Modelling of the optimal vehicle route in terrain in emergency situations using GIS data

M Rybansky¹
University of Defence in Brno, Czech Republic
E-mail: marian.rybansky@unob.cz

Abstract. Most navigation systems in transport are oriented towards the search for optimal paths (shortest or fastest), using vector GIS data. At the time of natural disasters and emergency situations is necessary to consider roads and terrain for transport. This article is focused on finding optimal routes in terrain, which contains a number of point, line and area obstacles. The most frequent point obstacles are trees in the forest. The paper analyzes the typical structure of tree stands in the forest, their characteristics in GIS databases, as well as dimensional parameters of vehicles moving in the forest. The quality of these data is a prerequisite for finding routes between point obstacles. Searching for the fastest or shortest route of the vehicle described in this article is based on the use of the relationship between the Delaunay triangulation and Voronoi graph, the application of Dijkstra's algorithm and the optimization of fractional line. The above-mentioned methods are also exploitable for searching for the shortest route of movement among line obstructions and area obstructions, such route can be apprehended as the joining of points defining impassable terrain. In such a case, the condition must be met that the distance of terminal points of joins has to be adjusted to the extent that it will be shorter than a vehicle width increased by safe margin.

1. Introduction
The methodology described in this paper enable the searching of the optimal route of a vehicle movement among point obstacles (e.g. trees) in vector format. This method is based on searching for movement route by comparing all possible variants of movement. This procedure is possible to use and analyse together with a rescue transportation analysis using air vehicles (for example searching for the optimal helicopter landing zones in a forest formation) see [3]. The above mentioned method is also exploitable for searching for the shortest route of movement among line obstructions and polygonal obstructions, such route can be apprehended as the joining of points defining impassable terrain. In such a case, the condition must be met that the distance of terminal points of joins has to be adjusted to the extent that it will be shorter than a vehicle width increased by safe margin.

In the following we will consider only trees that are the most common point obstacles in terrain. When passing other types of point obstacles we can use similar procedures as set out below.

2. Description of point obstacles in the forest
In order to make a basic digital model of a forest where we consider each particular tree, we need to know the following parameters:

- mean diameter of trunks;
- tree mean spacing;
- coordinates of individual trees or its position in relation to reference point;
- forest spacing lay-out (structure of planting).

¹ To whom any correspondence should be addressed.
The above-mentioned parameters we usually can find using forest maps or databases. We can also use the simulation of forest grow to change forest parameters in real time (see Rybansky, 2009). A simpler method for CCM modelling is generating forest mean tree spacing in a forest: for regular (triangular or square) lay-out of forest spacing, we deploy individual trees so that they copy a given matrix. A matrix will be made on the basis of tree mean spacing; for irregular lay-out we cannot use a matrix. That is why the coordinates of trees are deployed at random on the basis of random number generator.

2.1 Forest spacing Lay-out

Forest spacing lay-out gives information about tree positions, this is apprehended by the matrix of out planting of given forest. In man-made forests, the forest spacing lay-out is predominantly triangular or square, in natural forests the spacing lay-out is irregular (random), see table 1.

Table 1. Forest spacing structures.

| Forest spacing Lay-out | Description |
|------------------------|-------------|
| Triangular spacing     | – most frequent in man-made forests |
| Square spacing         | – typically occurs in man-made parks, forest parks, less frequently at commonly planted forests |
| Random spacing         | – naturally growing forest vegetation |

3. Process of searching for optimal route through forest vegetation

Every route can be evaluated by a certain parameter characterizing its qualities (length, gradient, surface, etc.). Of necessity, the optimal route may not be the fastest. The case can occur that the route is the shortest but heads into a steep slope whilst another longer route passes by. So we have to determine the criteria the optimum way. The definition of optimum way is to be comprehended as the lowest value of route parameter, whereas the parameter of route can be simple (e.g. length, time) or comprehensive (e.g. the shortest time by lowest gradient).

