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TOWARDS A RULE-DRIVEN APPROACH
FOR UPDATING DYNAMIC ROAD SEGMENTS

ABSTRACT

In recent years, the development of the GIS-T (Geographic Information System for Transportation) applications has gained much attention, providing the transportation planners and managers with in-depth knowledge to achieve better decisions. Needless to say, developing a successful GIS for transportation applications is highly dependent on the design of a well-structured data model. Dynamic segmentation (DS) data model is a popular one being used more and more for different GIS-T analyses, serving as a data model that splits linear features into new set of segments wherever its attributes change. In most cases, the sets of segments presenting a particular attribute change frequently. Transportation managers place great importance on having regular update and revision of segmented data to ensure correct and precise decisions are made. However, updating the segmented data manually is a difficult task and a time-consuming process to do, demanding an automatic approach. To alleviate this, the present study describes a rule-based method using topological concept to simply update road segments and replace the manual tasks that users are to carry out. The proposed approach was employed and implemented on real road network data of the City of Tehran provided by the Road Maintenance and Transportation Organization (RMTO) of Iran. The practical results demonstrated that the time, cost, human-type errors, and complexity involved in update tasks are all reduced.

KEYWORDS

GIS-T, dynamic segmentation, segment, automatic update, change type, rule

1. INTRODUCTION

Geographic Information System (GIS) can appropriately provide powerful and efficient tools to improve the quality of transportation decision-making process [1]. One of the most important functions of GIS-T is Dynamic Segmentation (DS) technique, which has been considered as an efficient means to make more precise and flexible road management. Early research in GIS in transportation by Dueker [2], Fletcher [3], and Vonderohe et al. [4] identified the essential need for this capability in GIS-T. Due to its core role in the field of GIS-T, the research of DS has gained much attention from both transportation and GIS experts [5, 6, 7, 8, 9, 10, 11]. DS technique provides a way in which a road can be split and segmented according to attributes, in other words, this method provides the flexibility to split linear features into new set of segments wherever its attributes change. In this approach, attributes are linearly referenced and linked dynamically to the entities forming the network [12]. An attribute can be viewed as a spatial (linear) event occurring on the network. DS uses data files called event tables to store segmented data for linear features [13]. Features containing segmented data often have attributes that change frequently. For example, data describing pavement conditions will need to change when the pavement deteriorates or is rehabilitated. These changes may occur extensively during short times. Therefore, manual updating of these data is a complex and time-consuming process. This is because replacing each new segment instead of old segment(s) requires executing of actions such as insert, delete, and update on the event table. Manual approach can lead to increasing time, cost, complexity, and human-type errors involved in update operation, especially when dealing with a huge number of new segments. Management of updates in order to maintain current representations of transportation systems is a growing concern [14].

To preserve advantages of DS for GIS-T it is necessary to find a method for easy and automatic updating of segments. Developing user-friendly automatic updating methods of spatial information becomes the key to successful maintenance of large GIS databases [15]. Fast and sustainable GIS database update is closely linked with the continuing up-to-date data sources and efficient mechanisms for update [16]. Until the present time, there has been no research on automatic update of segments for DS technique.

The purpose of this research has been three-fold. First, an approach for identifying topologically inconsistent segments including segment overlaps and gaps is presented. Second, the spatial relationships which model segment change types are described to be used for updating rules. Third, IF-THEN updating rules using different operations (e.g. insert, delete, and update) are defined according to every single change type.

2. METHODOLOGY

2.1 Dynamic segmentation concept

Arc-node data model (i.e. static segmentation) represents roads as linear features with associated attributes. The attributes are integrated so that they are restricted to arcs with similar length and location without due attention to the applications at hand. Static segmentation is the traditional method for modelling features of network segments. Multiple features (attributes or events) are directly linked to the geometry of the segment [17]. In order to improve the flexibility of such Arc-node presentation in GIS-T, DS was proposed. DS is widely used in GIS-T as an efficient measure to manage the heterogeneous attributes along the linear features [18]. The DS process transforms linearly referenced data (i.e. line events or point events) stored in tables on routes [19]. This technique generates geometry for events without any storage of geometry. It is dynamic, since a new set of segments can be generated on the linear feature wherever its attributes change. Therefore, it considers dynamically continuous attribute changes. DS involves the division or segregation of network links into segments that are homogeneous for the specified set of attributes [20]. This method is obviously helpful to avoid excessive and uncoordinated segmentation [21]. Furthermore, it concentrates on high-spatial-resolution segments. DS locates multiple

events on route without any duplication in route geometry and without having to break arcs by nodes. The segments ensure that more concentrated and precise data are available which provides managers with additional information in order to make better decisions.

