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Multilevel Linear Referencing System (MLRS)

An Automated Approach to Managing Components of a Linear Reference System Network and Event Data

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Hexagon provides geospatially-powered solutions that support the management of complex transportation systems. Our transportation solutions focus on satisfying the industry needs for managing, analyzing, and reporting enterprise data through the use of standard development practices and state-of-the-art technologies.

One of the core solutions Hexagon offers for the transportation industry is the Multilevel Linear Referencing System (MLRS). The MLRS serves as a foundation for transportation agencies to collect and manage locationally referenced roadway inventory and condition data. This white paper discusses the business needs an MLRS addresses and the tools needed to build and maintain it.

MLRS Overview

What is a multilevel linear referencing system? MLRS is an automated approach to managing the components of a linear reference system network and event data, regardless of the location method or geometric representation used. MLRS is different from the traditional LRS management practice in that the base network can represent multiple linear referencing methods (LRMs), such as county-routelogmile, streetname-address, intersection-offset, etc., and can be displayed on the map using multiple geometric representations. Hexagon's core data model and software manage the various parts of the LRS independently through database joins and relationships. A temporally stable datum links these component parts to support event location stability and temporal data management and analysis.

MLRS has been a topic of discussion since the early 1990s and the original National Cooperative Highway Research Program (NCHRP) 20-27 study. Hexagon developed the GeoTrans data model as a practical approach to implementing the study's requirements. The GeoTrans data model is a derivative of the NCHRP 20-27 model and focuses on ease of use (GeoTrans Data Model section). This enables GeoMedia® product line to support MLRS, as well as the traditional single-level linear referencing systems.

Since the inception of the MLRS concept, there have been several implementations and attempted implementations. This type of model addresses a wide variety of issues common to most transportation agencies, and raises the question as to why it isn't used more often. First, let's review some of the benefits of an MLRS, and then explore why more agencies do not use these models.

Multiple Linear Referencing Models

Perhaps the key issue addressed by multilevel LRS is support for multiple LRMs. Most transportation agencies have various sub-departments and external sources that collect data about their transportation network using a variety of measurement methods and sometimes different road or rail naming conventions. Figure 1 shows a few example LRMs.

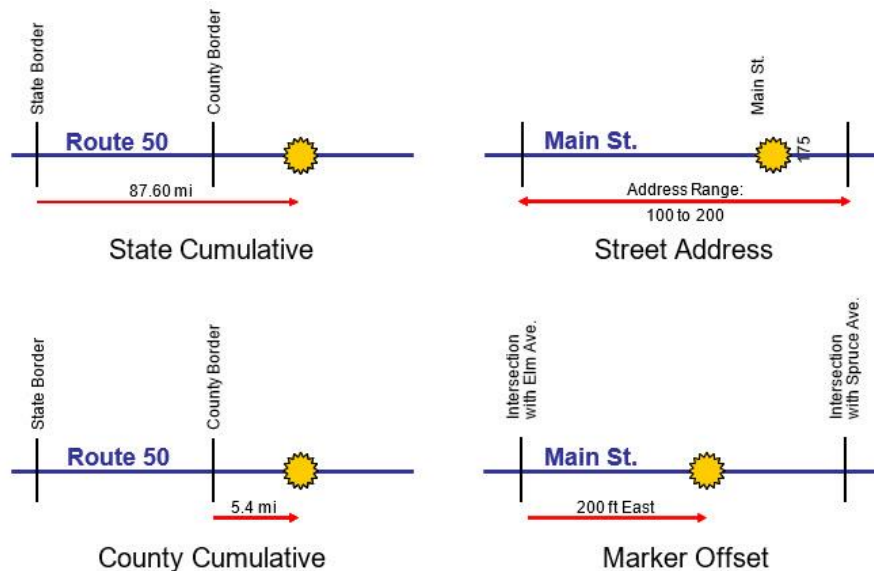


Figure 1: Multiple linear referencing models examples

The integration, analysis, and reporting of data collected from various sources depends on support for multiple LRMs. For example, if you want to locate segments of roadway where vehicle crashes occurred with no guardrail, you would need to use the different LRMs together to locate the crash data and overlay it with the guardrail information. This is difficult to do without a pre-existing relationship between the multiple LRMs.

Event Location Stability

A difficult challenge for transportation practitioners is how to account for changes to the transportation network during its history. These changes can include new names for roads, realignments, recalibrations, and more. To illustrate these effects, we have an example of a small piece of roadway with point and linear event data associated with it. The points represent crash locations along a road, and the linear event represents pavement conditions (Figure 2).

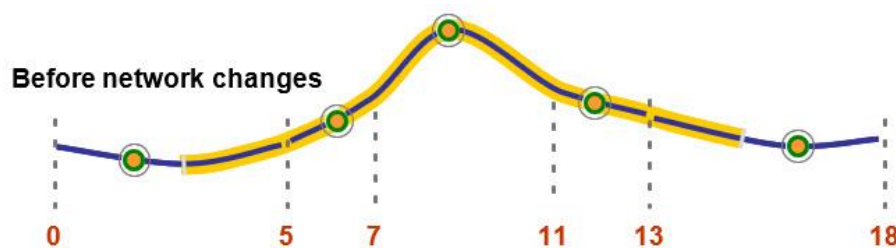


Figure 2: Small section of a road before network changes

Now let's see what happens to our roadway event data when the road segment is realigned and recalibrated. Because dynamic segmentation is an interpolation based on the road name, measures, and geometry, changes to the network can cause the linearly referenced event data to shift. In this example, the crash data shifts to the wrong location and pavement conditions for a now-abandoned road section are located along the new roadway (Figure 3).

Note: This is not the correct representation of where these events should be located. This is one of more popular problems associated with a traditional single-level LRS.