For that reason in this partial model for the determination of deceleration coefficient by the impact of growth, the characteristics of terrain features will not be in use (e.g. slope gradient and soil conditions), the length of route will be selected as the parameter searched. Now, the input result for the following computations will be the shortest route.

We determine the case of generated forest as the smallest deceleration of movement when passing through the given forest. Coefficient of movement deceleration \( C_2 \) is to be computed as the ratio of direct distance (clearance) \( L_D \) between initial and end point of movement and the length of the specific found shortest route \( L_K \) through forest vegetation.

\[
C_2 = \frac{L_D}{L_K} \tag{1}
\]

In the case of the absence of route searched, the user gets notification of this fact.

3.1 Input data

To find the optimal route through forest, it is necessary to know:

- parameters of trees;
3.2 Parameters of trees

Data concerning individual trees were already determined. They are namely stored at the each instance of subject Tree and it is a very straightforward matter to read out its values. To find the optimum route we apply those parameters:

- tree coordinates (coordinates of centre of circle representing a trunk);
- trunk diameter.

3.3 Parameters of vehicle

Data concerning the vehicle are necessary for the purpose of deciding whether or not a vehicle can pass through the space between two trees. For this decision is the influence of:

- vehicle width;
- vehicle length;
- vehicle turn radius;
- tolerance.

Tolerance determines the minimum distance of the vehicle from a trunk to pass between two trees safely.

3.4 Initial and end point of route searched

Both points are selected by the user with a mouse.

3.5 Optimal route searching

Searching procedure can be summarized to several points:

- finding all possible routes through a forest;
- selection of all routes that meet the parameters of vehicle;
- evaluation of partial sections of routes;
- selection of best appreciated route;
- optimization of route.

3.6 Finding of all possible routes through a forest

To find an optimal route we have to obtain an overview of all possible routes. The task was resolved with the use of an algorithm of graph theory called Voronoi’s graph - see also [1] and [2]. The principle of this algorithm use consists in the distribution of forest area to partial discrete surface sections always containing just one tree. Boundaries of discrete surface sections create uninterrupted fractional lines passing between each pair of trees. The algorithm is described in detail later in this Chapter.

3.7 Selection of all routes meeting vehicle parameters

By using Voronoi’s graph we do not solve situations when the vehicle is too big or two trees are too close to one another and hence the spacing between them is not trafficable. Minimum distance between trees for safe passing depends on vehicle parameters. To simplify the problem, we consider the width of vehicle and tolerance. Minimum distance between trees is defined in [1] and [2].

3.8 Evaluation of partial sections of routes
At present the characteristics of terrain (e.g. slope gradient and soil conditions) are not considered in this model, thus the particular elements of the route are evaluated by its length only.

3.9 Selection of the best appreciated route

In the list are fragments of various routes that we have to elaborate into a route which is continuous and also the sum of fragment evaluations is possibly as few as small. By implementing the Dijkstra algorithm of shortest route searching (described in more detail in this Chapter) we obtained the sequence of fragments creating the optimal route searched.

3.10 Optimization of a route

The resulting route has the character of a fractional line. We can optimize this fractional line in most cases. For the purpose of optimization, we can create a simple algorithm based on omitting redundant Voronoi nodes. The principle of the algorithm is described in detail in [1] and [2].

3.11 Algorithms used to find the optimal route

To search the optimal route, the following algorithms were used:

- Voronoi graph and Delaunay triangulation;
- Dijkstra algorithm of optimal route search;
- optimization of fractional line.

3.12 Voronoi’s graph, Delaunay’s triangulation

The set of points \( M = \{p_1, \ldots, p_n\} \) with coordinates \( \{x_{p_1}, y_{p_1}; \ldots; x_{p_n}, y_{p_n}\} \) is the data input.

The demand is to divide the area into partial regions (cells) so that each region has only one point \( p_i \) of the set \( M \) and that for the entire points inside the region the condition was valid that the distance of random points inside the region from point \( p_i \) is shorter than the distance to the other point belonging to set \( M \).

