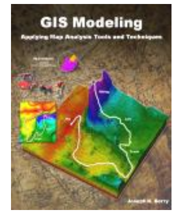

GIS Modeling book

Topic 8 – GIS Modeling in Natural Resources (Further Reading)

<Click here> for a printer-friendly version of this topic (.pdf).

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A Twelve-step Program for Recovery from Flaky Forest Formulations

(GeoWorld, June 2010)

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Earlier discussions ("*Harvesting an Understanding of GIS Modeling*," GeoWorld April 2010 and "*Extending Forest Harvesting's Reach,*" GeoWorld May 2010) described a basic spatial model for determining forest availability and access considering physical and legal factors that, in turn, was extended to include human concerns of housing density and visual exposure to harvesting activity. This section builds on those procedures for a further formulated model that 1) identifies the best set of staging areas for wood collection, termed "*Landings*" and 2) delineates the harvest areas optimally connected to each landing, termed "*Timbersheds.*"

The model involves logical sequencing of twelve standard map analysis steps that are described using MapCalc commands that are easily translated into other grid-based software systems (see author's note). The top portion of figure 1 uses the five "binary maps" created in the basic model to generate a map of potential landing areas. The maps are calibrated as 1 = available and 0 = not available for harvesting, and when multiplied together (*1. Compute*) results in 1 being assigned to all roads locations passing through available forest areas— 1*1*1*1*1= 1; if a zero appears in any map layers it results in a 0 value (not a road in an available forest area).

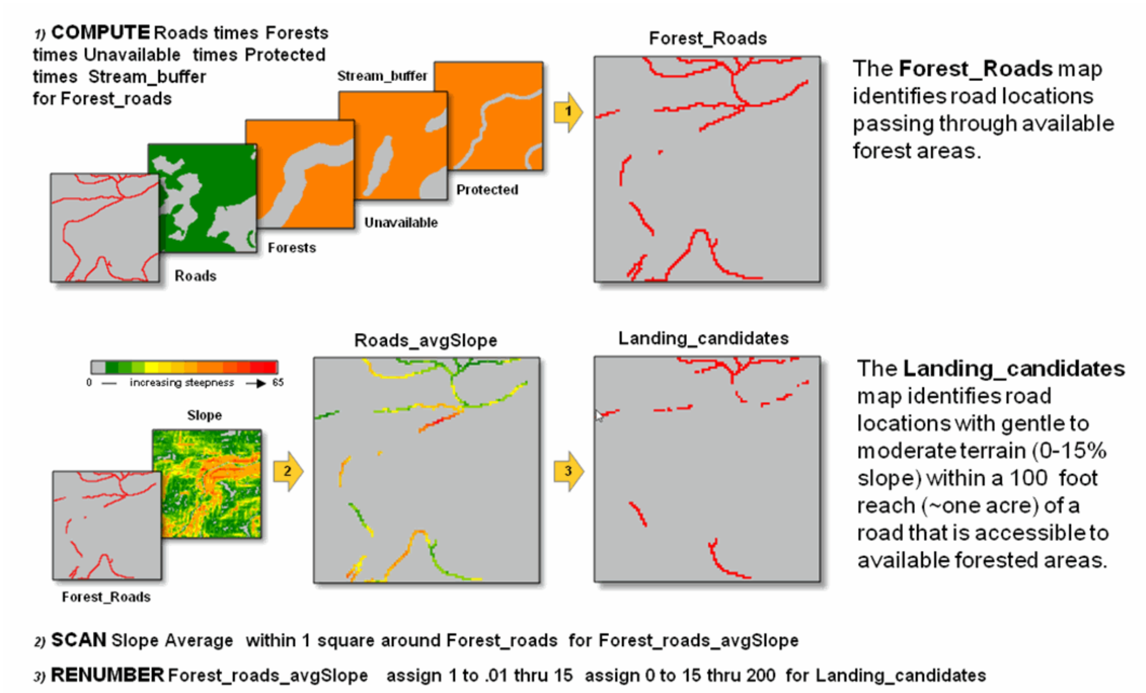

Figure 1. Identifying candidate Landing Sites that are along forested roads in gently sloped areas (steps 1-3).