A route is simply any linear feature in which there is a measurement system to contain measure values (i.e. distances) of event data. This research deals only with line event data (i.e. segments) for update purpose. Each route R_j of routes network is the line feature on which n ordered segments S_i are located:

$$R_j = \{s_1, s_2, \ldots, s_n\} \qquad [1]$$

where:

$\quad R_j$ = route j

$\quad n$ = number of segments on R_j

The position of segment S_i on route R_j is defined by two measurement locations "From" (S_i, R_j) and "To" (S_i, R_j):

$$S_i = (From (S_i, R_j), To (S_i, R_j)) \qquad [2]$$

where:

$\quad S_i$ = i^{th} segment on R_j, $1 \le i \le n$

From (S_i, R_j) = measurement location for the beginning of S_i

To (S_i, R_j) = measurement location for the end of S_i

These segments or line events are stored in LET so that every row in this table references a segment. In general, an LET consists of the following fields which identify the location and attribute(s) associated with segments:

RouteID: route R_j on which segment S_i is located

From: From (S_i, R_j) value for segment S_i

To: To (S_i, R_j) value for segment S_i

Attribute(s): Attribute value(s) of segment S_i

The following is an example of LET containing segmented data on pavement conditions. As shown in *Table 1*, each segment is associated with two attributes. Since linear features are initially segmented based on only one attribute (e.g. pavement condition), adding other attributes into line event table may result in the same values for other attributes (e.g. province name). *Figure 1* presents stored segments in LET for pavement conditions on five routes. The line events in LET are related to the routes through values of field "RouteID". Measurement values in fields "From" and "To" indicate location of segments on routes. These segments completely cover the routes they reference.

Table 1 - LET for segments presenting pavement conditions

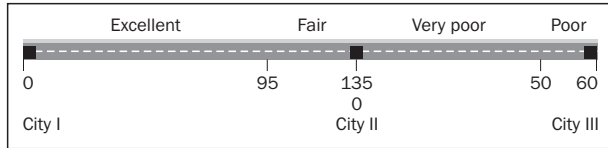| Segment	RouteID	From	To	Condition	Origin	Destination
S_1	R_1	0	95	Excellent	City I	City II
S_2	R_1	95	135	Fair	City I	City II
S_3	R_2	0	50	Very poor	City II	City III
S_4	R_2	50	60	Poor	City II	City III

Figure 1 - Segments and their measure locations on routes

2.2 Automatic update module

In most transportation applications, a large number of segments for a given event (e.g. pavement condition) change into new segments either spatially or non-spatially over time. In order to meet the needs for automatic update of segments, a rule-based automatic approach is proposed. It provides a practical easy-to-use way which ensures correct, consistent and timely updates of segments.

As mentioned earlier, for each segment (linear event), a record is stored in LET. This record contains spatial characteristic (measure locations) and attribute value(s) of each segment. In this research, update of segments means update of both spatial and non-spatial characteristics of segments. In this procedure, new segments are passed into automatic update module through Graphical User Interface (GUI). The module then updates the existing old segments in LET by new segments. This process will be executed each time that update is needed. *Figure 2* illustrates the proposed procedure by an example. In this example, old segments describing pavement conditions are automatically updated by new segments.