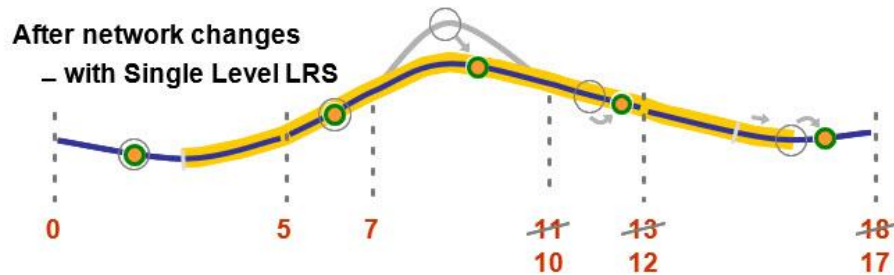


Figure 3: Same section of the road after network changes

Features of Hexagon's GeoTrans data model can address such problems. Using the GeoTrans data model, the crash and pavement condition data do not shift (Figure 4). In addition, the model displays pavement conditions only for roadway segments where the data actually occurred (even with linear event data).

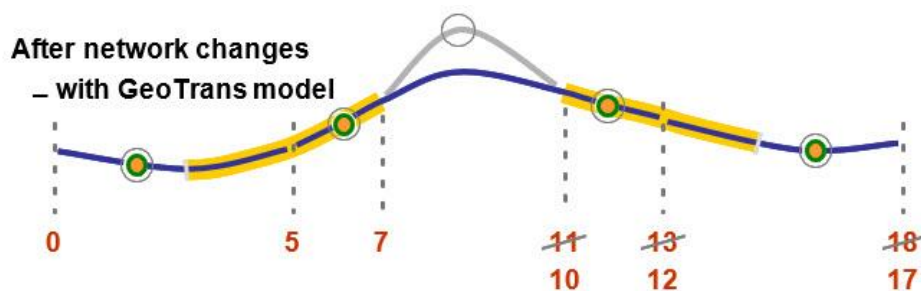


Figure 4: Section of the road after network changes using GeoTrans model

Inaccurate data can lead to bad decisions. Ideally, we should see only the events pertaining to the current version of the network. This should work for both point and linear events, and GeoMedia Transportation Manager and the GeoTrans data models make this possible.

Many agencies want to study the status of their networks for a specific time period and see only those events that pertain to the network as they existed during that time. This type of temporal analysis and temporal data management is made easy when you use GeoMedia Transportation Manager in conjunction with the long-term transaction capabilities of GeoMedia Professional. This application is discussed in Temporal Data Maintenance and Analysis section of this paper.

Multiple Geometric Representations

Your transportation agency often must manage more than one geometric representation of your network, which Hexagon's MLRS can support. For example, your agency may use different levels of generalization for different map products or different types of transportation analysis. Agencies often want to use the same event data against the different geometric representations, depending on whether they are performing large-scale or small-scale analysis (Figure 5).

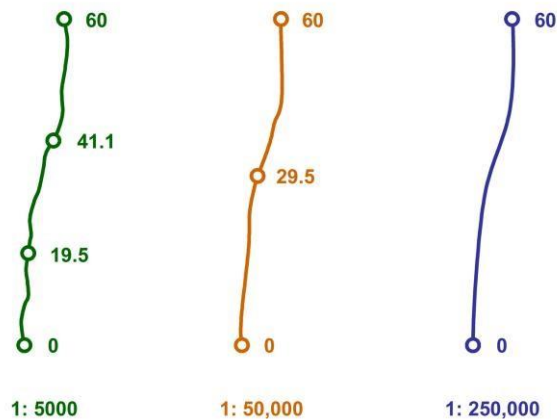


Figure 5: Multilevel LRS's allow agencies to use data against different geometric representations

Another common use of multiple geometric representations is when data comes from a regional or national agency, one or more local agencies, or a commercial data provider. Data coverage can overlap considerably, or many roads covered locally may not include regional data. For some analyses, you will want to see all of the local roads; for others, you will only want to use the major roads.



Figure 6: Multiple geometric representations are valuable when data comes from multiple agencies

Without an MLRS, you would have duplicated 100 percent of your LRS data maintenance efforts for each geometric representation. In addition, you are not assured that individual LRSs are synchronized, or if they will generate similar results. Agencies want to easily switch between geometric representations without worrying if this will affect the validity of their analysis. This is possible with Hexagon's MLRS (Figure 6).

Multilevel LRS Data Maintenance

So how does Hexagon offer the benefits of a multilevel LRS without unnecessarily adding complexity to the process? First, there is an easy transition from a traditional, single-level LRS to an MLRS. GeoMedia Transportation Manager provides a one-command conversion that both populates and cross-references the various tables of an MLRS (Figure 7).

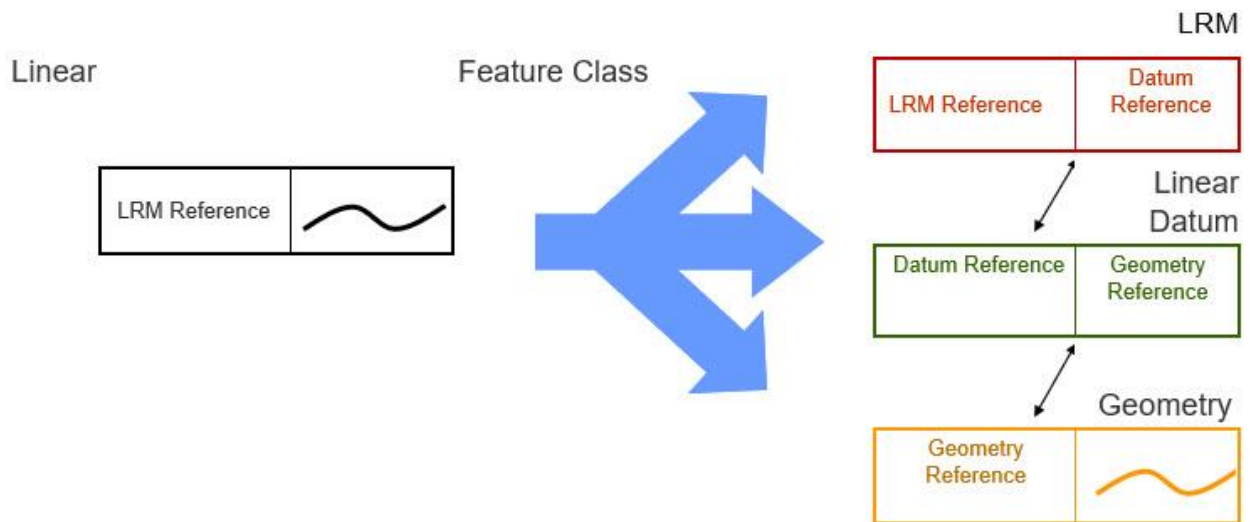


Figure 7: GeoMedia Transportation Manager populates and cross-references multilevel LRS tables

