

Oracle Database 10g:  
Building GIS Applications Using  
the Oracle Spatial Network Data  
Model

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# Building GIS Applications Using the Oracle Spatial Network Data Model

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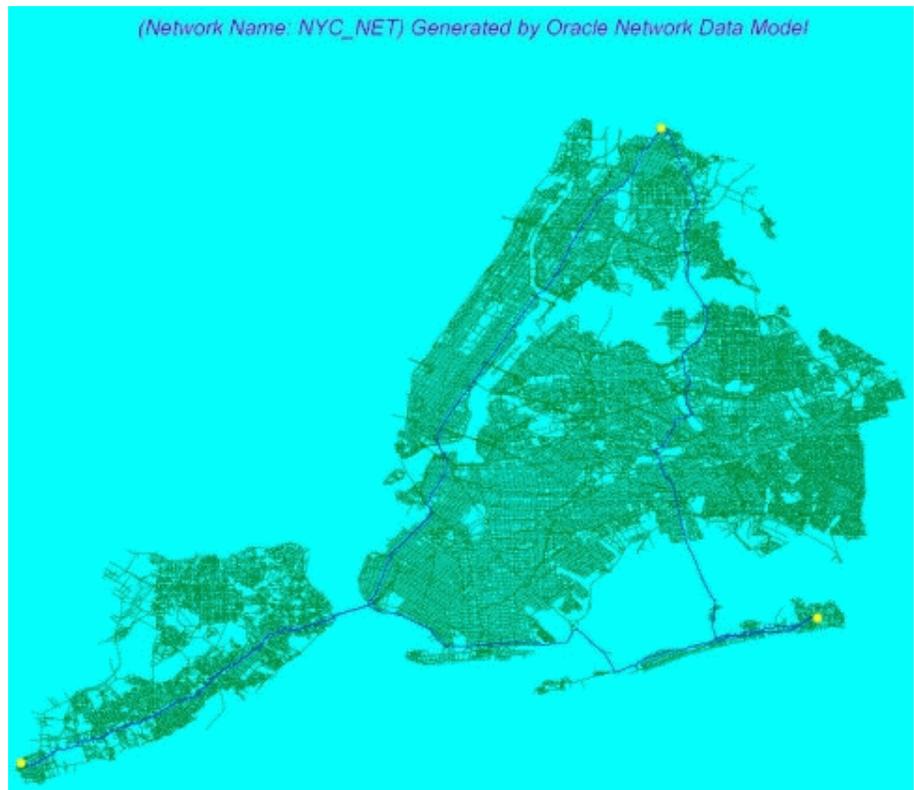
# Building GIS Applications Using the Oracle Spatial Network Data Model

## **ABSTRACT**

Network modeling, management, and analysis are common tasks for Geographic Information Systems (GIS). Network analysis includes routing (path computation) in transportation networks, tracing (accessibility) in utility networks, and resource allocation in decision-making and customer relationship management (CRM) applications. In this paper we present the Oracle Spatial network data model, an Oracle Database release 10g feature that lets users model and analyze networks. This feature simplifies network modeling, analysis, and management so that users can focus on application logic. The network data model provides an open, generic data model with many common GIS analysis capabilities. In addition, it fully supports Oracle Spatial objects of type SDO\_GEOMETRY. GIS applications based on the Oracle Spatial network data model are discussed in this paper.

## **INTRODUCTION**

There are two common types of GIS applications: applications that deal with spatial proximity, and applications that deal with both spatial proximity and connectivity. For many applications queries on spatial proximity, which mainly consider metrics like Euclidean or geodetic distances, are sufficient. However, there are instances when connectivity needs to be taken into account, such as in finding the shortest distance between two locations in a road network. Many GIS applications are networks that require modeling and analysis on object relationships (connectivity). Figure 1 shows a road network of New York City.



**Figure 1. New York City Road Network (60384 nodes, 151962 links. Source: NavStreets from NavTech)**

Oracle Spatial has supported spatial objects since release 8.1.5. A complete set of indexes, operators, and functions is available for managing information based on spatial proximity. The network data model extends Oracle Spatial to deal with connectivity. Currently there are many GIS vendors offering network solutions; however, their solutions may have the following issues:

- Their data model is stored in proprietary file formats, and cannot be integrated with their database.
- The data model and analysis capabilities cannot be extended.
- Application information cannot be separated from connectivity information.
- Spatial information management and hierarchical relationships are not directly supported.

