be the case, but the linear referencing solution must provide the ability to manage and report these assets against the linear network. So the question is: Should the linear referencing solution be considered an independent entity, separate from the business processes?

Consider the need to report against the network based on varying information along the length of the network. In the United States, the Federal Highway Performance Monitoring System (HPMS), which states are required to submit, relies heavily on the ability to dynamically segment the network based on features and assets and then using those same features and attributes in the resulting reports. Next, consider the latest trends in road safety that don't rely on what a reporting officer records against an incident, but also the road environment in which the incident occurred. In Australia, for example, the Roads to Recovery and Accident Black Spot programs submitted by local agencies can receive a real boost in potential project identification through the evaluation of accidents, condition, and assets stored against a linear network definition.

So what is an LRS? At the very least, it is a solution that provides the ability to model a road network, preferably in a spatial environment to view, edit, and share information in an easily understood and suitable manner. It enables organizations to identify the road environment along the length of a road network. This environment may include the number of lanes and road classifications. Ideally, the LRS will also provide the ability to locate the physical features along the road network, such as signs and guard rails. The LRS must then enable reporting against this road network and its associated events. These reports may range from simple tabular reports to complex charts or maps.

Regardless of what constitutes a linear referencing solution, it is imperative to fully consider the business processes the linear referencing solution needs to support. This will make clear why a linear referencing solution is important and what functionality it needs to provide. It will also make clear that the LRS should be driven by the business and not the technology.

Why Is a Linear Referencing Solution Needed?

We've established that an organization's business drivers determine why a linear referencing solution is necessary. Additionally, the overall goals and objectives for managing infrastructure must be identified. Care must be taken to avoid reviewing the individual goals and objectives of each business area independently. For example, all too often a business commences a phased approach that considers the initial challenge of managing the network centerline. This might result in a geospatial approach that requires business data to be managed through spatial geomteries. This results in a more costly approach to satisfying each of the identified objectives that rely on readily accessible business information.

For example, the maintenance team's objectives for maintaining the road network to specific standards might be based on quantities of work performed in previous years. A pavement management team's objective might be to identify specific locations where major funding needs to be focused to optimize long-term expenditure. Consider these together and the objectives might change, such that the maintenance team's objectives become the level of service based on surveys performed by the pavement management team, and the pavement management team's objective becomes one of providing a wider range of survey results across the network to support minor and major maintenance work. It is when the overall organization's objectives are considered in this way that the real benefits of a linear referencing solution are recognized.

A linear referencing solution brings together data from multiple business areas. For example, an organization might want to produce a combined report of routine maintenance work and crash data on the same road network. To cross reference that data, a common location referencing approach must be determined to identify events that occur at the same location. In the simplest case, both systems use the same network referencing approach so that a crash at reference post 4.1 is at the same location as the routine maintenance occurring at reference post 4.1. What happens if the two business areas use different linear referencing methods? Their measurement might be in opposite directions or they might begin measuring from different start points. This is where a linear reference supporting these different linear referencing methods (referred to as multiple linear referencing) offers value to the organization.

Perhaps the principal value of a linear referencing solution is the integration of data. The linear referencing solution becomes the hub for integrating any information that is associated against the linear network. Traditionally, the benefits of data integration might not have been considered valuable or essential to the business. However, with tighter budgets and demand for better service, there is a growing desire for a more connected data environment. In the field of safety, for example, safety engineers now include road environment information in their analysis to proactively identify other similar locations that could benefit from safety enhancements before they become high-incident locations. In the field of maintenance management, the full lifecycle maintenance approach is starting to demand that maintenance managers record work achievements against the assets themselves so that asset performance levels of service and improved planning and reporting can be achieved. A linear referencing solution that provides a connected data environment approach helps make data more accessible, helping organizations realize increased savings.

The benefits of a linear referencing solution to an organization can be tremendous. For starters, it is highly likely that the same users will be creating, editing, and updating the network and its associated assets.

The need for a linear referencing solution does not stop at integration. LRS is essential to many different business functions of the typical road owner and maintenance organization. Earlier, we stated that in the United States HPMS reporting relies heavily on the ability to dynamically segment the network at each change in specific road environment values. The same procedures, configured with different criteria, can also be used in Australia in the roads-to-recovery program. The key to dynamically segmenting the road network for an identified need is centered on the concept of storing data where it occurs and then dynamically segmenting for a specific need. Without this capability users are required to segment their network into static fixed-length sections. This makes it difficult to compare data from different reference sources, as each may be based on different fixed lengths with no common link between them.