The second key to Hexagon's MLRS data maintenance story is GeoMedia Transportation Manager's collection of MLRS-aware intelligent editing commands. For ease of use, these commands were designed to mimic the editing commands in GeoMedia Professional. However, they go further in two ways. The commands understand the GeoTrans data model and know that the road name and measure data go on the LRM level, that the geometry goes on the geometry level, and that all levels need to be linked together. The commands also recognize that certain rules must be followed in editing the LRS. For example, the Insert, Split, and Merge commands automatically handle measure attribution, the Redigitize command creates new datum segments only where there are changes to the geometry (Figure 8), and the Merge command only merges segments belonging to the same route. The two Calibration commands can quickly populate LRS-specific attribution.

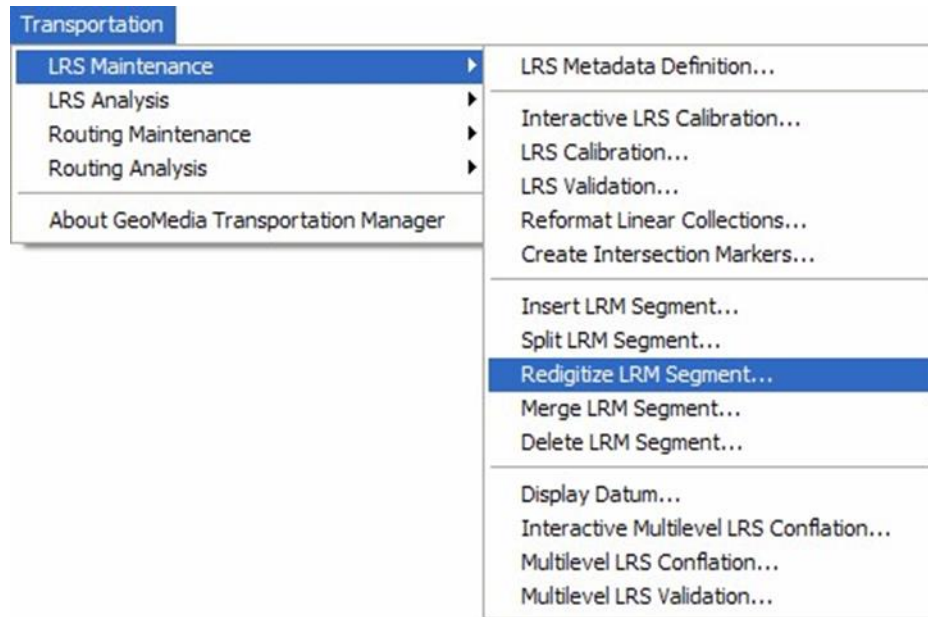


Figure 8: Redigitize command knows only to create new datum segments where there are changes to the geometry

Worthy of special note are Hexagon's special MLRS conflation capabilities. Conflation selectively and intelligently merges information from one data set with another data set. For example, you can use new global positioning system (GPS) data to update a roadway network, while keeping existing road-naming and measurement attributions.

LRS conflation is more complicated than generic conflation because the two data sets are not usually segmented identically, so there is no one-to-one correlation between elements in the two data sets. MLRS adds another complexity in that the merged information needs to go to specific tables. Hexagon provides special tools that understand and handle these complexities. These tools are provided for both interactive use (in GeoMedia Transportation Manager) and bulk use (requires both GeoMedia Professional and GeoMedia Transportation Manager).

MLRS conflation is an extremely flexible capability that can perform a number of important transportation data management tasks, which can include:

- Converting a single-level LRS to an MLRS
- Replacing existing data with better data – replacing old geometry data with better data, such as GPS, without affecting existing route name and measurement data
- Adding LRMs – extending an existing LRS with a street address LRM
- Adding geometric representations – extending an existing LRS by adding a geometric representation created by another agency
- Processing data updates – performing updates from a periodically updated data source to update changed data, to add new data, and, optionally, to delete portions of the network that are no longer in service
- Adding to existing data – adding roads related to new development
- Deleting existing data – deleting a whole region's worth of data or a particular LRM or geometry

Temporal Maintenance and Analysis

The long-term transaction capabilities of GeoMedia Professional are the key to both temporal analysis and temporal data maintenance. Both of these are important to transportation agencies charged with tracking improvements or deteriorations to the transportation network that may occur over time. GeoMedia Professional works with Oracle's Workspace Manager to transparently capture real-world history while you are editing (Figure 9). The basic workflow is as follows:

- Create a revision set and fill in the edit date (start an editing session)
- Edit as usual
- Commit or discard your changes and retire your revision set



Figure 9: Capturing real-world history during editing process

An important capability of the long-term transaction system of GeoMedia Professional is the ability to perform two different types of time stamping as needed. One type is for edits that represent real-world changes, such as a realignment. The other type of stamping is for simple data corrections that do not represent any actual real-world change. This level of detail is important in creating an accurate and useful temporal record.

Regarding temporal analysis, you can either review data that represents a point in time or a time range. You can even look at multiple time representations simultaneously. That means you might want to show your road network and its event data as they were during a five-year period in one color and another five-year period in another. This is useful for depicting trends or evaluating the impact of a capital improvement project.

Few Transportation Agencies Use Multilevel LRS

Transportation agencies can gain many important benefits when they use an MLRS. However, most agencies still use traditional, single-level LRS.