2.2.1 Topological consistency of segments

Before performing the approach, many certain constrains are specified to ensure if segments are topologically consistent, making appropriate context for the execution of updating rules. Several basic operations are employed to recognize which segment(s) overlap or

have gaps. In addition to having no overlapping set of segments and gaps, the segments on the given route are required to cover the entire route. The following statements are defined by means of which segment topological integrity and consistency can be ensured:

$$\forall S_i \in R_j, \text{From } (S_{i+1}, R_j) = \text{To } (S_i, R_j) \qquad (3)$$

$$\forall R_j, \text{From } (S_1, R_j) = 0, \text{From } (S_i, R_j) < \text{To } (S_i, R_j)$$
$$\text{and To } (S_n, R_j) = L_{R_j} \qquad (4)$$

where L_{R_j} is the length of R_j, S_1 represents the first segment on R_j, S_n is the last segment on R_j. In the above two statements, it is assumed that LET is sorted by two fields "RouteID" and "From" in ascending order. The statement (3) implies that segments on R_j cannot overlap and neither can they include gaps. The combination of (3) and (4) describes that segments on R_j continuously cover the entire R_j. *Figure 3* presents the detailed and step-by-step description of the procedure for recognizing the topological inconsistencies that exist between segments.

2.2.2 Segment change types approach

In order to perform rule-based automatic approach for the update of old segments, it is necessary to identify the type of changes from old segments into new segments. The determination of the form and type of changes is the key to characterize what kind of update operation is needed. In this study, a change type is considered as a spatial relationship between a new segment and old segment(s) on a route. This means that every change from old segment(s) into new segment can be spatially modelled so that each change type has its own mathematical condition. In general, changes are modelled in nine different types. *Table 2* shows these change types, their mathematical conditions and spatial representations. To describe mathematical conditions algebraically, the following notation is applied:
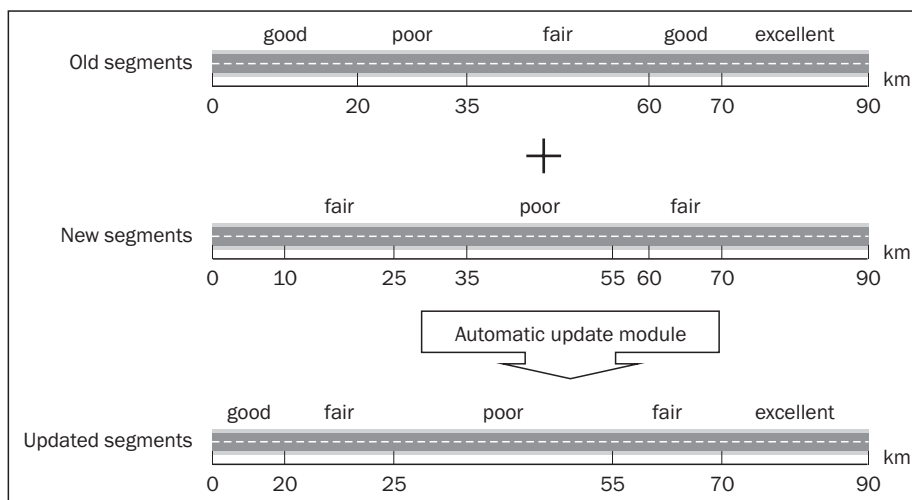

