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MPATHav: A Software Prototype for Multiobjective Routing in Transportation Risk Assessment

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INTRODUCTION

Most routing problems depend on several important variables: transport distance, population exposure, accident rate, mandated roads (e.g., HM-164 regulations), and proximity to emergency response resources are typical. These variables may need to be minimized or maximized, and often are weighted. 'Objectives' to be satisfied by the analysis are thus created. The resulting problems can be approached by combining spatial analysis techniques from geographic information systems (GIS) with multiobjective analysis techniques from the field of operations research (OR); we call this hybrid 'multiobjective spatial analysis' (MOSA). MOSA can be used to discover, display, and compare a range of solutions that satisfy a set of objectives to varying degrees. For instance, a suite of solutions may include: one solution that provides short transport distances, but at a cost of high exposure; another solution that provides low exposure, but long distances; and a range of solutions between these two extremes.

The increasing power of GIS now allows spatial data and computing power to be applied to long-established optimization techniques, which is generating interest in the OR, GIS, and environmental analysis communities. For instance, MOSA has been used to develop and display alternatives for a complex incineration vs. transport vs. on-site photolysis problem in Phoenix, Arizona (Wyman and Kuby, in press). For hazardous materials risk assessment, we believe that MOSA is a promising tool for site- or route-specific analyses that are complex, contentious, or non-standard. It also has good prospects for encouraging citizen participation, and for communication of analysis results to non-specialists. For example, stakeholders could help to define the objectives to be satisfied, then view and manipulate the solutions that emerge from the analysis by using interactive maps. Non-specialists can thus be assisted in grasping the costs, benefits, and tradeoffs

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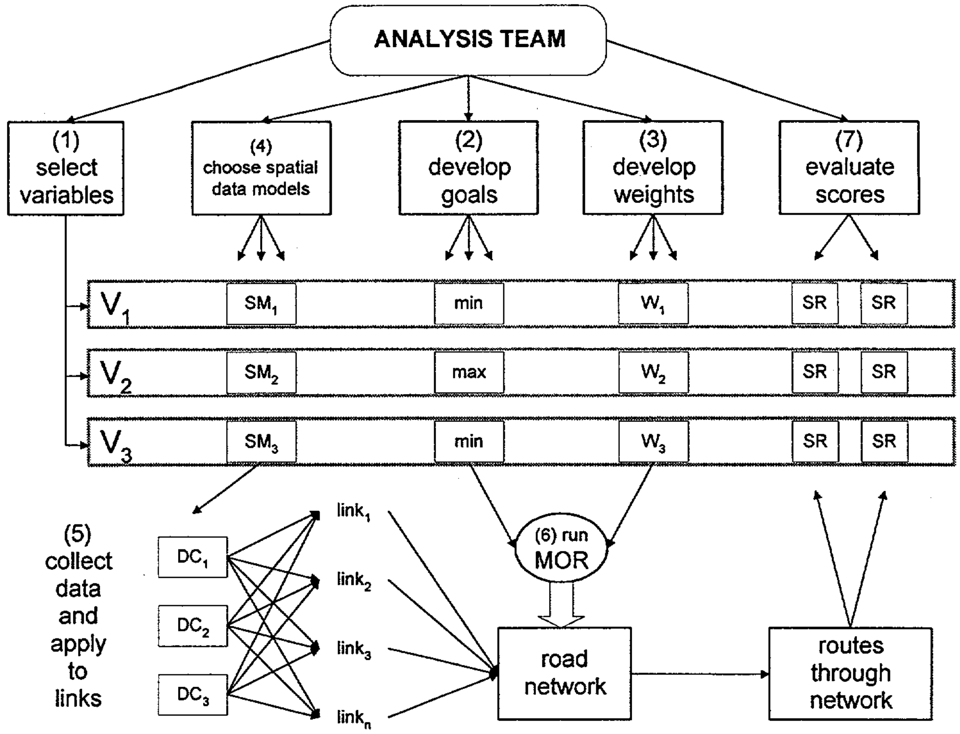