The lower portion of figure 1 depicts using a neighborhood/focal summary operation (*2. Scan*) to calculate the average slope within a 100-foot reach of the each forested road cell. The third step (*3. Renumber*) eliminates potential landing areas that that are in areas with fairly steep surrounding terrain (> 15% average slope). The result is removal of over two thirds of the total number of road locations.

Figure 2 shows processing steps 4 through 9 used to locate the best landing sites. In step 4, the Discrete Cost map indicating the relative ease of equipment operation created in the basic model is masked (*4. Compute*) to constrain harvesting activity to just the forested areas. The Accumulated Proximity from roads is calculated (*5. Spread*) resulting in an effective distance value for each forest location that respects the intervening terrain conditions from forested roads.

The optimal path from each forest location to its nearest road location is determined and the set of paths are counted for each map location (*6. Drain*) resulting in an Optimal Path Density surface. The insets in the upper-right portion of figure 2 shows 2D and 3D displays of this less-than-intuitive surface. Note the yellow and red tones where many forest locations are optimally accessed—with one road location in the southern portion of the project area servicing 785 forested locations. The long red path leading to this location is analogous to a primary road where more and more collector streets join the overall best route.

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The summary statistics, along with expert judgment is used to identify an appropriate final set of landing sites that is suitably dispersed throughout the project area (*10. Renumber*) as depicted in the upper portion of figure 3. These final locations for *Landings* are used to derive new effective distance values for each forest location considering intervening terrain conditions (*11. Spread*) in a manner similar to step 5. Finally, expert judgment is used to limit the reach in each of the Timbersheds to a manageable distance (*12. Renumber*).