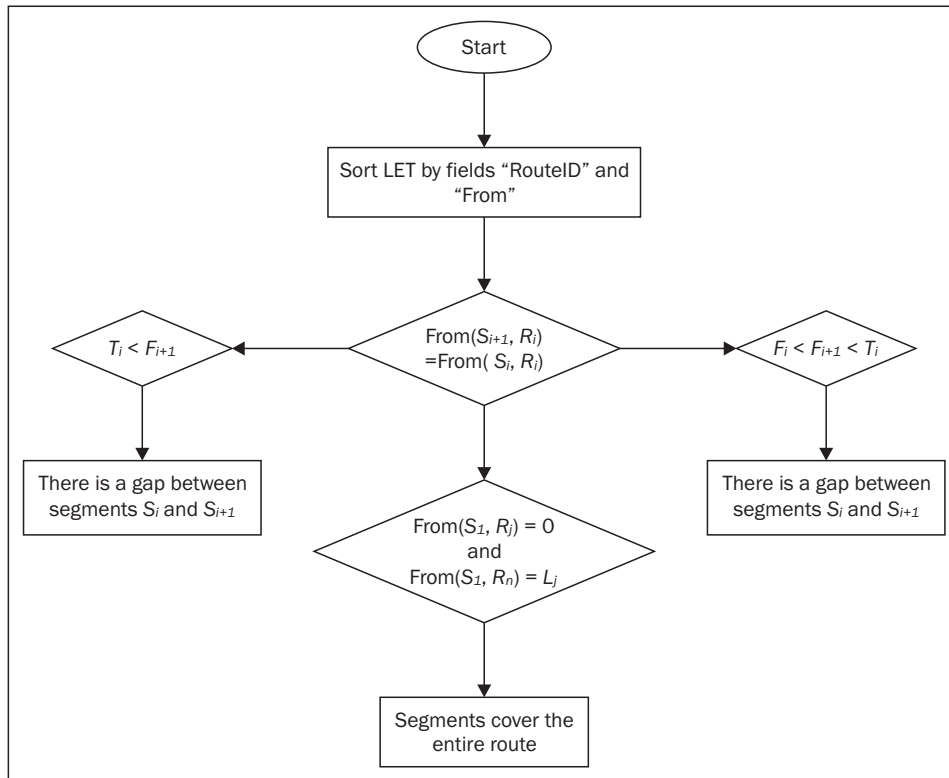*Figure 2 - Schematic diagram for automatic update of segments*

Figure 3 - Flowchart for recognizing the segments with gap and/or overlap

F_i = From (S_{O_i}, R_o) [5]

T_i = To (S_{O_i}, R_o) [6]

F_{new} = From (S_{new}, R_{new}) [7]

T_{new} = To (S_{new}, R_{new}) [8]

S_{O_i} = Old segment i [9]

S_{new} = (F_{new}, T_{new}) [10]

R_o = route on which S_{O_i} is located.

R_{new} = route on which S_{new} is located.

2.2.3 Change type rules

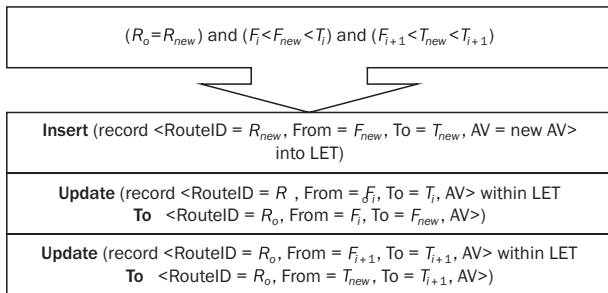Change types are already modelled, each of which needs a specific update operation for segments. To ex-ecute the required operation for every change type, a given rule must be defined. A rule is a structure that relates one or more conditions to one or more actions (consequences). This structure follows an "IF-THEN" statement so that the conditions are contained in the IF part of the rule, and the actions are contained in the THEN part. The mathematical condition of change type specifies the IF part of the rule. The THEN part consists of actions performing update operation for change type in IF part. The THEN part of these rules utilizes Data Manipulation Language (DML) statements of in-sert, update and delete for update and storage pur-poses. DML is a family of computer languages used by computer programs or database users to retrieve,

Table 2 - Types and mathematical conditions for segment changes

Change Types	Mathematical Condition
S_{new} is equal to one S_o	(R_o=R_{new}) and (F_i=F_{new}) and (T_i=T_{new})
S_{new} is covered by one S_o	(R_o=R_{new}) and (F_i<F_{new}) and (T_{new}<T_i)
S_{new} is left side matched and covered by one S_o	(R_o=R_{new}) and (F_i=F_{new}) and (F_i<T_{new}<T_i)
S_{new} is right side matched and covered by one S_o	(R_o=R_{new}) and (F_i<F_{new}<T_i) and (T_i=T_{new})
S_{new} is intersected by two S_o	(R_o=R_{new}) and (F_i<F_{new}<T_i) and (F_{i+1}<T_{new}<T_{i+1})
S_{new} is equal to sum of the (n+1) adjacent S_o	(R_o=R_{new}) and (F_i=F_{new}) and (T_{i+n}=T_{new}) and (n ≥ 1)
S_{new} covers (n-1) adjacent S_o	(R_o=R_{new}) and (F_i<F_{new}<T_i) and (F_{i+n}<T_{new}<T_{i+n}) and (n ≥ 2)
S_{new} is left side matched and covers (n) adjacent S_o	(R_o=R_{new}) and (F_i=F_{new}) and (F_{i+n}<T_{new}<T_{i+n}) and (n ≥ 1)
S_{new} is right side matched and Covers (n) adjacent S_o	(R_o=R_{new}) and (F_i<F_{new}<T_i) and (T_{i+n}=T_{new}) and (n ≥ 1)