One reason why more agencies do not use MLRS is that implementations have traditionally been very costly due to the lack of technology to support them. Until now, a commercial off-the-shelf (COTS) solution did not exist. Implementations required customization for a particular customer's needs or specifications. The toughest part of these custom implementations has not been analysis, but data maintenance. The data in an MLRS are spread over multiple, connected layers. A single change affects multiple layers and the relationships between those layers. The challenges associated with an MLRS implementation have been too difficult for most agencies to overcome.

GeoMedia technology can help you overcome these obstacles with COTS tools that integrate the benefits of MLRS, and tools used to maintain and make use of it. The GeoMedia product line can support traditional, single-level LRS, and also offers a complete set of tools for building, maintaining, and analyzing an MLRS. You can have all of the benefits of an MLRS, without the complexity. This allows for better, more accurate, and complete analyses of transportation data and makes the promise of MLRS a reality.

Routing

In addition to the ability to maintain a MLRS, GeoMedia Transportation Manager provides a fully functional routing environment. This enables your transportation agency to leverage valuable locationally referenced information in routing applications.

Commercial data sets often contain a rich amount of data on the street segments that are valuable to efficiently routing vehicles. You can add these types of data sources to the MLRS as an additional LRM and create a routable network through the process of LRS Conflation. You can add any or all parts of the data to the MLRS model. This allows incorporation of new data sources without the necessity to have a completely different set of maintenance procedures to maintain them.

You can also use LRM data from the MLRS to build a routable network. In addition, the system can locationally reference event data, such as bridge clearances and lane widths, against the network and restrict where certain classifications of vehicles are allowed to move through the network. In addition, the system can use other types of locationally referenced event data, such as construction projects, to define temporary restrictions that would affect the routing of vehicles. These could be used as a blockage or as a warning that traffic will be moving at a much slower rate of speed. Also, turn movements can be modeled to properly define the true cost of moving through the network.

The ability to generate routing applications through the Web is becoming more important for transportation agencies. GeoMedia WebMap Professional gives you the ability to create a routing Web service. You can use this Web service to generate routes based on a “best order” or “find closest” algorithm. You can also use the routing Web services in conjunction with the dynamic segmentation and LRS precision Web services to more accurately model the network and navigate vehicles safely through it.

Web Implementations

Thus far, we have discussed only desktop applications for managing MLRS data, such as GeoMedia Transportation Manager and GeoMedia Professional. However, a large number of Hexagon customers make use of GeoMedia WebMap Professional for transportation applications.

Hexagon’s approach to deploying transportation solutions make extensive use of GeoMedia WebMap technology. This is made easier by the fact that the desktop applications share much code with GeoMedia WebMap Professional. That means you can seamlessly use the same data for both desktop and Web-based applications. GeoMedia WebMap Professional has linear referencing, routing, and temporal capabilities (Figure 10).

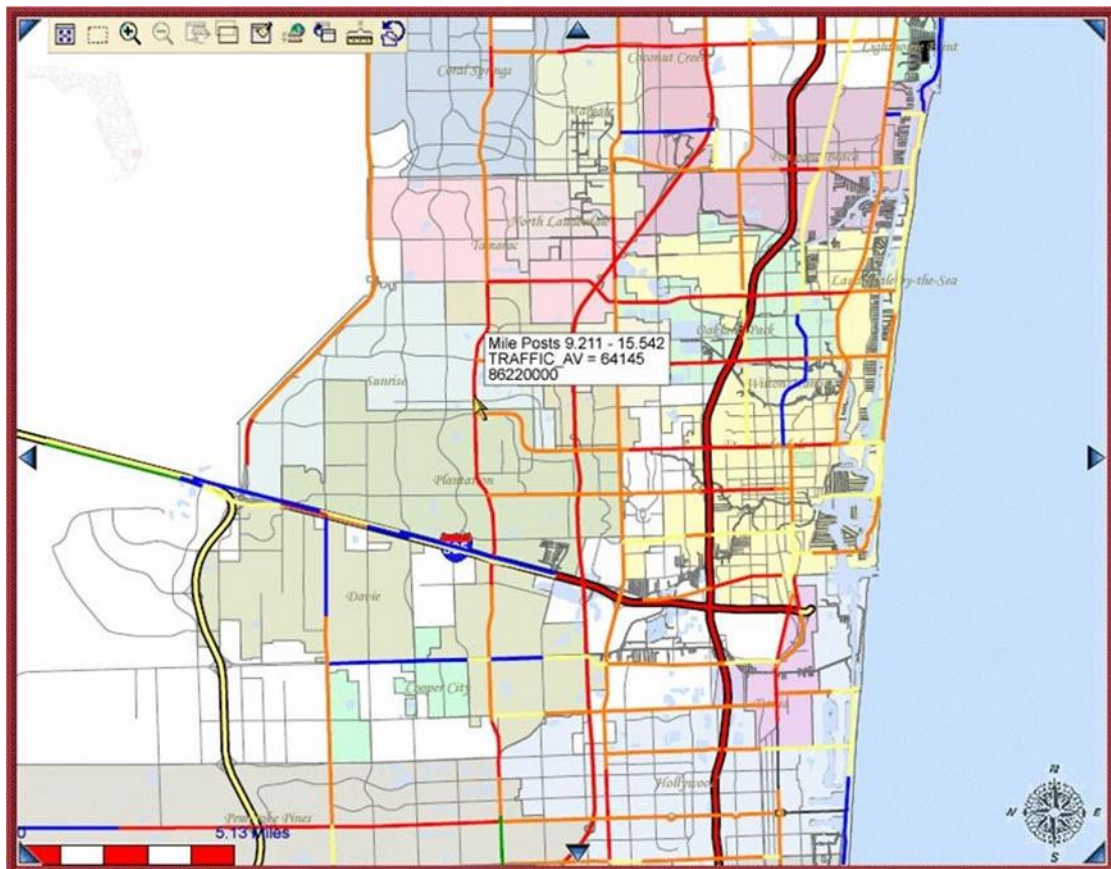


Figure 10: GeoMedia WebMap Professional has linear referencing, routing, and temporal capabilities

Continue the Evolution of Your Enterprise Linear Referencing and Geospatial Solutions

Transportation agencies have faced a multitude of issues that traditional LRS and LRS maintenance methodologies do not adequately address. These can include multiple location referencing methods, multiple geometric representations of the road centerline, event location stability when changes occur to the road bed, and inadequate techniques to temporally analyze the evolution of the transportation network. For agencies to adequately address these concerns, they need a more robust LRS data model and software to build and maintain it.

