Predicting Uncertainty in Tactical Decision Aids (TDA) Produced from Uncertain Geospatial Data

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Geospatial data, by its very nature, is an incomplete model of reality. In traditional terrain data production, data collection is controlled by a product specification that is designed to provide sufficient terrain data quality to support intended applications. In a military crisis, or natural disaster response, terrain data required for planning may not be readily available. To meet this contingency, the DOD is investing in rapid mapping technologies. In a rapid mapping environment, data collection is driven by time constraints of the crisis, rather than by strict product specifications. Because of wide variations in: source materials; access to the ground; and time to produce, there will likely be wide variations in quality of rapid mapping data. The available data will be used to produce tactical decision aids that will be used in planning and controlling the crisis response activities. There is a significant risk that faulty decisions could be made from this data. Decision makers need to evaluate the level of risk, based on understanding the level of uncertainty, introduced into their decision by the inherent inaccuracy, or inherent uncertainty, of the terrain data they are using. This requires the capability to quantify the quality of the geospatial data, propagate the data quality through the tactical decision aid model, and visualize the resulting uncertainty in the tactical decision aid.

The issue is the need for a general approach for predicting the uncertainty the tactical decision aids, and the decision maker's risk in relying on a tactical decision aid. This position paper describes a problem for which a mixed initiative decision theoretic system has potential to provide significant value added over the standard decision aid approach. The problem we describe is the computation and portrayal of cross-country mobility (CCM) for use in planning routes for military vehicles.

A CCM model portrays the speed that particular military vehicles can travel, off road, in a specified area. Planners use CCM models to determine friendly (or enemy) avenues of approach, mobility corridors, potential obstacle locations, and for route planning (find the fastest route between two points). The calculated CCM speeds depend on terrain factors (slope, soil strength, and vegetation) and vehicle parameters (weight, geometry, engine performance, ground pressure, wheeled vs. tracked).

The quality of the CCM prediction will depend on the accuracy of the data for vehicle parameters, the quality of the terrain data, and on the fidelity of the model. Vehicle parameters for a wide range of friendly, and potential enemy vehicles are well known with high accuracy. A number of algorithms for calculating CCM from vehicle and terrain data are available. For this analysis the Defense Mapping Agency CCM algorithm is used, and is assumed to be of sufficient fidelity. The quality of the terrain factors, and their influence on the CCM prediction, are the focus of this issue.

The terrain factors are provided by terrain data products produced by the National Imagery and Mapping Agency (NIMA), allied governments, or US forces. Although NIMA products have specifications for positional accuracy, and collection criteria (types, and classes of features to collect, feature attributes to be collected, minimum size of a feature to be represented, etc.), there are no specifications for data completeness (are all features mapped), accuracy of classification (if the data says it is X, what percent of the time is it really X), or accuracy and completeness of feature attributes.
The challenge in providing an uncertainty estimate for CCM predictions (and in general for a wide range of other tactical decision aids), includes:

- Estimating the quality of the terrain feature data.
- Propagating the terrain quality (or uncertainty) through the tactical decision aid model (CCM algorithm).
- Communicating the tactical decision aid results and the associated uncertainty to the decision maker.
- Interaction with the decision maker during planning.

We have developed an approach to uncertainty estimation and portrayal in CCM models. A brief description of how our approach addresses each of the above challenges is:

- Estimating terrain data quality: Ideally this would be done by comparison of the data to ground truth. Unfortunately, extensive ground truth is very expensive, and access to the ground to collect ground truth is often not possible in military applications. An alternative, is to elicit probability models that describe the expected data quality from experts involved in producing the data.
- Propagating uncertainty through the tactical decision aid algorithm: Standard error propagation techniques, that are used for propagating positional errors, cannot be used because the terrain factor data consists of categorical data like soil types, and vegetation classes. Instead, a Bayesian Network is used to encode the CCM algorithm. The terrain data, from available products, is uncertain evidence for the true values of the terrain factors. The Bayesian Network provides estimated CCM speeds, and a histogram of possible speeds for each point on the map.
- Communication the results to the user: The CCM results are normally displayed as a color coded map, with different color assigned to each predicted speed range. One way to visualize uncertainty is to modify the hue of the color within each class, based on the spread of the histogram for that area. In an interactive system, the user could query the actual histogram, that shows the range of CCM speeds, at any point of interest.
- Interaction during planning: During a route planning scenario, the user may be interested in the uncertainty in travel times between various points. If the risk that results from the uncertainty is too large, the user may query for the reason for the uncertainty (uncertainty in what terrain parameter is causing the largest uncertainty in the predicted CCM?). Then the user can allocate additional reconnaissance or collection assets, to collect higher quality terrain data, that will reduce the uncertainty in the CCM predictions. Potential improvements in CCM prediction quality, under various additional collection schemes, can be analyzed.

The approach described above has been prototyped using actual terrain data of the type used by route planners. Examples of CCM displays incorporating uncertainty will be presented in our talk. Uncertainty estimates for travel times on candidate routes will be shown.

The CCM tactical decision aid is only one example of a decision aid for which terrain uncertainty is critical. There are many other problems for which similar methodology would provide significant benefit.