This type of requirement is also critical to maintenance and pavement management engineers who need to manage and report on data within their own maintenance management system (MMS) and pavement management system (PMS) sections. Without a suitable linear referencing solution, this can be a time-consuming and lengthy process. These are just a few examples of the type of reporting that becomes a reality with an effective linear referencing solution. Others might include the ability to report all events along a specified length of network for inspection or condition monitoring, and the ability to summarize information for reporting to the public, government officials, and executives.

For many organizations, the benefits of a linear referencing system as part of road or linear features asset management might not be recognized immediately. As asset management continues, and the need to manage data along a linear feature matures, the capabilities for a well-defined linear referencing solution will become the norm. Only organizations with a linear referencing framework in place will be able to apply these new work approaches effectively. That framework starts with an effective linear referencing designed around the business practices. The obvious next question is, "What level of business functionality should a linear referencing solution address?"

Should Business Data Really Be Excluded from an LRS?

Some recent commentators suggest that linear referencing should be limited to the network capabilities and should exclude the closely related functionality of managing the business data (which might include assets) along the network. Those who take this opinion need to ask what they consider to be the network and then what they consider to be the business data associated with the network.

The network itself is potentially a centerline representation with connectivity between points. Grouping these connections together builds routes along the centerlines. Although the network itself is essential as the foundation for the linear referencing solution, it does not offer much business benefit in its own right. To consider the characteristics of the network, it is necessary to add the features that make the network functional in the real world. This includes numbers of lanes, speed limits, functional classifications, among others. Using this information, better-informed business decisions can be made and information can be reported against the network.

At this point only the network and its characteristics are defined and not any information about the assets on that network. This is where some might suggest that the network functionality ends and asset management solutions begin. This suggestion is not necessarily wrong, but should it be an approach that is set in stone? And, is it an approach that really provides the best long-term benefits for organizations embarking on implementing transportation asset management plans?

So, what is the difference from a 'data' point of view of the characteristics of the network and the business data located on the network? The answer to this question is, if modeled appropriately, there is none. Each is located somewhere along the network with a start point and, in the case of linear items, an end point. They each have attributes that identify their individual characteristics such as the speed limit or their height. They might also have a logical position across the cross section of the network, such as the first lane or in the sidewalk or footpath.

So, why not model and maintain these all in the same linear referencing solution? The benefits of this to an organization can be tremendous. For starters, it is highly likely that the same users will be creating, editing, and updating the network and its associated assets. Therefore, modeling in the same system enables a single interface that offers more efficient data management processes. It also reduces the risk of integration. There have been numerous studies that identify the integration tasks as being the highest risk factor in terms of the initial implementation and ongoing maintenance as systems evolve over time. A single-solution approach can eliminate this risk.

But, what is the cost of pushing the business data out to other solutions. Some of the most complex tasks in managing data relate to making sure that it remains up to date and correct in the face of an ever-changing linear network. Perhaps this complexity is often overlooked, or perhaps this is why some commentators prefer to defer this complexity to other solutions or later phases. Every realignment, even simple error corrections, require that the location information for an organization's business data remains accurate. This updating work must be performed somewhere, and performing

it within an integrated solution rather than relying on interfaces or API calls between numerous solutions ensures that the data remains accurate and valuable. It is widely accepted that incorrect data can be more costly than no data at all.

It is unlikely that every business event on the network can exist within the linear referencing solution. Some assets might be subject to very specific business functionality requirements that are best addressed by purpose-designed solutions. These might be assets such as advance warning systems, but they might also be events on the network, such as road traffic crashes and inquiries from the public. Any linear referencing solution must, therefore, provide the best of both worlds, enabling these external assets and events to be located and reported against the network alongside the characteristics and locally stored assets. It is the network that enables this integration through the linear referencing capabilities.

When considering this data integration, it is also important to consider the requirements for multiple linear referencing capabilities. This is where a solution will allow users to view data using their own linear referencing approaches regardless of the referencing approach that the data has been recorded or stored against. For example, a safety engineer might wish to view road environment information in relation to its offset within a safety corridor even though the data was recorded as offsets along a county route.