Used definitions:

- Voronoi cell - region suitable for the above-mentioned demand;
- Voronoi edge – creates the boundary of Voronoi cells; for the entire points incumbent on the edge it holds that its distance to two adjoining points of set \( M \) is identical;
- Voronoi node – initial or end point of Voronoi edge.

The algorithm is related very closely to Delaunay triangulation. The principle of the construction of Delaunay triangulation: let us imagine a situation when we have to divide a certain surface given by several points into elementary triangles. The edges of triangulation can be made by the non-intersecting joins of points. If the case occurs that two joins intersect, we will select only the shorter edge and the other edge is ignored.

It is true that under the conditions mentioned:

- Vertexes of triangles are in our case the points of set \( M \);
- Voronoi edges correspond with the axes of the sides of particular triangles and are bounded at its points of intersection;

The point of intersection of the axes of triangle sides is simultaneously Voronoi point and is identical with the centre of the circumscribed circle of a triangle.

Note: It is clear that Voronoi edges are perpendicular to the sides of triangles. Voronoi nodes correspond to the centres of circumscribed circles of elementary triangles.
3.13 Dijkstra algorithm of optimal route search

Dijkstra algorithm is used to find the shortest route between two nodes of graph, or (if you like) to find the shortest routes from the node of the graph given to all other nodes. The input is created by oriented or non-orientated graph with an evaluation of particular edges (see Fig. 2). We can say that it is an example of flood algorithm. The impulse rises in one point (initial point) and is afloat (as a flood) in the direction from the initial point.

The graph is presentable as a road map. If we imagine the joins between nodes as roads, then the nodes of the graph are crossroads. Non-orientated graph can be depicted as a system of two-way roads, and the network of one-way roads we can present with an oriented graph.

![Figure 2. An example of evaluated non-orientated graph.](image)

The challenge is to find the best evaluated route from node 1 to nod 10 with the use of evaluated routes. If the evaluation of joins corresponds with its length, it is simultaneously the shortest route. Decision procedure is published in [1] and [2].

The searched route leads through nodes: 10 – 7 – 6 – 2 – 3 – 1.

4. Displaying of vehicle optimal route through forest vegetation

To present cross-country mobility and to determine the vehicle optimal route through forest vegetation, tank T72 was chosen and the most frequent random types of forest was used. Regarding results obtained and time capabilities to determine a vehicle deceleration coefficient by the use of a method of simulation of forest passing, we can see as an added effective proceeding in the domain of vegetation traffic ability analysis, the possibility to obtain more precise data related to vegetation than in the event of present-day digital models or topographic maps see also [4], [5].
Figure 3. The route found for the T 72 MBT tank in irregular spacing type forest.

5. Acknowledgements
This paper is a particular result of the defence research project PRO K-210 GEORADIANT and Specific research project 2012 at the department K-210 managed by the University of Defence in Brno.

6. References
[1] Rybansky M and Hyrs F 2001 Cross-Country Movement analysis of forest (in Czech), VA Brno, p 102.
[2] Rybansky M 2010 The Cross–Country Movement – Modeling, Brno, p. 100, ISBN 978-80-7204-717-8.
[3] Kovarik V 2011 Possibilities of geospatial data analysis using spatial modelling in ERDAS IMAGINE Proc. International Conference on Military Technologies - ICMT’11 (Brno: University of Defence in Brno) pp 1307-13, ISBN 978-80-7231-787-5
[4] Talhofer V, Hoskova-Mayerova S and Hofmann A 2012 Improvement of digital geographic data quality International Journal of Production Research, vol. 50, no. 17, pp 4846-59, ISSN 0020-7543
[5] Talhofer, Kubicek P, Brazdilova J and Svatonova H 2007 Process of transportation monitoring of dangerous chemical substances Proceedings of the International Conference on Military Technologies (Brno: University of Defence in Brno) pp 597-607, ISBN 978-80-7231-238-2.