To address these issues, Oracle Spatial network data model does the following:

- Provides an open and persistent network data model.

The network data model is stored as relational tables in the database and is managed through SQL.

- Simplifies network data management and analysis

PL/SQL and Java APIs are provided for network data management and analysis.

- Separates connectivity and application information in the data model

Connectivity information can be separated from application information. Both application information and connectivity information are managed in the database. However, only connectivity information is required for network analysis.

- Allows the extension of data model and analysis capabilities

The Java API provides representations of network elements as Java Interfaces. Users can define their own network elements by extending these interfaces. As a result, users can implement their own user-defined representations and analysis functions.

- Integrates with Oracle Spatial technology for spatial information management

The network data model supports all Oracle Spatial data types.

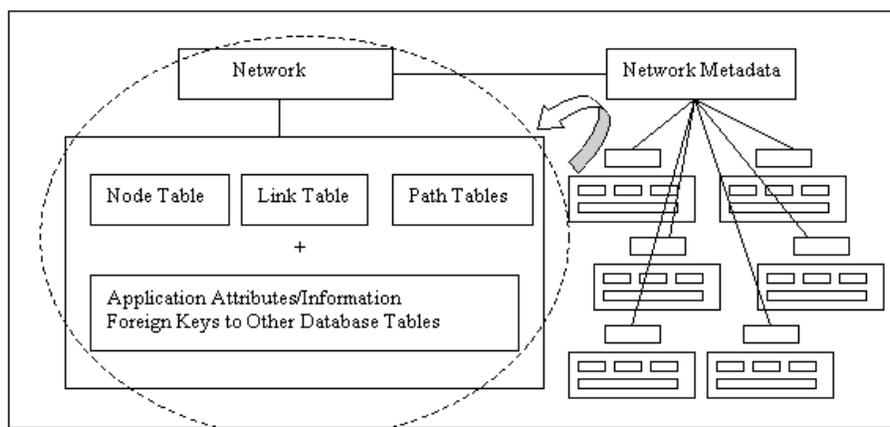
This paper is organized as follows: it presents the network data model database schema, APIs and architecture; shows how to use the data model; presents several GIS network applications built on top of the data model; discusses how to use network constraints to enhance analysis capabilities; and discusses the network data model editor that is used to edit and visualize networks.

## **ORACLE SPATIAL NETWORK DATA MODEL**

The network data model consists of two parts: a network schema and network APIs. The network schema is the persistent data storage used to store network information. The network APIs contain a PL/SQL package for data management in the database and a Java API for data management and analysis on the client-side (via Java JDBC drivers).

### **Network Data Model Schema**

A network contains network metadata, a node table, and a link table. In addition, path information (path table and path-link table) can be stored with the network if desired. Figure 2 shows a schematic view of a network in the database. Note that only connectivity information is stored. Additional application information can be stored in the network tables, or in other tables and referenced by foreign keys.



**Figure 2. Oracle Network Data Model (Schematic View)**

### Network Metadata

Network metadata provides general information about networks. It includes the following network details:

- Directed or undirected
- Logical or spatial
- Hierarchical or flat
- Information about nodes, links, and paths
- Geometry information -- for spatial networks

### Network Tables

An Oracle network contains two tables: a node table and a link table. A path table can be added if needed. Figure 2 shows the schema for the network data model, which includes these tables. The schema represents the information necessary for network management and analysis. Application attributes can be added to these tables or referenced from other application tables (through foreign keys). Note that the network data model is also capable of handling geometry information. That is, the network data model can represent both logical and spatial network applications. Adding geometric data to a logical network will allow the logical network to be displayed.

### Oracle Spatial Network Data Model APIs

The network data model provides a PL/SQL API and a Java API for network management on the database and client sides. The Java API can also be used for network analysis. The three-tiered network data model application architecture is shown in Figure 3.