In summary, a linear referencing solution can be confined to the simple modeling of the network. However, significant benefits can be attained when we also consider modeling and locating business data within the linear referencing solution itself. The realities of the real world in each organization might dictate this decision. However, the flexibility to model assets within the LRS, as well as being able to access and combine assets and events in external systems without the need to duplicate data, will offer the more cost-effective approach.

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Major Functionality an LRS Should Provide

Once the organization's goals, objectives, and business requirements are identified, it becomes clear why a linear referencing solution is needed, and what type of solution is required. Organizations recognize that a full asset lifecycle management solution that also provides comprehensive linear referencing capabilities provides the most cost-effective, long-term approach. Determining the solution approach is the first step in selecting the most appropriate linear referencing solution to meet the organization's requirements. Organizations can simply implement a solution that addresses the linear referencing requirements, or they can implement a system that provides long-term transportation asset management benefits. These benefits might include the flexibility to meet future requirements and the ability to provide the foundation of a total asset management solution. Whatever the approach, the following functional areas should be considered.

Handling Multiple Networks

A major consideration is the ability to manage multiple networks, potentially, of different types. If an organization currently manages a single network, it should consider if multiple networks might be managed in the future. Economic pressure is now pushing many organizations to review work performed by multiple agencies, which might result in reorganizations and the need to share network information. A solution that supports multiple linear referencing will more effectively share network information by configuring the additional network definitions and applying them to the base datum. This could result in the need to manage major and local networks in a single linear referencing solution in addition to other networks such as rail and ferry. When managing multiple networks in a single solution it's a good idea to consider how these networks need to interact with each other in terms of sharing assets or interconnectivity at the nodes.

Multiple Linear Referencing

In addition to managing multiple networks, it is important to consider multiple linear referencing. This provides the ability to locate events on the same roadway network using different location referencing methods. For example, a maintenance team might have maintenance sections and locate its work in relation to its offset along these sections. A planning department might locate its assets in relation to its offset from the start of the route. Each business must locate its own features using their preferred referencing methods. A business must also be able to view other business area features using its preferred referencing methods.

Multiple linear referencing provides the capability of the linear referencing solution to become a database integrator or connected data environment. Integration is achieved by merging data from any system and then reporting that information against the road network. Some organizations have invested considerable effort in attempting to ensure they standardize on a single linear referencing method with varying degrees of success. In reality, regardless of how successful implementing a single method is within the organization, there will inevitably be factors or data originating outside of the organization that are not referenced to this LRS. A multiple linear referencing system can support data integration in these situations and the benefits this functionality provides should be strongly considered.

Managing Network Changes

Because networks are subject to continual change, including realignments, new facilities, and decommissioning, the software used to define and maintain the network must manage changes effectively. Not only does the network require management, but also the features and events that are associated along the network. For example, realigning a network might or might not result in events also being realigned or removed. Some actions of network editing can be done textually, such as rescaling an incorrectly measured segment, while others will depend heavily on spatial network editing, such as digitizing the centerline of a new alignment. Effective network

management, therefore, becomes the critical functionality that determines the success or failure of a linear referencing solution. A number of key factors determine effectiveness; the ability to ensure that the events' locations remain correct as a result of editing that ensures any overlying routes are maintained and that changes are tracked as they occur over time.

Flexibility to Meet Changing Business Requirements

Not only does the network and associated assets change, but so do the business processes and rules as the asset management experience matures. Off-the-shelf solutions typically offer better long-term investment, as they provide the configuration flexibility to maintain business processes and rules as they change. Changes might include reference data, such as the types of events or rules that determine how new or updated events are managed. Failing to invest in a flexible configurable solution will result in potentially costly future system development or maintenance work.

The linear referencing solution should model assets and road network characteristics in one combined solution. The reality is that these assets and characteristics are all events against the road network, and should be modeled in a similar fashion.

Unrestricted Characteristics/Assets Definitions (Events)

As described above, the linear referencing solution should model assets and road network characteristics in one combined solution. The reality is that these assets and characteristics are all events against the road network, and should be modeled in a similar fashion. The solution should allow any number of different events or asset types to be modeled with any number of features describing the event or asset.

Security Access to Data

Just about any off-the-shelf solution will provide some level of security access control. This might range from simple user name logins to complex security that restricts the types of assets and events that can be accessed and updated within geographic zones of responsibility. Security requires careful consideration when implementing a solution, as the initial assumption might be that simple restrictions (CRUD) on the type of transactions users can perform are adequate.

