Trafficability Analysis Engine

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Trafficability is a measure of how easily vehicles can drive through a particular piece of terrain. Manual processing of trafficability analysis is time-consuming and coarse. A new trafficability engine has been developed that takes into account previously ignored aspects of trafficability and degrades gracefully when data are missing. This article describes the design and implementation of this trafficability engine, as well as needed future work.

Trafficability is a measure of how easily vehicles can drive through a particular piece of terrain. Military terrain analysts have a requirement for an automated tool to conduct trafficability analysis as part of a larger decision-support framework. The proof-of-concept system described in this article uses an expert system to combine the outputs of various geography modules into an estimate of trafficability.

The unique aspects of this system are its rating of trafficability as a floating-point number between zero and one; the use of a confidence measure to assess the accuracy of the trafficability prediction; and its consideration of the capabilities of individual vehicles with respect to slope, vegetation, and soil conditions. In addition, the system degrades gracefully as terrain data are missing and reflects the confidence in the predicted outcome; if data are missing, the system does not break but instead provides the best estimate possible. Finally, this system reflects the effects of weather on trafficability.

This article describes the design and implementation of this trafficability engine, as well as needed future work.

Background and Motivation

Trafficability is important to the U.S. Army. Detailed, thorough trafficability analysis helps tactical decision makers determine likely enemy avenues of approach and possible friendly avenues of approach. Manual processing of trafficability analyses is time-consuming and coarse. The output of the manual terrain analysis process often takes days and results in a product known as the Modified Combined Obstacles Overlay (MCOO).

The MCOO classifies terrain into one of three coarse categories: *go*, *slow-go*, and *no-go*. The names are self-explanatory, but they do not provide a sufficient amount of information to the intelligence officer who must plan for such routes as enemy avenues of approach, friendly attack routes, and supply routes.

Many factors that affect trafficability are not considered in the manual process. First, as a manual process, its efficacy is dependent on the experience and skill of the intelligence officer who usually prepares the MCOO. Trafficability analysis often is concerned with tracked vehicles, wheeled vehicles, and dismounted soldiers. This process assumes that all wheeled vehicles, for instance, are created equal. Recent effects – and projected effects throughout the operation – of weather are often ignored. The load-bearing capacity of soil is dependent on its moisture content. Roads often become *slow-go* or *no-go* after heavy rains.

The purpose of this research was to build a trafficability analysis engine that had the following attributes:

- Predicts trafficability as a floating-point number between zero (a cliff) and one (the salt flats of Utah).
- Considers the capabilities of individual vehicle types (e.g., the M113A3 armored personnel carrier) rather than generalizations (e.g., a generic tracked vehicle), with respect to slope, vegetation, and soil conditions.
- Degrades gracefully as terrain data are missing.
- Reflects the confidence in the predicted outcome.
- Performs most of the difficult computation at a server and sends just the results of the analysis to the user.
- Allows a skilled user to modify the rules by which trafficability is determined.
- Reflects the effects of weather on trafficability.

The prototype described in this article takes into account geographic factors, including location, vehicle type, off-limits terrain, water, weather, soil, land use, topography, vegetation, and roads. In addition, the system was designed to be user-friendly. The goal of this work has been to build an architecture in which various trafficability modules can be inserted. If a developer has a better soil-moisture evaporation module, it could easily replace the one used in this prototype.

Design and Implementation

The design of this system is modular as shown in Figure 1. The overall architecture involves a terrain server (or hierarchy of servers) above the Army division level. The user (at lower echelon units) selects an area of interest and sends that information to the trafficability engine's server. The trafficability engine's server fetches terrain data (in the form of ASCII files in the case of this proof-of-concept system) from the terrain server(s). If terrain products are unavailable for the area of interest, the engine's server may ask the user for general information about the area. For instance, the engine may query the server for recent precipitation information such as dry, wet, or very wet. Once the trafficability analysis engine has all available information, the geography modules begin processing the data.

As the clients are meant to be thin, in this proof-of-concept, the user interface is a Web browser. In the target application, a Web browser might be sufficient; however, the interface might be connected directly to systems within the Army Battle Command System such as the All-Source Analysis Station (ASAS) [1]. The trafficability engine is implemented as a Java servlet (running on a Jakarta Tomcat server). Each of the geography modules is a Java object called by the servlet.

Geography Modules

The geography modules each look at different aspects of trafficability such as weather, topology, vegetation, land use, and soil. Some modules' output serves as input to other modules. For instance, the results of the weather module are inputs to the soil and road modules. While the actual implementation is a two-dimensional array of Java objects, one can think of each of these geography modules as filling in an *overlay*, as shown in Figure 2. Each cell of an overlay includes two elements: an estimate of the trafficability of that point on the ground and a confidence in that estimate. This confidence is not strictly a standard *deviation* because it is computed in an *ad hoc* manner by the expert system; however, for purposes of this research it serves much the same purpose.