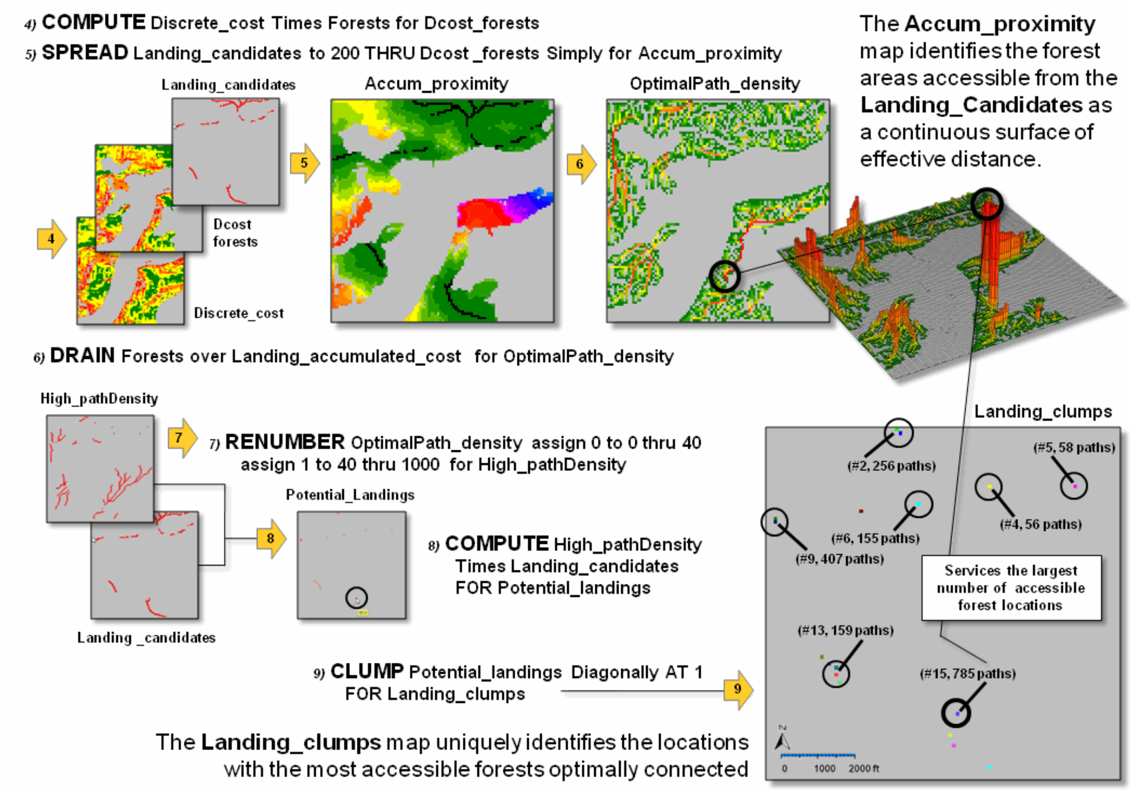

Figure 2. Locating the best Landing Sites based on optimal path density (steps 4-9).

The lower portion of figure 2 shows the steps for isolating the best landing sites. The highest levels of optimal path density are isolated (*7. Renumber*) and then masked to identify the forested road locations with the highest optimal path density (*8. Compute*). In turn these locations are assigned a unique ID value (*9. Clump*) and summary statistics on each of the "best" potential landing sites are generated.

To put the spatial analysis into a decision context, a "thumbnail" estimate of the wood chip resource for Timbershed #15 is 164ac * 40T/ac = 6560 tons. At $15 to $30 per ton this converts to 6560T * $22.50 = $147,600. From another perspective, assuming 6000 to 8000 btu per pound of woodchips the energy stored in the biomass translates to 6560T * 2000lb/T * 7000btu/lb = 91,840,000,000 btu. At 3412 btu per kilowatt hour this converts to 91,840,000,000btu / 3412btu/kWh = nearly 27 million kilowatt hours …whew!

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Any way you look at it there is a lot of energy locked up in the giga-tons of beetle-gnawed biomass blanketing the Rockies. GIS modeling of its availability and access is but one of several critical steps needed in determining the economic, environmental and social viability of a "wood utilization" solution.