This might be the correct approach for a simple linear referencing solution within one business area. However, as the network database is opened up to more users across multiple departments and external users, it often becomes more desirable to not only limit the type of functions these users can perform, but also the types of data they can access. For example, it might be desirable that lighting engineers be restricted to update functionality against lighting points only within the district to which they are assigned. This also highlights one of the many benefits of combining business data with the linear referencing solution: enforcing this type of security across multiple solutions is cumbersome to implement and maintain.

Date Tracking Changes (Temporal Data)

The importance of tracking changes to the linear network and the associated assets is often underestimated. Simple approaches, such as rolling back the database, are presented as viable approaches. The reality is date tracking and the ability to view the network at any time in the past (or future) is an essential component of any linear referencing solution. As we identified earlier, the network and the associated assets will be subjected to continuous changes. Data will not only be retired but also replaced and updated.

The ability to specify a date and view the network as it existed at that point in time, spatially and logically, serves many purposes, including responding to insurance claims and monitoring conditions. It is essential that users be able to query historic data dynamically without rolling back the database that will affect all other users performing normal business functions. To achieve this dynamic approach, the database must have been carefully designed to allow in-depth date tracking to occur at the business data and spatial data levels. For example, there is no point in allowing the user to select an effective date and view the business data if he or she cannot also view the data spatially as it existed at that point in time.

Another major consideration for date tracking is the ability to enter or load data based on an historical date. This typically occurs where surveys might have taken place on site and later need to be loaded while applying the date on which the survey took place. In this case, it is essential that the user specify a date and that the data be loaded against the network as it existed at that point in time. Another example relates to crash data, in which incident records are only received or processed perhaps quarterly. When this occurs, each incident needs to be located against the network as it existed when it occurred and not against the current network configuration. Although this data might be located against the network as it existed in the past, once it is loaded it must be displayed to the user at the correct location reflecting any changes to the network.

Another benefit of this type of date tracking approach is the ability to track changes made by individual users. This negates the need to maintain separate auditing as all changes are traced to individual users.

Engineering Dynamic Segmentation

The ability to dynamically segment the network using any available characteristic, such as road classification, lane profile assets, and conditions, allows users to model data in a logical, normalized fashion. The advantage of dynamic segmentation is that management of the network is not required at the finest partition – such that each time a characteristic changes a new section has to be defined. Instead, each data type is modeled in a logical sense with splits occurring only at points that are natural such as intersection to intersection or at operational boundaries. Engineering dynamic segmentation provides re-segmenting for reporting purposes, leaving the underlying network in place.

This, in turn, makes network maintenance easier and provides much greater reporting flexibility. HPMS reporting is a perfect example of the many uses for dynamic segmentation, as it allows users to create reporting sections and then report on the HPMS items within that section. Another example relates to safety reporting, in which current trends require average crash rates to be determined across the network for various network classifications. The Roads to Recovery program also benefits from engineering dynamic segmentation, providing user-defined selection criteria and then sections identified programmatically for their begin-and-end limits, resulting from data analysis.

The ability to dynamically segment the network is a powerful and critical function. However, to provide the capabilities described above it needs to be supplemented with functionality that creates reports and data output. This might include engineering dynamic segmentation that provides the ability to calculate averages or maximum values within the generated segments. It may also include the ability to specify criteria or bandings that must be met before a new segment is created or incorporated in the results. For example, this might involve segmenting only the network in which the speed limit is banded between 10-30 and 30-50. For safety reporting, users might only want segments created and included in the result sets in which there is a specific type of safety barrier.

Dynamic segmentation is a highly desirable function and should be delivered as a tool within the LRS that provides a configurable approach. When delivered correctly, it becomes the most crucial item in helping the linear referencing solution deliver business solution results.

Regardless of the approach taken for each of these off network assets, the provision of this functionality opens up potential business benefits to the organization, adding more value to the linear referencing solution.

Managing Geographical Areas

The ability to manage geographical areas supports reporting and data security. These geographical areas might include district operational areas, maintenance sections, political boundaries, or other business operations and reporting areas. Although the management of these areas might not be crucial to the core business requirements, this can be a powerful capability in terms of reporting against network and assets within boundaries and providing information to external systems. However, because boundaries can change, it is essential that the solution caters for boundary changes and that these changes be reflected through the network and associated assets. Changes to these geographical boundaries must also be date tracked to interrogate and report historically correct data.