Figure 1: Flowchart of the Multiobjective Spatial Analysis (MOSA) process

involved in a range of options. This could lead to discussion and exploration of alternatives using MOSA in lieu of lawsuits and other challenges. In the event of legal actions, MOSA could be used to contrast technical issues with more emotional arguments. MOSA is also ideally suited to the analysis of risk and environmental equity, which is required by Executive Order 12898 (Clinton 1994). Risk equity (the equal sharing of risk among socioeconomic, racial, and ethnic groups) can be measured using census data, and used as an objective.

MOSA is a relatively new technology area, with limited theory, technology, and user experience. Sandia National Laboratories has begun to prototype and test software tools for MOSA. This paper describes one such prototype.

THE MOSA PROCESS

MOSA generally proceeds through the following seven steps (Figure 1). The first and most fundamental step (Step 1) is selection of candidate uncorrelated variables; this is an *a priori* choice of what should be balanced in the multiobjective trade-off. These variables are then recast as 'objectives' by stating the intent of the optimization. Intent includes the goals of whether variables should be maximized or minimized (Step 2) and their relative weightings (Step 3). The next series of steps creates the data on which the analysis will operate. It should be noted that multiobjective routing (MOR) itself is non-spatial; it simply grows a number of solutions (routes) through a topological space of links which have numerical attributes. But these attributes are created by spatial analysis, a 'condensation' of spatial measures like length, area, and density onto the links (Figure

