StateGEN/StateNET—A Structured Method to Perform Route Comparisons*

J.W. Cashwell and C.M. Erickson

*Sandia National Laboratories**, Albuquerque, New Mexico, United States of America*

INTRODUCTION

StateGEN/StateNET is a modelling structure and routing algorithm designed expressly to address the needs of state and local governments to perform analyses of routing alternatives. StateGEN/StateNET is designed to permit the user to construct a network and assign attributes of interest to the network on a personal computer (PC). The completed network is then transferred via a modem to the TRANSNET system (Cashwell, 1989) and the preferred route is determined based upon attribute weights assigned by the user.

This modelling structure permits the state or local government to perform a routing analysis, such as that required by the U.S. Department of Transportation (DOT) for Highway Route-Controlled Quantity shipments of radioactive materials, with a minimum of resources. StateGEN/StateNET provides a computerized version of the DOT guidelines (Cashwell, 1989) or allows the user to structure their own network parameters.

Sandia National Laboratories (SNL) is the Department of Energy's (DOE) lead organization for transportation research and development. The DOE Office of Defense Programs has been the prime sponsor of development of models and associated databases used to analyze the impacts of the transportation of radioactive materials. The routing algorithms used in StateGEN/StateNET were based on the existing models on TRANSNET, a system which was developed to enable outside users to access analytical codes and associated data developed for the DOE.

*This work performed at Sandia National Laboratories, Albuquerque, New Mexico, supported by the United States Department of Energy under Contract No. DE-AC04-76DP00789.

**A United States Department of Energy Facility

BACKGROUND OF THE TRANSNET SYSTEM

TRANSNET is being used to support DOE site environmental analysis, risk assessments and systems analyses for the defense and repository programs, routing assessments for the DOE and states and operational analyses as well as basic research.

The goals of the TRANSNET system are to speed transfer of transportation risk and systems analysis technology to the public sector by permitting users to access the most comprehensive and up-to-date transportation risk and systems analysis models and associated databases. Models are updated and refined as information and techniques become available. TRANSNET provides the user with the latest version of these models and databases in a timely manner. Users of the TRANSNET system are allowed to construct input files and to use or modify input files previously developed for DOE-sponsored analyses. User operating and equipment costs are minimized by establishing the TRANSNET system on a centralized computer and allowing access via a modem-equipped personal computer. This realizes another prime goal, which is to develop and operate the TRANSNET system with a maximum of flexibility while minimizing system costs.

Prior to placement on the TRANSNET system, codes are modified to incorporate a user-friendly interface, if one did not already exist. Input data from analyses performed by SNL for the DOE are structured to allow use either directly or with editing. The user is also permitted to construct an input data set. Output files from each of the codes are structured to permit levels of detail that correspond with typical user requirements. In addition, interfaces between the codes and data sets are built to permit direct data transfer between codes.

GENERAL BACKGROUND

The DOT specifies in 49 CFR Part 177 that Highway Route-Controlled Quantity shipments of radioactive materials should travel from origin to destination via the shortest Interstate highway route unless alternative route(s) have been designated by the state(s) through which the shipment would pass. The DOT provides states with a methodology for assessing potential alternative routes through the assignment of primary and secondary factors. These factors are determined locally, but the methodology employed by the state routing agency to determine an alternative route must be equivalent with that proposed by the DOT "which adequately considers overall risk to the public." Each state interested in determining alternative route(s) must interact with the adjoining states to assure continuity of the transportation system.

The primary goal of the StateGEN/StateNET system is to assist state and local governments in this effort by providing a structured technique consistent with models used in national analyses. Through the use of the TRANSNET system, state or local governments can benefit from the analytical capabilities of the models, including indicators of the radiological and nonradiological risks of transport. This is accomplished through a two-part methodology; the first, entitled StateGEN, allows the user to define a transportation network of interest, construct the network, and assign specific attributes to the network. The network is defined by nodes, or uniquely numbered geographic locations such as

intersections or boundary lines, with links (pathways) connecting the nodes. The particular attributes of interest are determined by the user; however, it is assumed that the DOT route selection methodology will assist in the determination of particular attributes. After gathering the necessary data, the user assigns these data to the individual links consistent with the structure provided in the StateGEN system. Link-specific attributes could include data regarding the link as well as calculated attributes, such as the risk parameters mentioned above. The DOT methodology categorizes these into "primary and secondary factors" which include objective and subjective attributes of interest to a specific jurisdiction. This network data is structured in a form consistent with the StateNET model on a personal computer, thus minimizing TRANSNET hookup time and costs. StateGEN also permits the user to assure continuity of the data regarding the network and to perform a single-attribute route selection. StateGEN is transferred to the interested user on a flexible disk.