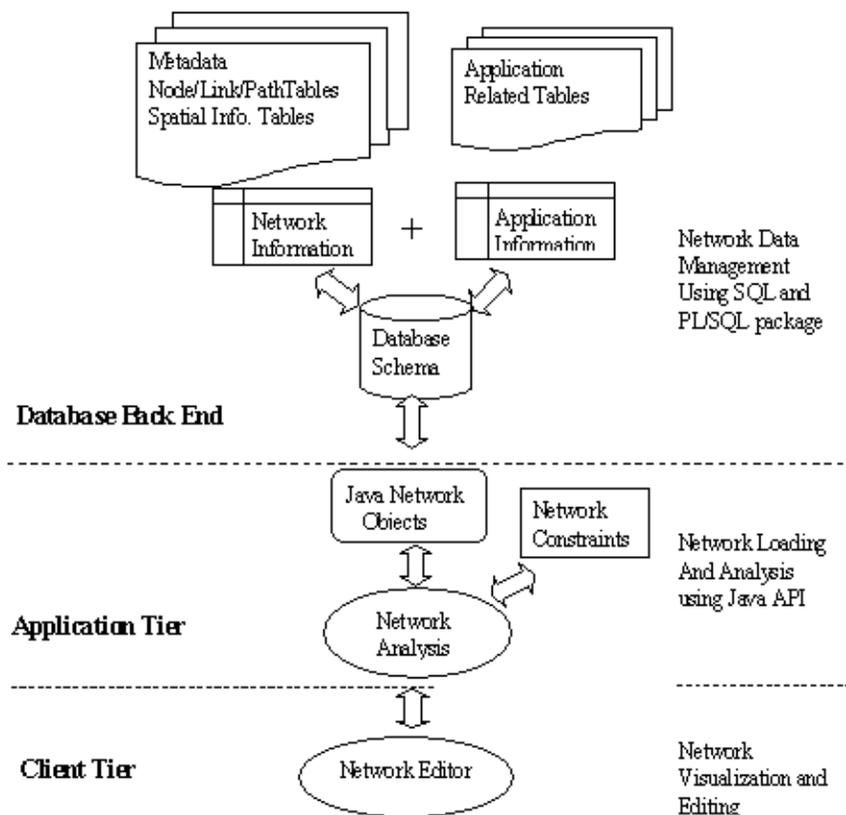


Figure 3. Network Data Model Architecture

### Network Data Model Analysis Capabilities

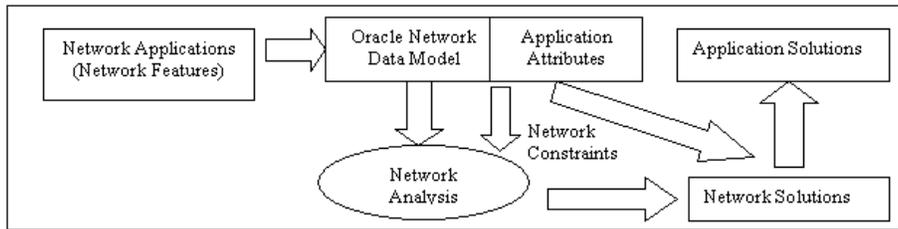
The following analyses are supported in the network data model:

- Shortest Path: The shortest path from node A to node B
- Accessibility Analysis: Is node A accessible from node B?
- Minimum-Cost Spanning Tree: What is the minimum-cost tree that connects all nodes?
- Within Cost Analysis: What nodes are within a given cost from (to) a given node?
- Nearest Neighbors: What are the N nearest neighbors of a given node?
- K Shortest Paths: What are the K shortest paths from node A to node B?
- Connected Components Analysis: Label connected components with IDs.
- Graph Operations: Graph union, intersection, and difference.
- Traveling Salesman Problem: What is the minimum-cost tour that visits a set of cities?

- Single Source, Single Sink Maximum Flow Analysis: What is the maximum allowable flow that can flow from the source node to the sink node? (Oracle Spatial 10g Release 2)

### Modeling Network Applications

The network data model takes a generic approach to solving network problems, by separating connectivity information from application-specific information. Figure 4 shows how a typical network application can be modeled and analyzed. First the network connectivity information (node connections and link cost) is extracted and separated from the application-specific information. Application-specific attributes are stored, if needed, with the connectivity information or separately. Once the connectivity information is extracted, network analysis is conducted on the generic model. Additional network constraints can also be considered. The final result is then mapped to application-related attributes, and displayed. This approach avoids customized network solutions and simplifies the data management of connectivity and application-specific information.



**Figure 4. Network Modeling and Analysis Using the Network Data Model**

### Network Constraints

The network data model introduces the concept of network constraints, which provides a mechanism to guide network analysis. For example, you may want to compute the shortest path that passes through network links of a specific type. With network constraints, applications can easily incorporate application-specific logic into the network data model analysis engine without knowing how the engine works. Other constraints, such as path depth, or cost, can also be included in analysis. The network constraint is a Java interface and must be implemented by the application.