insert, delete and update data in a database. For instance, the IF part and the THEN part for change type "S_{new} is intersected by two S_o" is presented below:

$$(R_o = R_{new}) \text{ and } (F_i < F_{new} < T_i) \text{ and } (F_{i+1} < T_{new} < T_{i+1})$$

Insert (record <RouteID = R_{new}, From = F_{new}, To = T_{new}, AV = new AV> into LET)

Update (record <RouteID = R , From = $_{o}F_i$, To = T_i, AV> within LET **To** <RouteID = R_o, From = F_i, To = F_{new}, AV>)

Update (record <RouteID = R_o, From = F_{i+1}, To = T_{i+1}, AV> within LET **To** <RouteID = R_o, From = T_{new}, To = T_{i+1}, AV>)

3. SYSTEM IMPLEMENTATION

In order to implement the proposed approach, ESRI's ArcGIS software was customized by using ArcObjects technology and VB.NET. ArcObjects, which is based on the Microsoft Component Object Model (COM) technology, enables users to develop and to customize their GIS applications using any COM-compliant development languages such as VB, VB.NET, and Visual C++ [22]. In ArcGIS, the DS process computes the map location (segments) of events stored in LET along their route reference. The result of DS is a dynamic feature class known as a route event source. It is displayed as a feature layer in ArcMap and like other feature layers it can be used for display, query and to perform analysis. *Figure 4* shows segments in route event source presenting pavement conditions for the roads of Tehran, Iran.

The developed application provides two different GUIs (Graphical User Interface) in ArcGIS environment; one for detecting the gap and/or overlap that exist between segments and another one for the automatic update of segments. As shown in *Figure 5*, users first
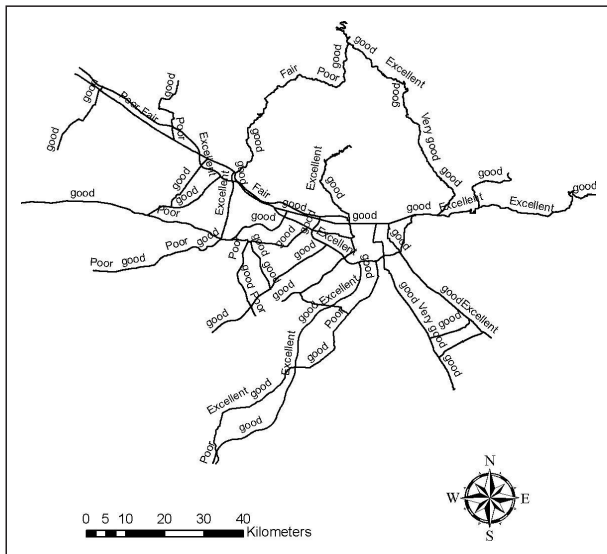

Figure 4 - A sample route event source layer

set the parameters required to identify the gap and/or overlap and the system then searches for the LET and represents those parts. *Figure 6* shows the custom dialogue window in which the user can handle automatic update operation of segments. In this window the user inserts the location and the associated attribute of each new segment in a row of the table. Then, the system automatically replaces the old segments in the chosen LET with the entered new segments.
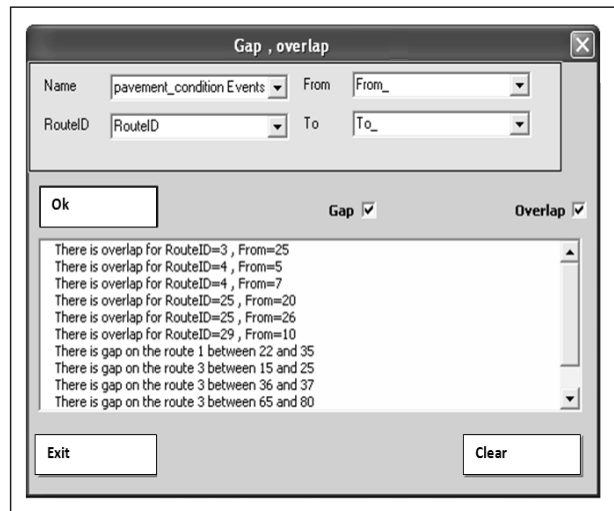