After development of this structured network and associated attributes, the user transfers the files to StateNET, on the TRANSNET system, which allows a user to maximize or minimize each network attribute of interest and assign a weight to each. The StateNET model may then be used to determine the route that best represents the user-assigned characteristics. An additional flexibility offered to the user of TRANSNET is to use StateGEN to structure input data files for the RADTRAN risk assessment model, calculate link-specific risks for the user's network, and then edit the StateGEN network to include these factors. The user can then calculate the route alternative on StateNET using risk parameters specific to the network.

DISCUSSION

StateGEN/StateNET Objectives

The StateGEN/StateNET code and User's Guide were designed to meet the following needs:

* To build models of transportation networks.
  The networks may be used to calculate and compare all possible routes through a region. The region size and network are determined by the user. Networks are described by nodes, or geographic points, and links, or connecting routes between the nodes that have common characteristics. The length of each link (i.e. the distance between two nodes) is required input.

* To consider attributes of the transportation network.
  It is assumed that factors of local concern other than distance will be used to determine route alternatives. Attributes regarding the characteristics of each of the links on the network are assigned by the user. These attributes could be data or calculated parameters from models on TRANSNET or others.

* To fit available data accurately to the transportation network.

The task most challenging to the user is how to extract a specific value for each link from the available data, which will most likely have been collected independently of the design of the network.

* To make temporary changes to a network model.
  In the analysis of a single problem, different configurations of a network may be desirable in order to calculate different sets of optimal routes. By combining weighted optimization of properties with temporary reconfigurations of the network (i.e., temporary inclusion/exclusion of certain links), the routing possibilities are further expanded.

* To maintain a current network.
  Over time, network models require modification. The network must accurately describe the current status of the link attributes to be of use in additional analyses. StateGEN allows for rapid retrieval and editing of all network data.

The StateGEN Module

StateGEN allows the user to create data files needed to construct a model of a transportation network. The files needed are:

a. A file of nodes to identify the geographic boundaries or "break points" on the network (these are most commonly described as intersections, particularly for the roadway system);

b. A file of links to identify the network connections between nodes;

c. A data dictionary file to list the attributes of links that are of interest to the user, e.g., the primary and secondary factors described in the DOT methodology.

The primary StateGEN program, FILES, uses menus and windows to add, edit, and delete data in these files. Data entry and network maintenance are minimal. The same data item is never entered twice. Validation of the network model may be performed at any time while FILES is in use. Modifications needed when a network is changed are performed automatically. For example, when the user adds an attribute to the data dictionary, a file that reflects the current network is automatically created to hold that data for each link on the network. When the user changes the network, the attribute file (along with other attribute files) is automatically updated to reflect the new network.

The user should:

a. Determine what attributes are of interest,
b. collect data about these attributes, and
c. use these data to assign a specific numeric value to each link for all the defined attributes. These values are then used by StateNET to calculate optimal routes within the network.

The programs provide assurance to the user that the network model contains reasonable data and is contiguous.

ROUTES is a simplified version of StateNET. It calculates a route between any origin and destination on the user's network by minimizing or maximizing a single attribute.

The validation option in FILES does internal checking on the data fields required for proper operation of the routing algorithm. If a set of data files passes inspection, it represents a valid network and is valid to use as input to ROUTES and StateNET.

StateGEN is provided in executable form on one diskette. It is to be used on a IBM-compatible personal computer. It is not necessary (or even possible) to be logged onto TRANSNET in order to run StateGEN. The StateGEN diskette and user guide are mailed upon request, free of charge, to TRANSNET subscribers.

The StateNET Module

StateNET is a routing program that resides on TRANSNET. To indicate, which constraints should dominate the search for an optimum route, the user assigns weights to the parameters of interest. This ability to weight attributes greatly increases the number of possible outcomes from the routing algorithm.

StateNET input data are the files developed using the StateGEN programs. These files are uploaded from the user's personal computer to TRANSNET, where they reside in the user's personal directory. No other TRANSNET user has access to them. Networks may, however, be shared with other TRANSNET users by special arrangement with SNL.

StateNET also permits modification of the network. To effect a change in the optimal route without changing the weighting of the attributes, links may be temporarily ignored by changing their routing status from active to inactive. An inactive status makes a link unavailable to the routing algorithm.