Hexagon's transportation solutions, coupled with GeoMedia Transportation Manager and MLRS, provide both the robust data model (GeoTrans) and the off-the-shelf maintenance tools (GeoMedia Professional, GeoMedia Transportation Manager) to deploy a sophisticated solution. The solution addresses these and many other challenges for transportation agencies.

Until now, an MLRS data model was strictly an academic and/or manual exercise since there were no automated tools to maintain it. Now you can easily address many of the challenges commonly associated with managing linear networks and continue the evolution of your enterprise linear referencing and geospatial solutions through the use of Hexagon technology.

GeoTrans Data Model

We review the development and structure of the GeoTrans data model that is the core of Hexagon's MLRS solution. The GeoTrans data model is derivative of the NCHRP 20-27 model. However, we have made some tweaks to improve event location stability and temporality and to allow for more flexible segmentation.

Before we get into the GeoTrans data model, let's look at a logical representation of the traditional, single-level LRS (Figure 11). A single-level LRS consists of an LRS linear feature class with geometry, name, and measurement data. This LRS linear feature class is the foundation for linearly referencing any number of event tables. The LRS linear feature class and the event tables are "joined" via dynamic segmentation. This model works fine for a static network with just one LRM and just one geometric representation of the network, and has been state-of-the-art for years.

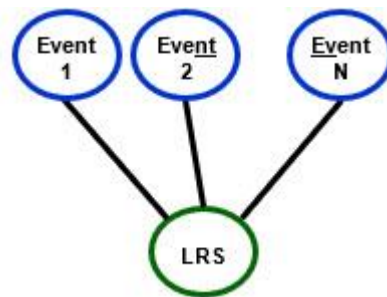


Figure 11: Traditional single-level LRS

Now, what do we do if we have a network that changes over time (road-name changes, realignments, etc.) if we have more than one LRM, or if we have more than one geometric representation of our network? The theory behind MLRS is to abstract out into separate entities those parts of the network that change independently (Figure 12). To that end, we have abstracted the route naming and measurement part into an LRM layer that can contain any number of LRMs. We have also abstracted the geometric representation part into a geometry layer that can contain any number of physical representations of our network. We have tied both of these to a linear datum. The linear datum acts as a non-changing anchor to which these other layers can tie. A unique feature of the GeoTrans model is that the linear datum records can neither be edited nor deleted. They can only be added to when there are new roads or realignments. This permanence is, as we shall see, the key to event location stability.

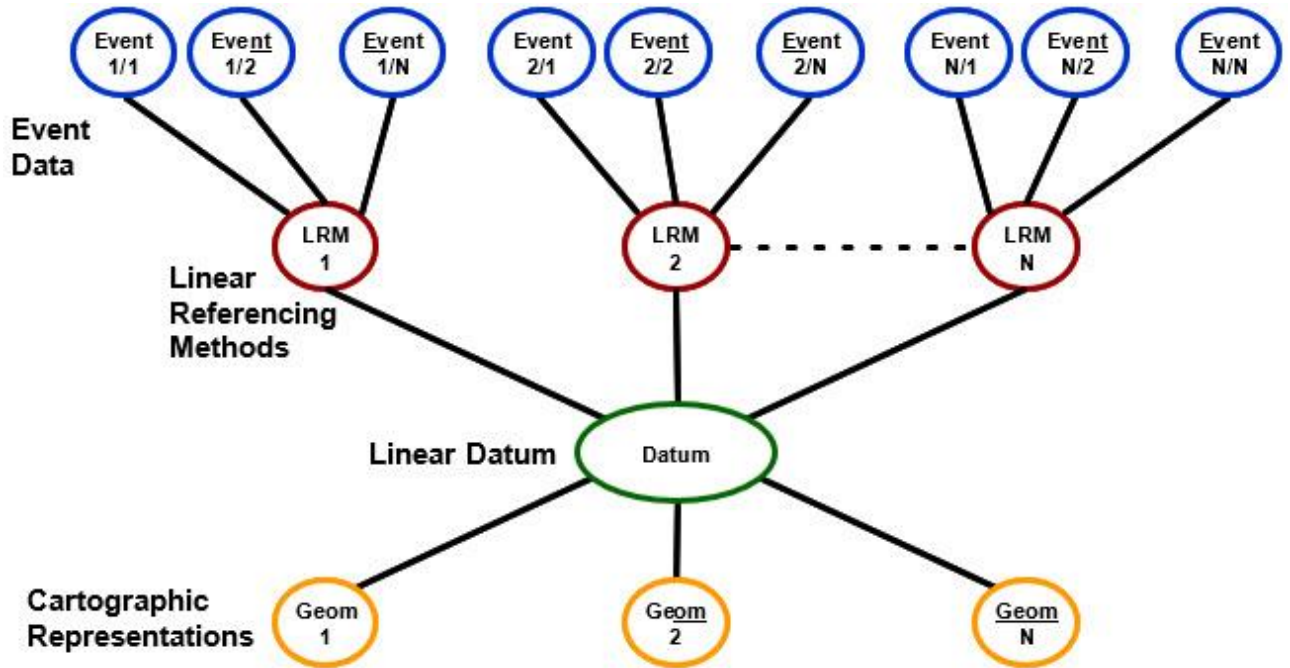


Figure 12: Multilevel LRS reflects changes to the network over time

So from a practical standpoint, how do we relate the individual LRMs and geometries back to the linear datum? When we need a one-to-one or a one-to-many relationship in a database, we use a “join,” where one field in one table exactly matches a field in another table. However, if we do not want to force our model to have all geometries and LRMs segmented identically, then what we have is a many-to-many relationship. This is handled by having an intermediate table to store the relationship. The ability to have completely independent segmentation is a unique feature of the GeoTrans data model. We accomplish this by not using a standard many-to-many join, but rather by using dynamic segmentation to establish our relationships.