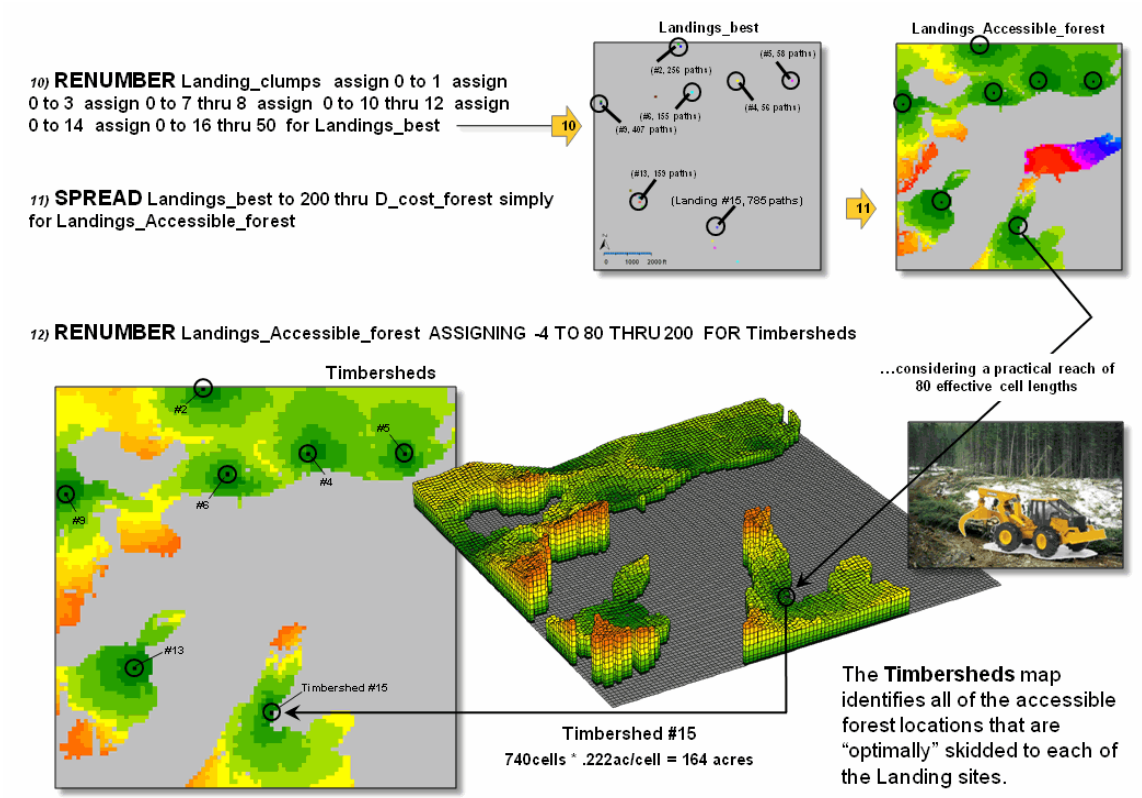

Figure 3. Identifying and characterizing the Timbersheds of the best Landing Sites (steps 10-12).

Author's Note: *See http://www.innovativegis.com/basis/MapCalc/MCcross_ref.htm for cross-reference of MapCalc commands to other software systems. An animated PowerPoint slide set of this 3-part Beyond Mapping series on "Assessing and Characterizing Relative Forest Access" and materials for a "hands-on" exercise are posted at www.innovativegis.com/basis/MapAnalysis/Topic29/ForestAccess.htm.*

Bringing Travel and Terrain Directions into Line

(GeoWorld, December 2012)

(***return to top of Topic***)

Precious discussions addressed "Backcountry 911" that considers both on- and off-road travel for emergency response ("*E911 for the Backcountry*," GeoWorld, July 2010; "*Extending Emergency Response Beyond the Lines*," GeoWorld, August 2010; "*Comparing Emergency Response Alternatives*," GeoWorld September 2010). As identified in the left portion of figure 1, the analysis involves the development of a "stepped accumulation surface" that first considers on-road travel by assigning the minimum travel-time from headquarters to all of the road locations. As shown in the figure, the farthest away location considering truck travel is 26.5 minutes occurring in the southeast corner of the project area.

The next step considers disembarking anywhere along the road network and moving off-road by ATV. However, the ability to simulate different modes of travel is not available in most grid-based map analysis toolsets. The algorithm requires the off-road movement to "remember" the travel-time at each road location and then start accumulating additional travel-time as the new movement twists, turns, and stops with respect to the relative and absolute barriers calibrated for ATV off-road travel (see Author's Note 2).