The StateNET Data Grouping Algorithm

When a route is calculated by optimizing (minimizing or maximizing) only one parameter, then the raw number assigned to each link can be used as the optimizing value. The minimum-value route is then determined by the Routing Algorithm. When a parameter is to be maximized, the reciprocals of the raw data values are grouped into the distribution.

When more than one parameter is used to calculate a route, the parameters are normalized prior to assigning weights. The formula used to normalize each parameter is:

$$U_i = (X_i - X_o) / C \qquad (1)$$

where:

U_i = normalized value for a link, $0 < U_i < 1$
X_i = raw value as read from the file
X_o = lowest value present in that file
C = difference between the highest value and the lowest value in that file, or the range of values.

The normalized value U_i is then multiplied by 100 to expand its range from 0-1 to 0-100. The normalized value is multiplied by the user-assigned weight for the parameter divided by the sum of the weights given to all parameters. This is:

$$W_p = N_p / \Sigma\ N_p \qquad (2)$$

where:

W_p = weight by which link parameter U_i is to be multiplied
N_p = integer entered by the user as a weight for this attribute

A single frequency distribution summing the weighted parameters is then used by the StateNET routing algorithm to determine the route.

The StateNET Routing Algorithm

The process of finding an optimal route requires three pieces of information about each highway link: the two endpoint node numbers and a single optimization value. This optimization value may be raw network data, or it may be the result of the data-grouping algorithm described above. In addition, the node numbers of the route origin and destination must be known.

The mechanics of this algorithm involve two sets of node numbers: the open set and the closed set. The open set contains all the node numbers, paired to represent all the links on the network. At the beginning of a calculation, the open set contains all the links and the closed set is empty. The closed set becomes a list of nodes that have been optimized.

In the initiation of the algorithm, the route origin node is placed in the closed set. On the first pass through the algorithm, the closed set (i.e., the origin node) is examined for an optimal route from the origin. In other words, the links emanating directly from the origin are compared to find one with the smallest optimization value. The node at the other end of the shortest link is moved into the closed set, and is removed from the open set.

The closed set now contains the origin node and the node closest to it. On the next pass through the algorithm, links in the open set that have an endpoint node in the closed set are compared for total optimization value from the route origin. The shortest path back to the origin that includes one more node is found. This additional node is moved into the closed set. The last link in the found path is removed from the open set.

All optimal routes are saved in the optimal-path array as the calculation progresses in widening circles through the network. Calculation time is reduced by saving in a separate tracking array the position (row and column) in the optimal-path array where each closed-set node is at the end of an optimal path from the route origin. The row number and the column number plus one is then directly referenced in order to save a newly-optimized node at the end of the row of node numbers which represents the optimal route from the new node back to the origin. (The origin node is in the first column of all the rows of the optimal-path array.) The alternative to a tracking array would be a lengthy search of the optimal-path array after each node is optimized for a match on its paired node.

When the destination node joins the closed set, then the optimal route between the origin and the destination is known.

Pruning of the search space (the open set) may be performed to reduce the calculation time. If not carefully coded, attempts at pruning will occasionally drop links from the network too soon and the algorithm will sometimes be able to find only the second-best route. Pruning is not currently used in StateNET, but it will be added as large networks are built that require a faster calculation.

CONCLUSIONS

Released to TRANSNET users in Spring, 1988, StateGEN/StateNET allow local governments and other interested parties to perform a detailed transportation network analysis using methods developed for the DOE's defense waste management program. Together with other capabilities available on the TRANSNET system, the user can perform network optimization consistent with the requirements of the DOT as well as local-area interests.

StateGEN/StateNET equipment requirements are consistent with those of TRANSNET: an IBM-compatible personal computer, Hayes-compatible modem, telephone, and communications software.

Parties interested in using StateGEN/StateNET on the TRANSNET system should submit a written request for access, including contact person, sponsor and intended use to:

J.W. Cashwell, Division 6321
Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185

REFERENCES

Cashwell, J. W. "TRANSNET--Access to Transportation Models and Databases," SAND89-0982C, TTC-0882, Sandia National Laboratories, Albuquerque, NM, June, 1989.

U.S. Department of Transportation, Guidelines for Selecting Preferred Highway Routes for Highway Route Controlled Quantity Shipments of Radioactive Materials, DOT/RSPA/OHMT-89/01, January, 1989.