In Figure 13, we show the intermediate tables that store this special many-to-many relationship. We call these cross-reference tables (G-D cross-reference refers to geometry to datum cross-reference, and L-D cross-reference refers to datum to LRM cross-reference). The diagram also shows the multilevel dynamic segmentation that relates each of these tables together. This complexity is managed for you by the software, so you get the benefits of the model without the extra trouble.

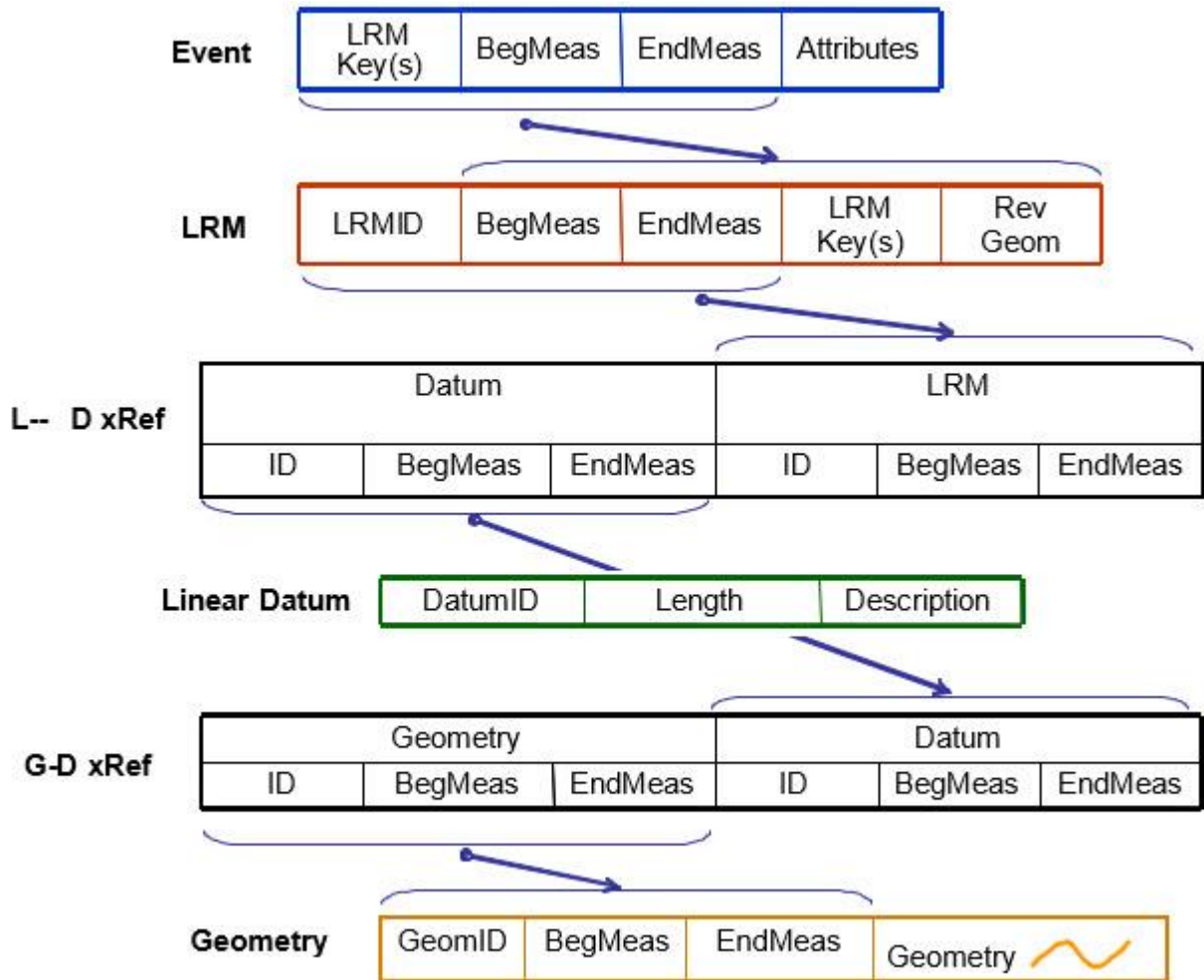


Figure 13: Intermediate tables store many-to-many relationships

Another key part of the model pertains to our event location stability methodology. By way of contrast, we will describe two common alternative methods that some have used to accomplish this same thing.

The first alternative method is sometimes referred to as permanent event geometry, which simply means storing geometry created during dynamic segmentation permanently with the event data. The upside of this methodology is its simplicity. One downside is that it works well only if you have just one geometric representation and you never expect to update it with newly collected geometry. Another downside is that it does not handle temporality well. If a road gets realigned, this method will still show event data along the old alignment that no longer exists.

The second alternative method is sometimes referred to as cascading edits. This method develops database triggers that will change the measures of all event data associated with an LRS any time the LRS changes. The upside of this method is that the custom code it contains gives a lot of flexibility. However, it has several downsides. First, as in most transportation agencies, there could be a performance issue when a large number of tables are affected. Second, it assumes all event tables are stored in the central database and thus are accessible to these triggers. Third, this problem is fairly difficult to implement for events associated with the segment of the LRS that is actually changed. Lastly, once the measures are changed, they no longer are in the correct location in relation to the “old” version of the LRS. This creates an event location stability problem if you try to look at a temporal view of the data the way it once was. Thus, this method is ill-suited for temporal analysis.