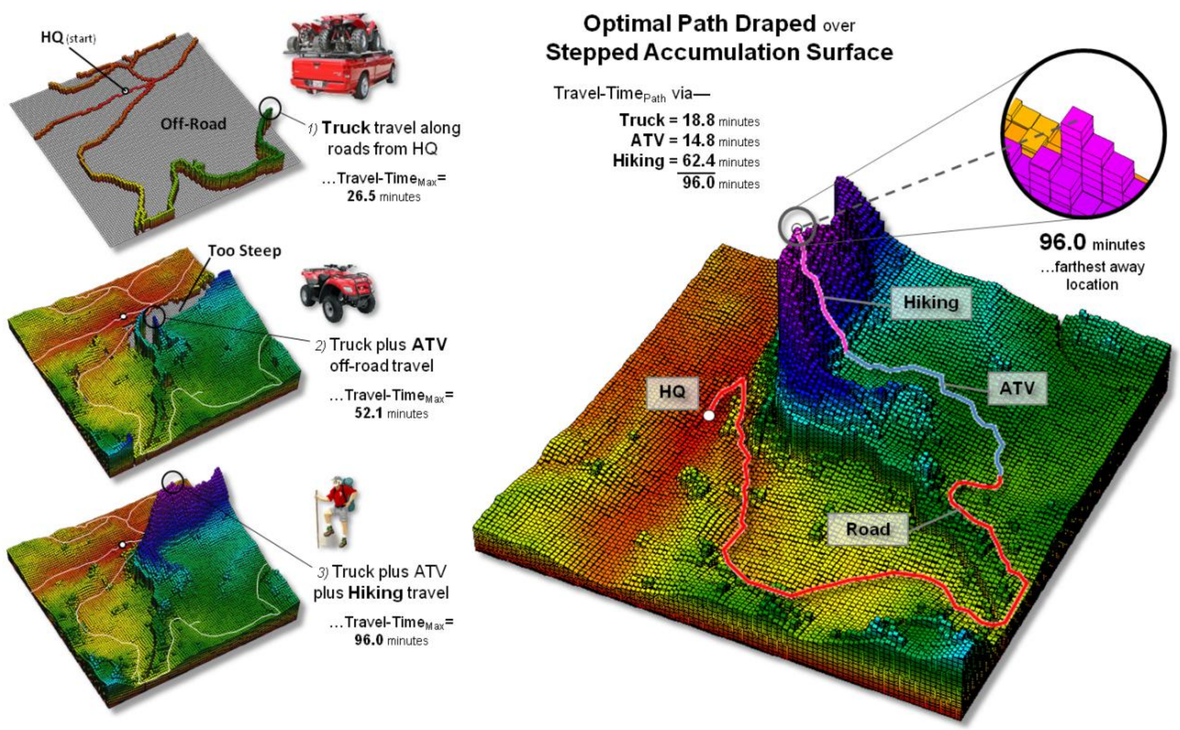

Figure 1. A backcountry emergency response surface identifies the travel-time of the "best path" to all locations considering a combination of truck, ATV and hiking travel.

The middle-left inset in figure 1 shows the accumulated travel-time for both on-road truck and off-road ATV travel where the intervening terrain conditions act like "speed limits" (relative barriers). Also, ATV travel is completely restricted by open water and very steep slopes (absolute barriers). The result of the processing assigns the minimum total travel-time to all accessible locations comprising about 85% of the project area. The farthest away location assuming combined truck and ATV travel is 52.1 minutes occurring in the central portion of the project area.

The remaining 15% is too steep for ATV travel and necessitates hiking into these locations. In a similar manner, the algorithm picks up the accumulated truck/ATV travel-time values and moves

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into the steep areas respecting the hiking difficulty under the adverse terrain conditions. Note the large increases in travel-time in these hard to reach areas. The farthest away location assuming combined truck, ATV and hiking is 96.0 minutes, also occurring in the central portion of the project area.

A traditional accumulation surface (one single step) identifies the minimum travel-time from a starting location to all other locations considering “constant” definitions of the relative and absolute barriers affecting movement. It has two very unique characteristics— 1) it forms a bowl-like shape with the starting point (or points) having the lowest value of zero = 0 units away from the start, and 2) continuously increasing travel-time values reflecting the relative ease of movement that warps the bowl with areas of relatively rapid increases in travel-time associated with areas of high relative barrier “costs.”

A stepped accumulation surface (top-center portion of figure 2) shares these characteristics but is far more complex as it reflects the cumulative effects of different modes of travel and the impact of their changing relative and absolute barriers on movement. Note the dramatic “ridge” running NE-SW through the center of the project area, as well as the other morphological ups and downs in total combined travel-time.