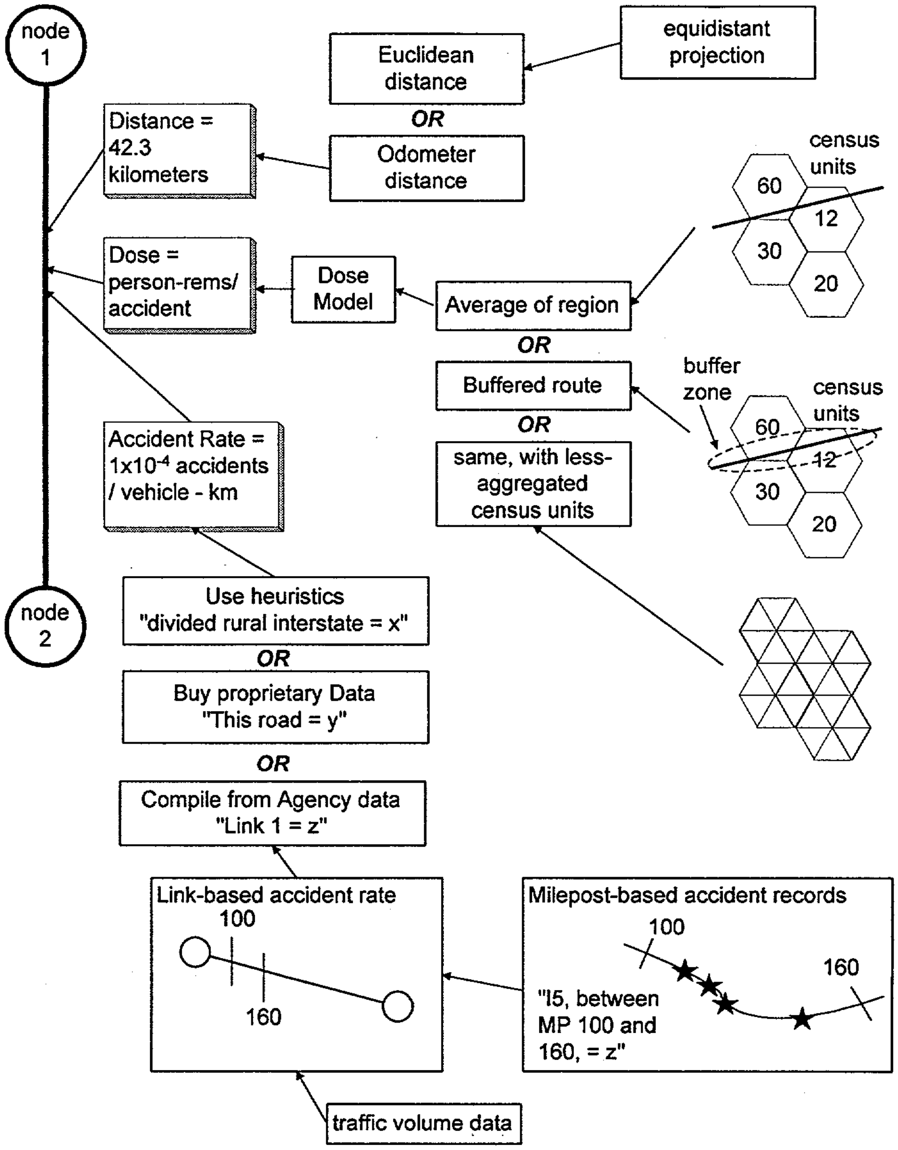


Figure 2: Diagram of typical spatial modeling decisions in MOSA

2). After MOR is run, geography returns in the form of maps that show the solutions/routes. Thus, MOR is non-spatial, but the quality of the results that it generates is totally dependent on appropriate spatial modeling.

The analysts must choose appropriate spatial models (Step 4) for the geographic phenomena that express the variables (Figure 2). For instance, if one variable is dose, then a value for the link must be created using a dose model. Since dose models depend on population, how is population expressed spatially? Fundamentally, population is a person at a place. The US census aggregates these data by area, giving number of people for a particular unit: census block, block group, tract, etc. This approach also yields a population density, since the areas of the census units are known. The next decision that must be made is how routes are related to the population regions (Figure 2, middle). An average population can be derived, or the route can have a buffer zone created around it, or either approach can be used at higher resolutions (such as census blocks instead of tracts).

For some types of data, as suggested by the highway accident data at the bottom of Figure 2, availability and compatibility are extremely limiting. At each step, the analysts have to choose from a number of options. If the spatial data inputs are inadequate, MOSA can yield simplistic or erroneous results. It is thus no better and no worse than any other technique (i.e., garbage in, garbage out).

Step 5 is the process of spatial data collection for a given spatial model. This is a relatively simple step compared to Step 4, but it can be time-consuming, expensive, and hold surprises that were not anticipated in the previous step. For example, highway accident data from adjacent states which appear to be compatible may in fact use a slightly different linear referencing (e.g., mile post) system. (A MOSA process could also include non-spatial data such as temporal constraints (curfews, scheduling, etc.) but in the MPATH prototype these data would have to be mapped onto links in some manner.)

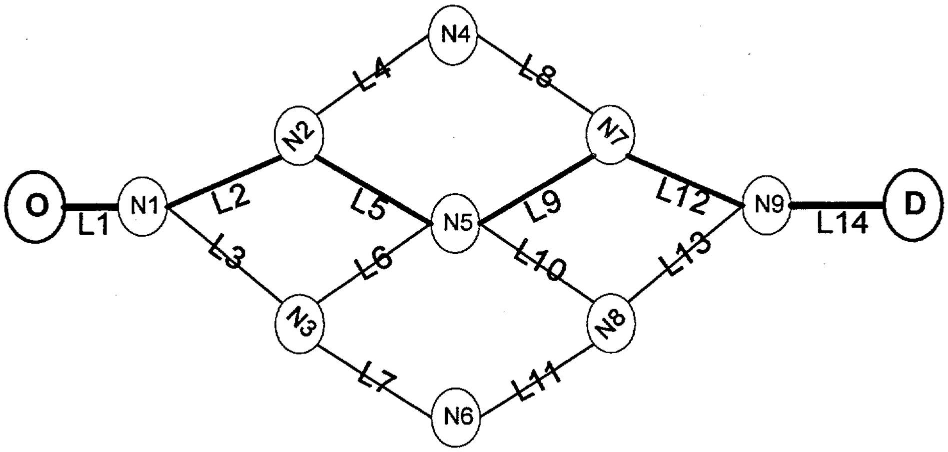
Once the data have been assembled and validated into a network, the MOR analysis can be run (Step 6). MOR assembles the goals, the weights, and the links expressing the variables. It then produces a number of routes that satisfy the objectives to varying degrees. The routes are scored based on the objectives. They can then be compared by the analysts in Step 7. This is a complex step, and can be aided by maps and charts.