The method we have implemented in GeoMedia Transportation Manager and the GeoTrans data model is called event registration. The downside of this method is that it requires users to perform a onetime event registration step whenever they bring in new event data. The upside is that it has none of the other downsides described previously.

The LRS Event Transform command performs the event registration step. One of the options of this command is to convert LRM-based names and measures on event tables to datum-based names and measures. Once this simple step is complete, you can use event data regardless of how the network changes over time. Road names can change, routes can be recalibrated, and realignments may occur – but the event data will still locate correctly. This same command can transform event data from one LRM to another (Figure 14).

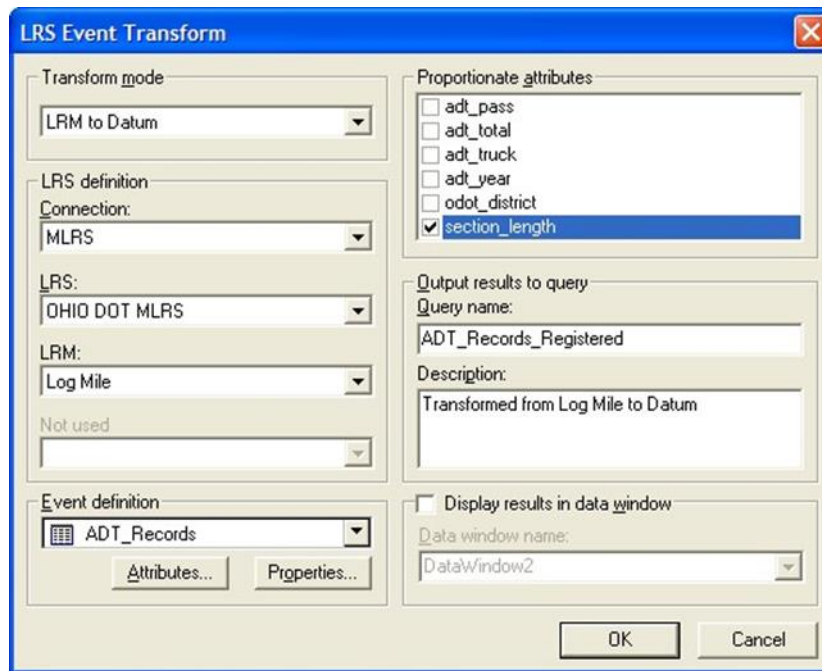


Figure 14: LRS event transform command can transform data from one LRM to another

Figure 15 shows the complete GeoTrans logical model. Note that this model shows some events as LRM events and others as datum events. The datum events are those that have gone through event registration and thus will receive the benefit of Event Location Stability. Also shown on this diagram are the two types of external markers now supported by the GeoTrans data model. The ones labeled “LRM” markers are the same as those used by traditional, single-level LRS. The ones labeled “datum markers” are LRM markers that have gone through event registration and, therefore, have the same location stability as datum events.