### Java Representations of Network Elements

The Java network representations (network, nodes, links, and paths) are defined as Java interfaces and can therefore be extended. These interfaces specify the necessary behaviors for the network and its elements. In addition to these interfaces, user-defined analysis functions can be used by applications, allowing the modeling and analysis capabilities of the network data model to be extended.

## Software Requirements

The Spatial network data model is shipped with Oracle Database release 10g. The PL/SQL package is pre-loaded in the database and required Java .jar files are provided; the Java API supports JDK (or JRE) version 1.3 or later. The network editor is also included as a utility tool for the network data model. For more information, see the *Oracle Spatial Topology and Network Data Models* manual.

## USING THE NETWORK DATA MODEL

This section explains the usage of the network data model. There are three major steps.

### 1. Create a Network

1. Create and populate network tables and add metadata to the database.
2. Create a Java network object using the Java API and save it to the database.

### 2. Visualize or Edit the Network

1. Load a network from the database or an XML representation.
2. Visualize or edit the Java network object using the network data model editor. Store the network in the database, if needed.

### 3. Analyze the Network

1. Load a network into a Java network object.
2. Conduct network analysis. Save the path results, if needed.

## NETWORK DATA MODEL EDITOR

The network data model editor is a standalone Java application that helps create, edit, and visualize networks. The editor supports viewing operations such as pan, zoom, and auto-fit. It also provides functions to navigate between network elements. All analysis functions are supported in the editor. With the editor, users can create a network from scratch in the client-side and save it to the database. The editor is configurable on element styles, colors, and sizes. Figure 5 shows the network data model editor.

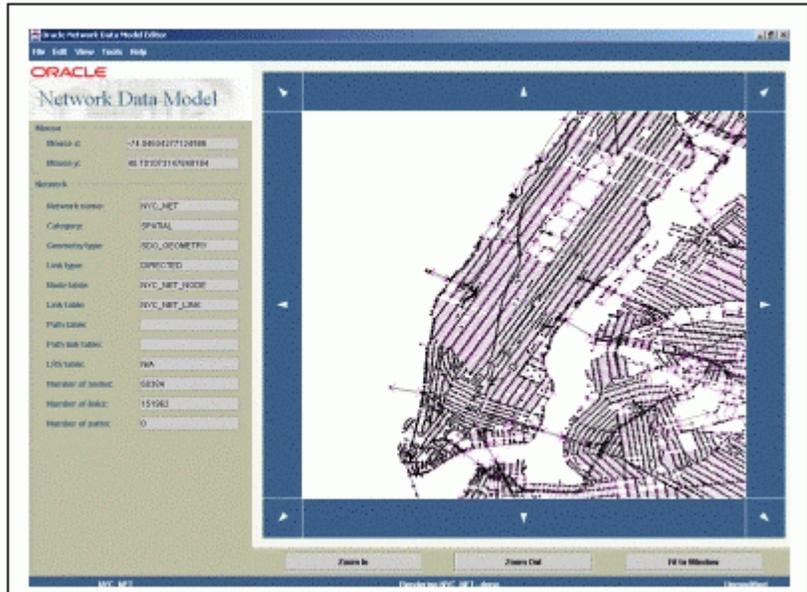


Figure 5. Network Data Model Editor

## GIS APPLICATIONS USING THE NETWORK DATA MODEL

GIS network analysis may include network tracing, network routing, and network allocation.

### Network Tracing Applications

Tracing applications deal with queries like *Is node A reachable from node B?* or *What are the nodes that are reachable or can be reached from a given node?* Such queries are common in water or utility networks. Another type of tracing analysis is to find out how many connected components are in a network. Figure 6 shows some such queries.

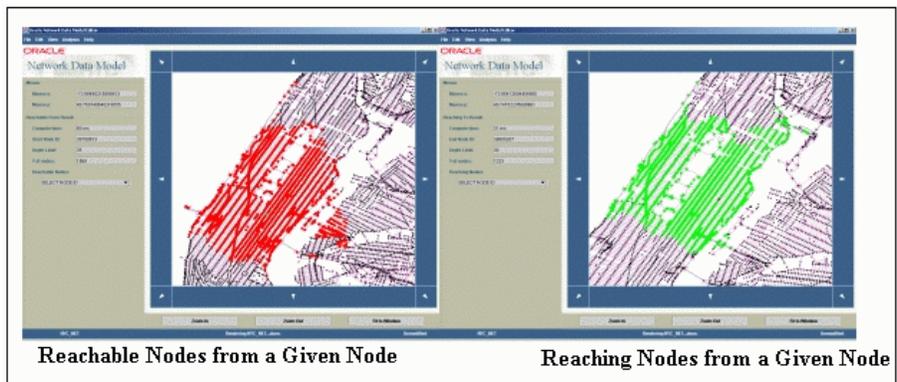


Figure 6. Reachable and Reaching Analysis

### Network Routing Applications

Routing analysis or path computation, probably the most studied topic in network applications, is divided into the following categories:

- Shortest Path or Fastest Path (transitive closure problem) (see Figure 7).
- K Shortest Paths: Find k shortest paths from a start node to a destination node.
- Traveling Salesman Problem (see Figure 7): Find a minimum-cost tour that passes a set of locations.

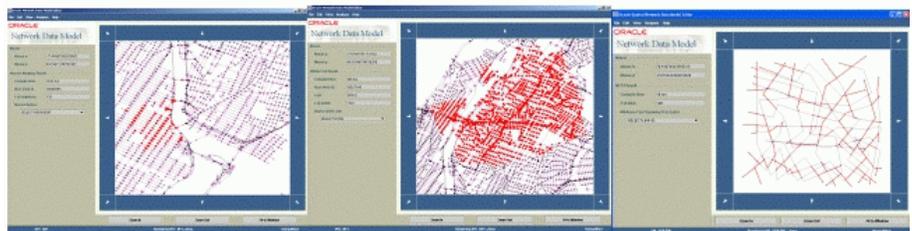


**Figure 7. Shortest Path and Traveling Salesman Problem**

### Network Allocation Applications

Allocation analysis deals with designating destination points within a network. It provides information on a service area or coverage for points of interest. The network data model supports the following allocation analyses (see Figure 8):

- Within Cost: Find all points of interest within a certain distance from a designated location.
- Nearest Neighbors: Find the N nearest restaurants to a designated location.
- Minimum-Cost Spanning Tree: Find the cheapest way to connect all nodes.

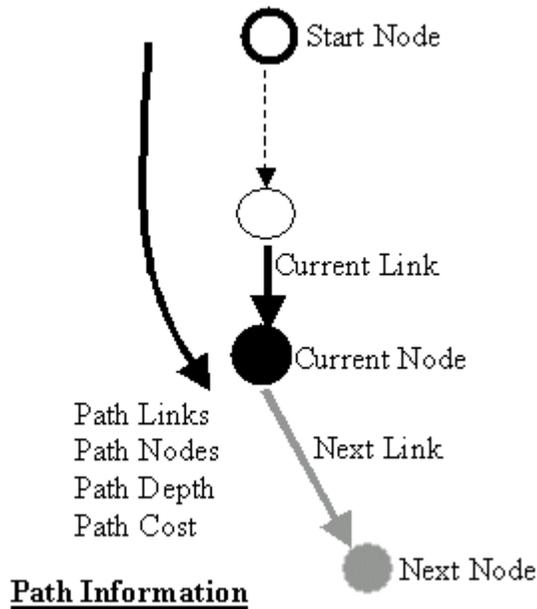


**Figure 8. Nearest Neighbors, Within Cost, and Minimum Cost Spanning Tree Analysis**

### Using Network Constraints in Analysis

Constraints are conditions to be satisfied during analysis. The network data model supports network constraints so that applications can impose application-specific conditions on the network during analysis. The Java interface *NetworkConstraint* can

be implemented by the user, and passed into any network data model analysis function. Figure 9 shows analysis information that is available for users to implement their network constraints



**Figure 9. Analysis Information for Network Constraints**

The following are some examples of network constraints:

- Depth (number of links), cost, and MBR constraints

Network analysis can be limited based on the depth of the search path, the cost limit, or the area (minimum bounding rectangle) where the analysis occurs. These constraints can be used to specify a preferred subset of possible solutions. The network data model provides a *SystemConstraint* class (which implements the *NetworkConstraint* class) for these common network constraints. Users can create an instance of *SystemConstraint* and use it in analysis.

- Temporarily inactivated nodes or links

Sometimes nodes or links must be temporarily turned off before analysis begins, for example, road segments (links) under construction in a road network, or water valves (nodes) shut down for repair in a water network. You can make a node or link inactive by setting its state to false. Network elements that are inactive will not be considered during analysis. Note that changing the state of nodes and links does not affect the persistent data model.

- Routing with specific types of links and nodes

Sometimes network analysis must only be conducted through nodes and links of specific types or with specific requirements.