In the next section, we consider Step 6 (the MOR operation) in more detail by describing our prototype MOR routine (MPATH).

MPATH: A MULTIOBJECTIVE ROUTING (MOR) ROUTINE

Multiobjective Path (MPATH) is a stand-alone routine that performs the multiobjective routing that is at the heart of MOSA. MPATH is part of the MCNET (Multi-Criteria NETwork analysis) methodology and prototype that was co-developed under contract to Sandia National Laboratories by Prof. George List (Rensselaer Polytechnic Institute) and Prof. Mark Turnquist (Cornell University) (List, 1993; List and Turnquist, 1993); early versions were called HLRW-ESITE. In MPATH, the primary routing objective is to find a path for a single *origin-destination (OD)* pair, or perhaps multiple paths for multiple OD pairs, such that a balance is struck between other secondary desired objectives.

We will briefly describe the MPATH routing algorithm; see the network diagram and associated summary table of Figure 3. Although the simulated node-link example is quite simple, it shows the general logic and sequence of MPATH. The algorithm searches, evaluates and selects partial paths beginning with the 'origin' node, until ultimately generating an entire route to the 'destination' node.



Links	Origin	L1	L2	L3	L4	L5	L9	L10	L12	L14	Route
Nodes	O-O	O-N1	N1-N2	N1-N3	N2-N4	N2-N5	N5-N7	N5-N8	N7-N9	N9-D	O-D
Objective 1	0.00	1.00	2.00	7.00	8.00	3.00	4.00	12.00	5.00	6.00	21.00
Objective 2	0.00	1.00	1.10	1.60	1.70	1.20	1.30	2.10	1.40	1.50	7.50
Objective 3	0.00	1.00	1.01	1.06	1.07	1.02	1.03	1.11	1.04	1.05	6.15
Summation	0.00	3.00	4.11	9.66	10.77	5.22	6.33	15.21	7.44	8.55	34.65
Product	0.00	1.00	2.22	11.87	14.55	3.67	5.36	27.97	7.28	9.45	3004.33
Algorithm	Initiate	Dominates	Dominates	Dominated	Dominated	Dominates	Dominates	Dominated	Dominates	Dominates	Terminate
Action	Extend	Extend	Extend	Discard	Discard	Extend	Extend	Discard	Extend	Extend	Integrate
Path	P_0	P_1	P_2	–	–	P_3	P_4	–	P_5	P_6	P_0-P_6

Figure 3: Simulated MPATH analysis of a simple network

In the path-building algorithm, the objectives are placed arbitrarily in lexicographic order and a vector of zeroes, known as a 'partial path', is attached to the origin node O. The partial path which is lexicographically the shortest is selected for extension, which at this point is the initial vector containing all zeroes. The selected partial path is designated as p_0, and is subsequently extended to all nodes reachable via one arc or 'link.'

One of the new partial paths, say p_1, will lexicographically be the shortest. It is selected to be extended next and a label is attached for the objective values of p_1 (Figure 3; Sum: 3.00, Product: 1.00) and the partial path from which it was originally extended (p_0). New partial paths are then generated by extending p_1.

If one of the newly generated partial paths, p_{10} for example, dominates some previously generated partial path, say p_8, at the node where p_{10} terminates, the prior path (p_8) is discarded. The process terminates when all of the non-dominated partial paths reaching the destination node D have been identified. Note that the dominance tests between candidate partial paths are performed on a node-by-node basis, and the path search continues until all possible non-dominated routes are found.