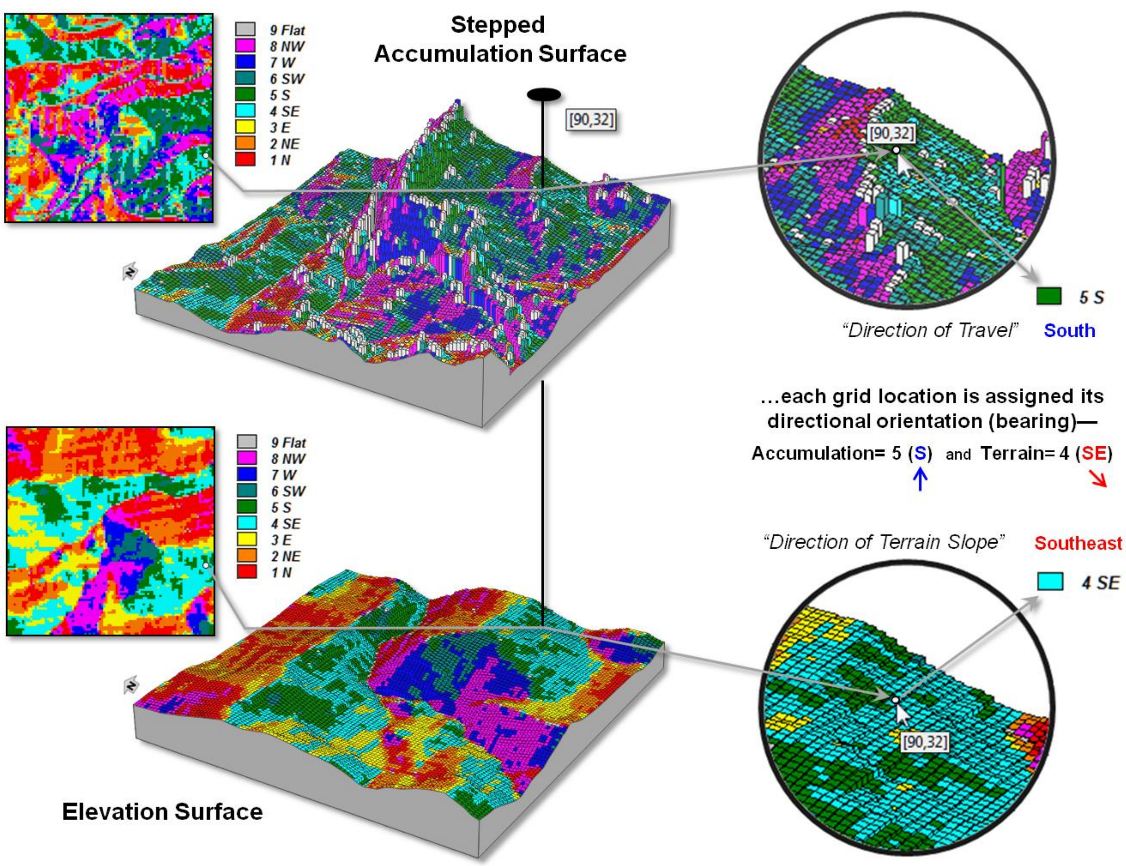

Figure 2. Maps of travel and terrain direction are characterized by the aspect (bearings) of their respective surfaces.

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In a sense, this wrinkling is analogous to a terrain surface, but the surface's configuration is the result of the relative ease of on- and off-road travel in cognitive space— not erosion, fracture, slippage and subsidence of dirt in real world space.

However like a terrain surface, an "aspect map" of the accumulation surface captures its orientation information identifying the direction of the "best path" movement through every grid location. The enlarged portion in the top-right of the figure shows that the travel direction through location 90, 32 in the analysis frame is from the south (octant 5). The lower portion of the figure identifies the terrain direction at the same location is oriented toward the southeast (octant 4). Hence we know that the movement through the location is across slope at an oblique uphill angle.

Figure 3 depicts a simple technique for combining the travel and terrain direction information. A 2-digit code is generated by multiplying "Travel Direction" map by 10 and adding it to the "Terrain Direction" map. For example, a "11" (one-one, not eleven) indicates that movement is toward the north on a north-facing slope, indicating an aligned downhill movement. A "15" indicates a northerly movement up a south-facing slope.