Support for Field Data Collection

To determine what data is recorded and maintained against the network, it is important to consider that the data must always be up to date and at the correct location on the network. Incorrect or out-of-date data can be more damaging than not having data at all. Of course, the more data that's collected and stored the more data there is to maintain. This is sometimes a difficult balance to identify, but the general rule of thumb is to only collect and maintain data that supports the business processes identified at the outset. It is always easier and more cost-effective to add required data later, rather

than collect unnecessary data at the outset and have to maintain it or delete it. This is why a solution must be configurable so that new features can be added or removed as the business processes change over time.

The actual method of performing data collection is not covered in this paper, but benefits can be achieved when using the same vendor to provide the data collection software as the linear referencing solution. This is because the validation rules for the on-site collection and the subsequent loading of the data into the database might be managed better and provide less risk during upgrade processes.

The Ability to Integrate Business Data across the Organization

A major benefit of the linear referencing solution is its ability to integrate business data across the organization. This might be through data consolidation or data warehousing into the linear referencing solution. Integration might also include the ability to view data in other solutions and then display this data alongside the data within the linear referencing solution. This other data is sometimes referred to as "external assets" and might include specialist asset data such as bridges or electrical points. It might also include the incidents stored in a safety database.

The benefit of this approach is that these specialist items can be maintained in specialist solutions. Then, through the external asset functionality, they can be simply reported within the linear referencing solution alongside other features at their network locations. The key to external asset functionality is that the data is presented without the need for data duplication.

Another capability is the use of web services that either allow other solutions to request information from the linear referencing solution, or update other solutions following network updates. For example, an external solution might have the spatial coordinates of an incident and need to know the network location. By making a call to the linear referencing solution with these spatial coordinates, the external solution can retrieve the nearest linear network location. Alternatively, the realignment of the road network could result in calls reaching out to these external databases and updating the network location of the incidents accordingly.

The provision of these approaches to providing HUB functionality delivers major business benefits to a linear referencing solution. Moreover, it demonstrates the value a linear referencing solution delivers to the entire organization.

Managing Network Events and Assets

Not all events or assets will actually be located on or near the road network. Even for assets that are located along the network, it might be desirable to present these to the user as polygons. For example, a grass area or a parking lot. One consideration for these types of events and assets is whether they should still be located against the network, even if they are not physically on it. For example, a gravel pit might be identified as a polygon with spatial coordinates and located on the network where the entrance and exit to the gravel pit exists. Regardless of the approach taken for each of these off network assets, the provision of this functionality opens up potential business benefits to the organization, adding more value to the linear referencing solution.

Ability to Attach Photos, Images, and Documents

With the availability of specialist document management solutions in which many organizations have invested, the issue is typically how the linear referencing solution can be integrated with the document management solution. Ideally, there should be an ability to attach photos and documents to any object within the linear referencing database. The provision of a document management tool within the linear referencing solution moves one step closer to a connected data environment.

In Conclusion

Whether to implement a linear referencing solution independently or as part of an overall transportation asset management plan should not be considered lightly. There are differing views on what a linear referencing solution should actually be and also what technologies need to be considered. The bottom line is a linear referencing solution must meet the business requirements and the objectives of the entire organization and its overall transportation asset management plan. Just because the centerline network might be modeled using spatial geometries does not mean that spatial geometries should drive the business processes.

A design/build approach or a simple GIS approach might provide an initial procurement price that is very appealing, but both can result in much higher long-term costs. Much of the cost of implementing a linear referencing solution might actually result from the implementation of local requirements, training, and historical data capture. These approaches also overlook the provision of embedded configurable tools required to report and analyze the data. For example, tools that enable dynamic segmentation to be performed and data to be extracted, reported, and analyzed against in a configurable approach. Without these types of configurable tools initial implementation costs can be overshadowed by significant business delivery costs. The ongoing cost of system reconfiguration to meet changing standards and legislation must also be considered.

Remember that a business-focused approach can also pay dividends. All too often, an organization will not only specify the business requirement that needs to be addressed, but also the technology that it expects that solution to deliver. A solution provider with worldwide experience can provide alternative approaches from other regions that might address these requirements in ways that better suit the goals of the organization.