THE *MPATHav* PROTOTYPE: *MCNET* WITHIN THE *ArcView* GIS

MCNET development concentrated on the core multiobjective routing capability, with limited development of the user interface. In order to work on the larger issues of MOSA utility and usability, we extracted the routing portion of MCNET (the MPATH module), and integrated it into a prototype called *MPATHav* (pronounced 'empath ay-vee'). Thus, MPATHav does not include the siting capabilities of MCNET. MPATHav runs under the ArcView® 2.1 GIS software (Environmental Systems Research Institute [ESRI®], Redlands, Ca.), and is written in the *Avenue*™ language that is included with ArcView. The ArcView product provides a relatively user-friendly and low-cost 'desktop' for manipulating maps (termed 'Views'), tables, and charts.

An example MPATHav session is shown in Figure 4. *Italics* indicate ArcView terminology and features. ArcView has a user-interface that includes a number of basic *Menus*, *Buttons*, and *Tools.* These controls change depending on which *Documents* such as *Views* and *Tables* are in use. MPATHav adds several specialized Buttons and Tools (see label 1 on Figure 4).

When MPATHav starts, the user is presented with a map of the United States in an ArcView *View* window (see label 2 on Figure 4). The nodes and links *themes* are turned on, as indicated by the check marks (3). The user then chooses an origin (node 812) and a destination (node 785) by applying the OD *Tool* to the View (4). These values are automatically placed in the 'O-D Volumes' *Table* (5). The user then enters a volume (in this case, 4000 shipments) for the origin-destination pair. The origin-destination pairs are chosen at random for illustration purposes only and do not reflect any actual or planned shipment campaigns

When the user is satisfied with the origin-destination pairs, they press the Run MPATH button (6), which runs the multiobjective analysis. By pressing the View Scores button (7), the user can view the numerical scores for the generated paths (not shown).

Pressing the Show Views (8) button creates a new View for each O-D pair. Within the View is a Theme for each of the solutions: the paths. These paths are numbered and colored to distinguish them from each other. Since some of the paths will obscure others, the user can turn them on and off using the check boxes. Another way to help see the routes is by pressing the Trace button (9) which flashes the route segments in sequence.

If the user presses the Chart button (10), a bar *Chart* is drawn for each View. The chart shows, for each objective, the scores for each route. The southern route through California (11a) has a much higher population (11b) then the more rural route (12a) and (12b). While the origin and destination are entirely fictitious and the underlying dataset is for prototyping only, this example does suggest the type of insights that users could gain.

SUMMARY OF MULTIOBJECTIVE SPATIAL ANALYSIS

We believe that MOSA is a valuable 'downstream' analysis tool. That is, MOSA can allow analysts to do tradeoff analyses on a large and complex volume of data that have already been produced by other analytical tools (e.g., population, dose, accident models). If numerical values can be applied to transportation links, then the data are amenable to MOSA. It follows, therefore, that MOSA is only as good as the data that go into it. We have shown a prototype (MPATHav) that has promise as an interface for running MOSA and allowing non-specialists to 'visualize' the tradeoffs that are common in transportation planning and risk assessment.

REFERENCES

Clinton, W. *Executive Order on Environmental Justice*. Executive Order 12898 (1994).

List, G.F. *Emergency Response Team Siting Model Development*. Report prepared for Sandia National Laboratories, October 1993 (1993).

List, G.F. and M. Turnquist. "Routing And Emergency Response Team Siting For High-Level Radioactive Waste Shipments," presented at 1993 HazMat Transportation Conference, August 23-25, 1993 (1993).

Wyman, M.M. and M. Kuby. "Proactive Optimization of Toxic Waste Transportation, Location, and Technology," accepted for *Location Science* (in press).