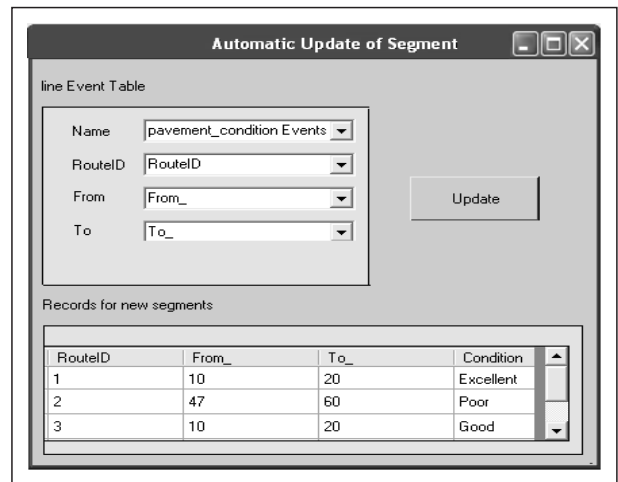*Figure 5 - GUI to detect the gap and overlap between segments*

Figure 6 - New segments dialogue window for automatic update operation

Automatic update of segments was applied by RMTO to the real segmented data of pavement conditions for routes of Tehran. The comparison between the experimental results of updating of these segments manually and automatically justifies the preference of automatic approach. According to this comparison, the automatic approach is expected to be better in terms of time, cost, human-type errors, and complexity involved in update operations. Many GIS experts carried out manual and automatic updates sev-

Table 3 - Measured time of manual and automatic update for each change type

Chang type	Automatic approach time (Sec)	Manual approach time (Sec)
S_{new} is equal to S_o	0.2	15
S_{new} is covered by S_o	0.4	39
S_{new} is left side matched and covered by S_o	0.4	25
S_{new} is right side matched and covered by S_o	0.2	28
S_{new} is intersected by two S_o	0.3	30
S_{new} is equal to sum of the (n+1) adjacent S_o	0.2	55
S_{new} covers (n-1) adjacent S_o	0.2	50
S_{new} is left side matched and covers(n) adjacent S_o	0.3	62
S_{new} is right side matched and Covers (n) adjacent S_o	0.3	58

eral times for each change type. Manual updates were executed through ArcMap editing tools allowing users to construct and update event data, while automatic updates were just involved with entering new segments data into GUI. The average amount of time (in seconds) spent on update operation in both manual and automatic approaches were measured. The measured times obtained are summarized in *Table 3*. From *Table 3* it is quite clear that automatic approach takes much less time than the manual approach.

4. CONCLUSION

The potential of GIS-T dynamic segmentation technique to manage heterogeneous attributes along the linear features allows for efficient spatial transportation data model, offering more precise analyses for the right and effective decisions. Thus, employing an automatic approach to update segments is of critical importance. In this study, a method for checking the topological consistency was proposed and then a rule-driven updating method was adopted to effectively support the easy and rapid update of segments. To accomplish this, the update operation is performed by means of a set of pre-defined IF-THEN rules. The rules are constructed in the way that the IF part of the rule describes the type of change from old segments into new segments and the THEN part performs the update operation needed. Change types are in fact the spatial relationships between old segments and new segments representing different templates as IF parts. In contrast to the manual approach, the proposed automatic method effectively reduces the time spent on the update process, thus reducing the cost of human work needed. Moreover, the results reveal that employing automatic approach can greatly minimize the complexity and human-type errors. It is worth noting that the automatic method is executed on the ordinary plain tables thus not needing any special software anymore.

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