- Turn restrictions

Turn restrictions are constraints involving two links. They are common in routing for transportation networks. In the following example, a prohibited turn is represented by a start link and an end link (see Figure 10). For intersections with turn restrictions, such as no “U” turn or no left turn, if the search encounters the start link of a prohibited turn, the search does not continue through the end link of that prohibited turn. This type of restriction can be easily modeled using *NetworkConstraint*, since information on the current link and next link is made available to users.

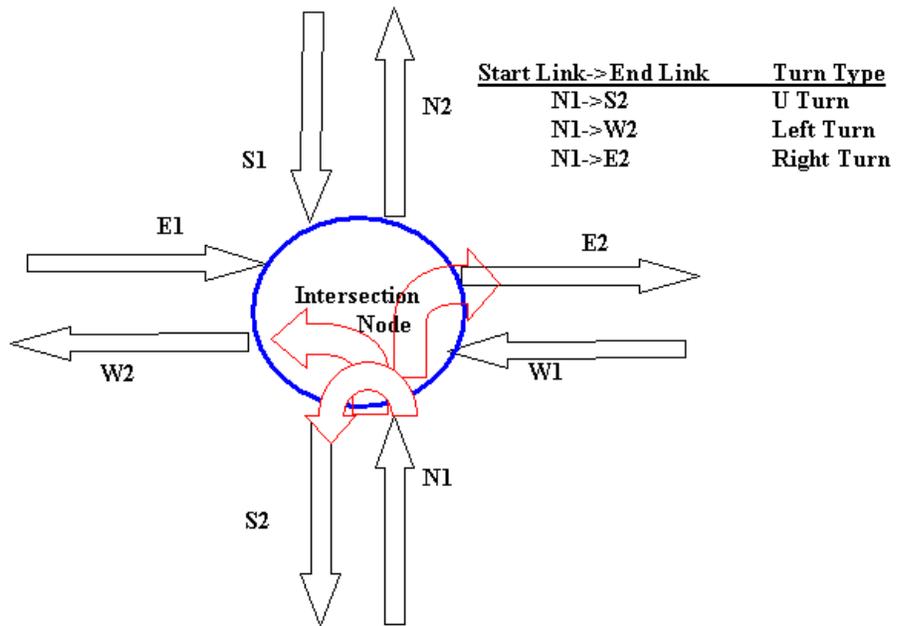


Figure 10. Turn Modeling for Road Networks

### NEW FEATURES IN THE ORACLE SPATIAL 10G NETWORK DATA MODEL

With Oracle Spatial 10g Release 2, the network data model provides the following features:

#### Network Modeling: Link Direction

The directionality of a link can be further specified at the link level. Unlike the network directionality that determines the directions of all links, a directed network can have links that are directed or bi-directed. A **BIDIRECTED** column can be added to the link table and used to indicate if a directed link is bi-directed. This modeling enhancement will reduce the storage requirement for directed networks with non-homogeneous link directions (unidirectional and bidirectional).

## **Network Analysis: Maximum Flow Analysis**

The maximum flow analysis function is provided for a single source and single sink flow network. Each link in a flow network has a flow capacity associated with it. The goal of this function is to find the maximum allowable flow that can flow from the source node to the sink node. This type of analysis is commonly seen in communication or logistics network planning.

## **PL/SQL Wrapper Package**

Prior to Oracle Spatial 10g Release 2, only the network data model Java API could be used for network editing and analysis. Now, a PL/SQL wrapper package is also provided that helps users edit and analyze networks in PL/SQL. This wrapper package provides nearly equivalent functionality as the Java API. It is done through database Java stored procedures and Java virtual machine in Oracle.

## **CONCLUSION**

The Oracle Spatial network data model, available with Oracle Spatial 10g, is a generic network (graph) modeling and analysis environment for network applications. GIS applications for routing, tracing, and allocation have been discussed. The network data model provides an open, easy-to-use, scalable, efficient, and manageable approach to developing GIS network applications. We are currently working with our customers and partners to extend the modeling and analysis capabilities of the network data model.

## **REFERENCES**

*Oracle Spatial Topology and Network Data Models*, Oracle Corporation.

*Oracle Spatial User's Guide and Reference*, Oracle Corporation.

*Oracle Linear Referencing System: A Technical White Paper*, Oracle Corporation.

*Oracle Spatial Network Data Model: A Technical White Paper*, Oracle Corporation.



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