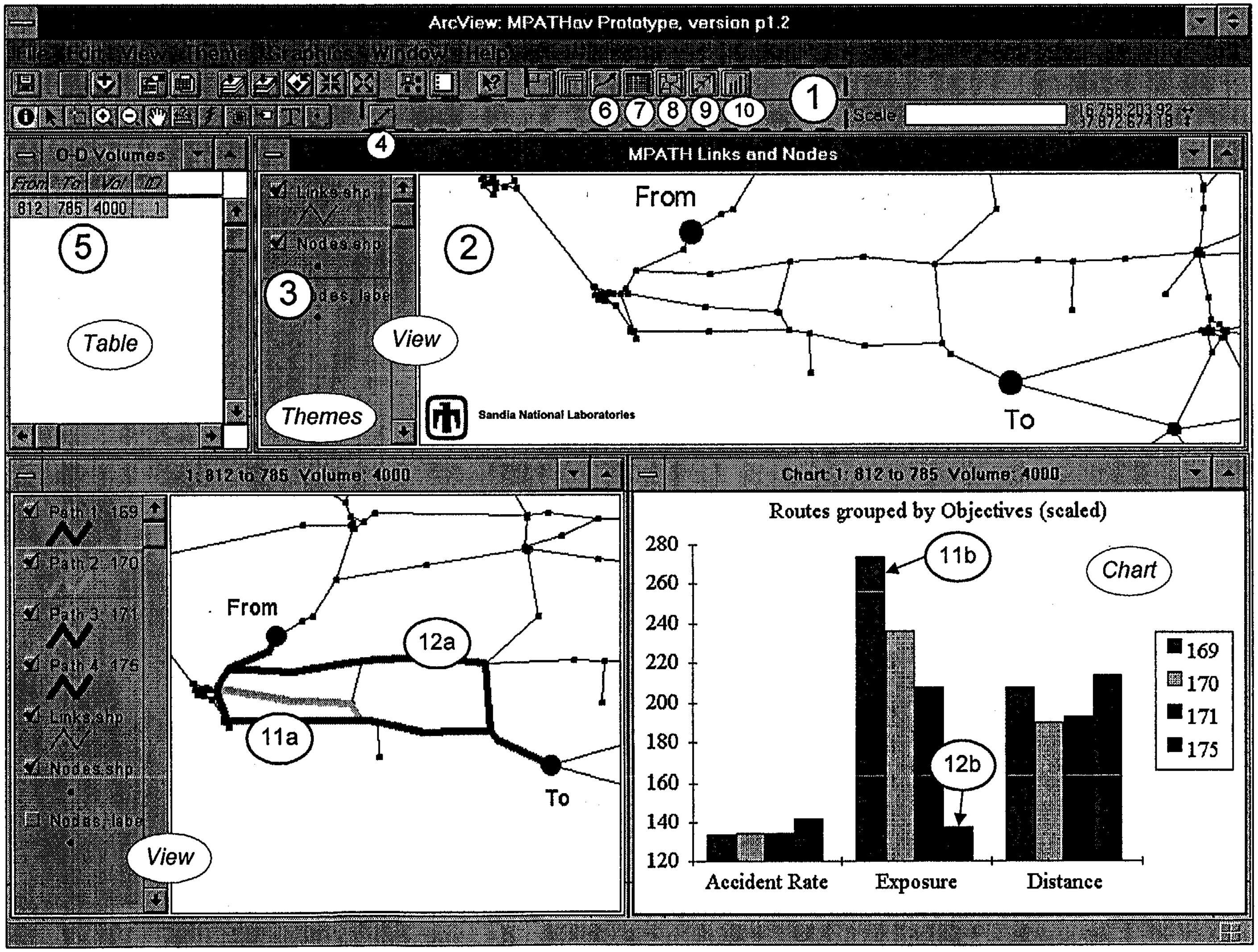


Figure 4: The MPATHav multiobjective routing prototype. See text for explanation of labels.