An advantage of the modular design is that each module can use the most appropriate mechanism to compute trafficability. The Topography Module takes the floating-point slope value at each point and compares it to the known maximum slope capability of each specific vehicle, using a formula found in FM 5-33 [2]. The result of this calculation is an estimate of trafficability as a floating-point number between zero and one.

The Soil and Vegetation Modules query a lookup table and determine the characteristic of each different type of soil or vegetation at that specific point. That value is then used in further computations to determine trafficability based on soil or vegetation, respectively.

Each module fills in values on its respective overlay, which in turn are used to perform the final trafficability computation.

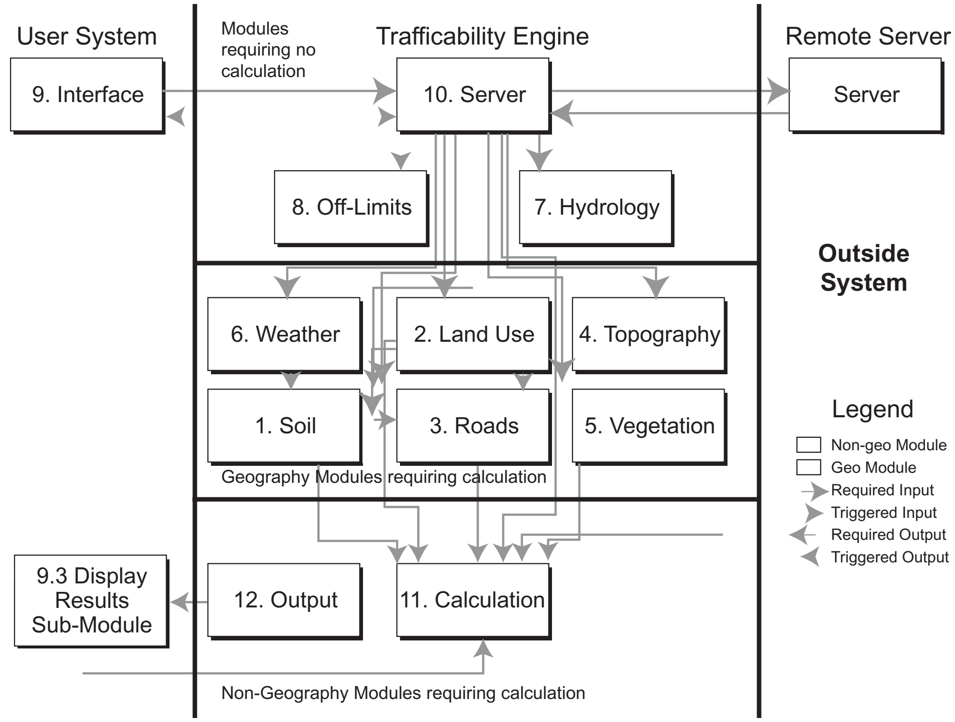


Figure 1: *Architecture of the Trafficability Engine*

Trafficability Computation

Once each module has performed its analysis, the calculation module uses an expert system to give each node an overall trafficability rating. Though often slower than compiled code, an expert system was chosen for the final analysis for two reasons:

- Expert systems provide a means of explaining to the human user how a decision was reached.
- Human experts could modify the expert system without modifying or recompiling the base program.

The expert system shell used is the Java Expert System Shell (JESS), developed at Sandia National Laboratory [3]. While the JESS project began as a port of C Language Integrated Production System (CLIPS) [4] to Java, JESS is now richer than CLIPS in many ways. The current expert system uses only crisp rules; however, support for fuzzy logic, using Matlab.fis files [5], has been implanted in Java and linked to the program.