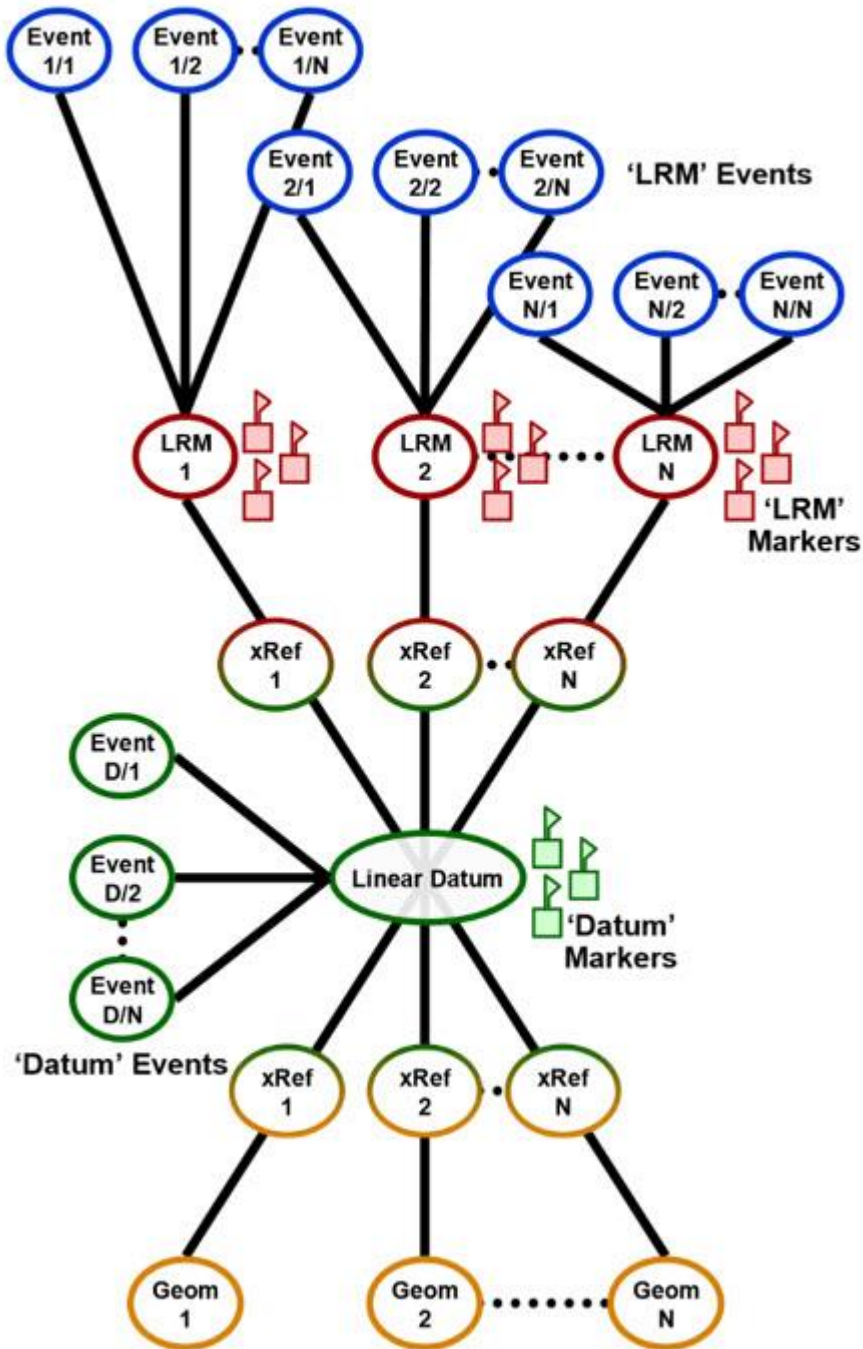


Figure 15: Complete GeoTrans logical model

Another important consideration in the design of this model is support for temporality. Many agencies want to not only be able to analyze their transportation network as it is – but also how it was (for trend analysis) or how it might be (for design and planning purposes). When you use GeoMedia Transportation Manager with the long-term transaction capabilities of GeoMedia Professional, you can automatically store historical versions of the network as it is being edited to represent the latest changes to your network. Likewise, you can model designs for future changes to the network without destroying the current representation. With events that have been registered, you can view both the network and linearly referenced event data correctly for any time for which you have data.

Please note that use of the long-term transaction capabilities of GeoMedia Professional is not required in order for you to use the Multilevel LRS capabilities of GeoMedia Transportation Manager, but without it only current network analysis is possible.

Figure 16 duplicates the logical model diagram above and shows it side-by-side with a physical model template.

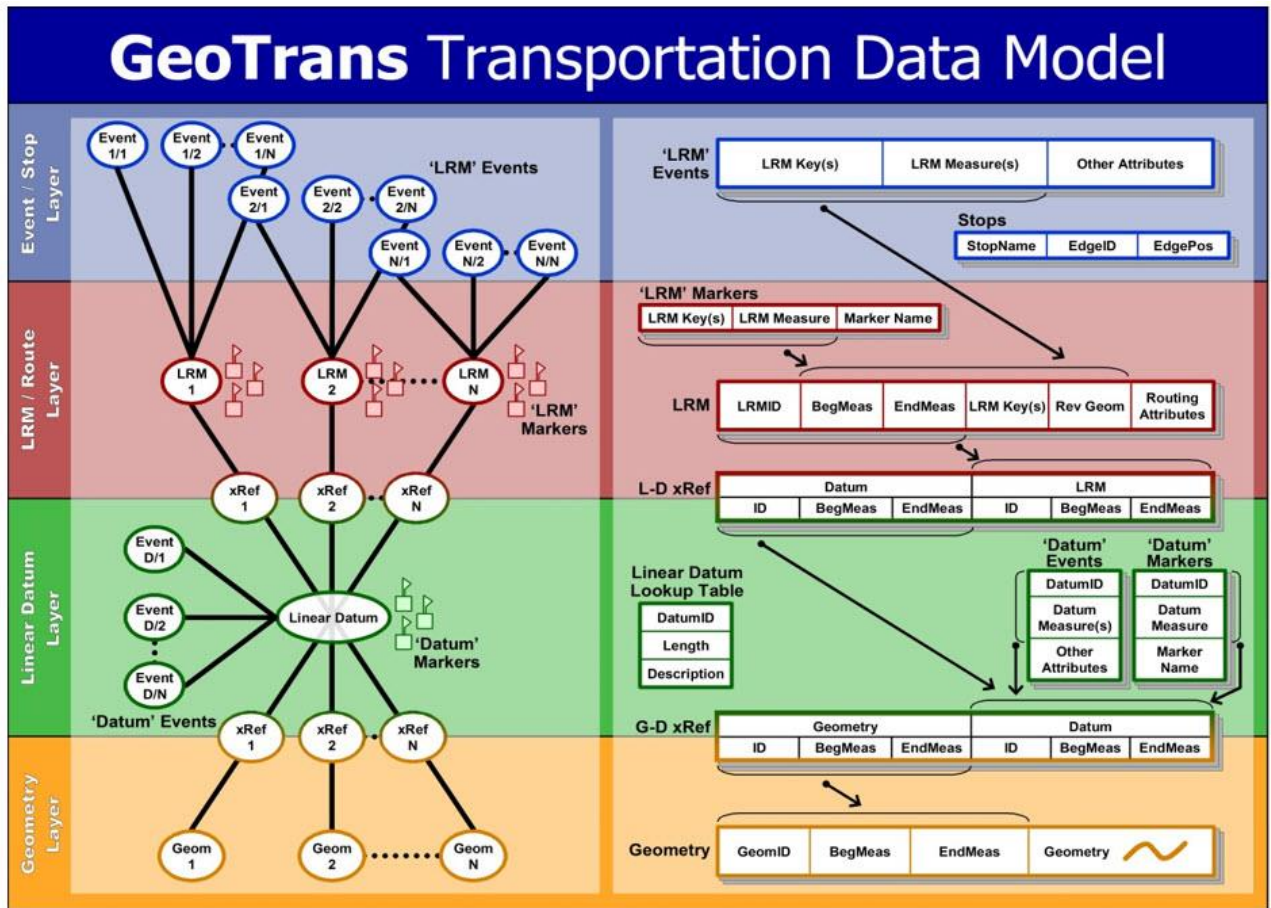


Figure 16: GeoTrans logical model with the physical model template



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Hexagon is a global leader in sensor, software, and autonomous solutions. We are putting data to work to boost efficiency, productivity, and quality across industrial, manufacturing, infrastructure, safety, and mobility applications.

Our technologies are shaping urban and production ecosystems to become increasingly connected and autonomous — ensuring a scalable, sustainable future.

Hexagon's Geospatial division creates solutions that visualize location intelligence, delivering a 5D smart digital reality with insight into what was, what is, what could be, what should be, and ultimately, what will be.

Hexagon (Nasdaq Stockholm: HEXA B) has approximately 21,000 employees in 50 countries and net sales of approximately 4.4bn USD. Learn more at hexagon.com and follow us @HexagonAB.

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