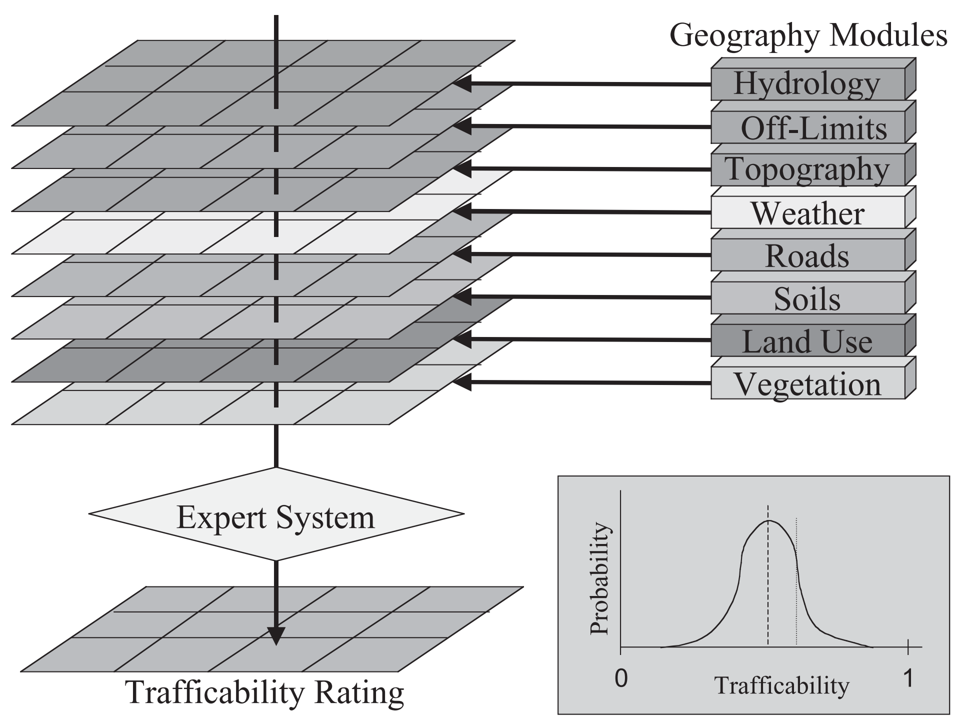
The manner in which the expert system combines the various ratings of confidence is purely arithmetic at this point. A weighted average of the eight *overlay* means is used. If an overlay is missing data (or the overlay is missing entirely), this has a large, negative impact on confidence. In the proof-of-concept system, all overlays are weighted equally. For future work, experiments will be conducted to determine which overlays have the greatest impact on trafficability in various geographic regions. For instance in Kansas, most of which is very flat, missing the topography overlay might have less effect on trafficability than missing the soils overlay. This *sensitivity analysis* will help determine the weights' uses in the weight-average computation.

The use of a *mean* (i.e., the estimate of trafficability) and *standard deviation* (i.e., measure of confidence) allows the system to degrade gracefully when data are missing. When data are missing, the system still provides an estimate of trafficability; however, the system indicates (through its confidence rating) that it is less certain of the estimate. The Engineer Research and Development Center's Topographic Engineering Center for whom this work is being done, has indicated that in the future, terrain products will come tagged with confidence in the data, and that confidence might not be uniform across the product. This technique also allows the system to adapt easily to non-homogenous input (i.e., input files in which the level of fidelity is not uniform across the whole file). As a result, the system provides the user with useful information even when some data are missing or it is a *best guess*.

Results

In the proof-of-concept system, the out-

Figure 2: *The Output From the Various Geography Modules Is Combined in an Expert System*



come of the analysis is a matrix that rates the trafficability of each point in the area of interest. The highest resolution input file determines the size of this matrix. If the area is 10km x 10km with 10m resolution, the final matrix would be 1,000 x 1,000 cells.

Clearly the speed of computing trafficability is based on the size of each of the overlays and is an order of magnitude of *n*, where *n* is the number of cells in the final matrix. (Since the area does not have to be square, complexity cannot be based on just height or just width of the area.) The slowest execution of the computation is the use of the expert system for each cell in the final matrix.

Even though the computations in each of the geographic modules need to be more fully developed and refined, the output of this system is very close to the results gained through detailed, manual analysis. Since the manual computation takes days, the fact that this system takes less than three minutes is a major improvement.

Future Work

Improving the Fidelity of the Geography Modules

The algorithms used in many of the geography modules came from existing field manuals [2]. In the process of implementing the geography modules, it became obvious that some badly needed models are missing. For instance, there seem to be no readily available models for the moisture content of soil. Such a model would need to take into account recent precipitation, soil texture, air temperature and humidity, topography, etc.

Parallelize the Computation

The ability of the system to automatically make use of multiple processors must be incorporated. Ideally, the system could first assign each geography module to different processors then assign portions of the final trafficability computation (since it is the slowest) to different processors. As there is no interaction (at this point) between the computation of trafficability in one cell of the final matrix and that of its neighbors, this process is easily made parallel.

Displaying the Results

While the output of the trafficability analysis engine is a matrix, that matrix is not what is displayed to the user. The proof-of-concept system converts that matrix into a GIF file that is displayed over the top of a map. This system is really intended to interface with other command-and-control systems such as the Maneuver Control System and ASAS [1]. The matrix would then be converted into an overlay for those systems and displayed to the user.

The trafficability analysis engine computes a trafficability estimate and a confidence for each point. Research must be conducted to determine how best to convey to the user the confidence in the estimate. Options include right-click functionality; however, the goal is a means by which the user can see the trafficability estimate *and* the confidence without any active querying.

Trafficability is computed as a floating-point value between zero and one. In the proof-of-concept system, arbitrary thresholds are set for *no-go*, *slow-go*, and *go* terrain, and the categories are assigned colors of red, yellow, and green, respectively. The intent is to display a gray-scale view of trafficability in which colors close to white (255, 255, 255) would represent go terrain and colors close to black (0, 0, 0) would represent no-go terrain. When this overlay was made transparent, the areas of terrain that were most clearly visible through the trafficability overlay would be most easily traversed.◆

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