The center inset in the figure isolates all locations that have "aligned uphill movement" (opposing alignment) in any of the cardinal directions indicated by 2-digit codes of 15, 26, 37, 48, 51, 62, 73, and 84. Locations having "aligned downhill movement" are identified by codes of 11, 22, 33, 44, 55, 66, 77, and 88. All other combinations indicate either oblique or orthogonal cross-slope movements, or locations occurring on flat terrain without a dominant aspect.

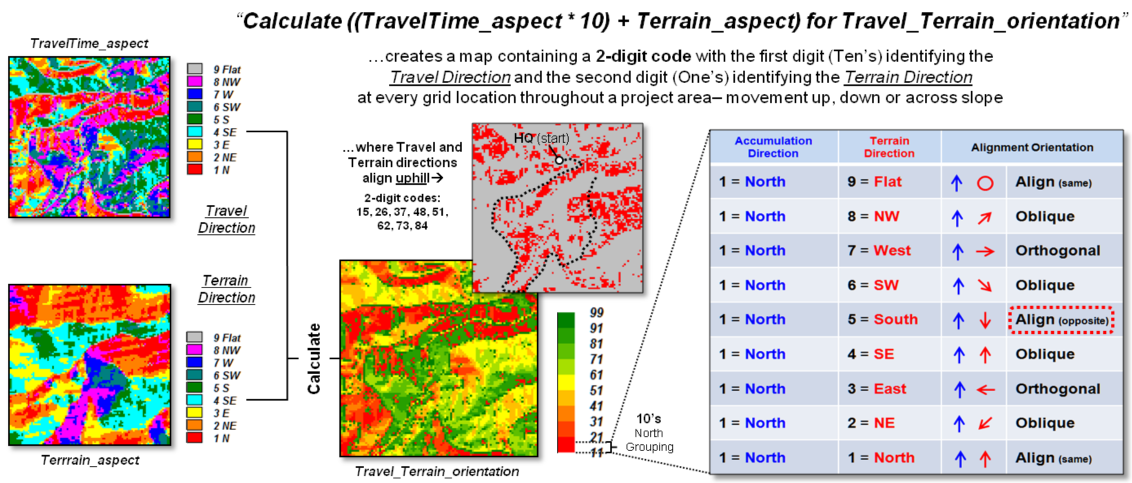

Figure 3. A 2-digit code is used to identify all combinations of travel and terrain directions.

I realize the thought of "an aspect map of an abstract surface," such as a stepped accumulation surface might seem a bit uncomfortable and well beyond traditional mapping; however it can provide very "real" and tremendously useful information. Characterizing directional movement is not only needed in backcountry emergency response but crucial in effective timber harvest

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planning, wildfire propagation modeling, pipeline routing and a myriad of other practical applications— such out-of-the-box spatial reasoning approaches are what are driving geotechnology to a whole new plane.

Author's Note*: for a detailed discussion of "stepped accumulation surfaces," see Topic 25, calculating Effective Distance and Connectivity in the online book Beyond Mapping III posted at www.innovativegis.com/basis/MapAnalysis/.*

Optimal Path Density is not all that Dense (Conceptually)

(GeoWorld, January 2013)

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The previous section addressed "Backcountry 911" that considers both on- and off-road travel for emergency response. Recall that the approach uses a stepped-accumulation cost surface to estimate travel-time by truck, then all-terrain vehicle (ATV) and finally hiking into areas too steep for ATVs.

The result is a map surface (formally termed an ***Accumulation Surface***) that identifies the minimum travel-time to reach all accessible locations within a project area. It is created by employing the "splash algorithm" to simulate movement in an analogous manner to the concentric wave pattern propagating out from a pebble tossed into a still pond. If the conditions are the same, the effect is directly comparable to the uniform set of ripples.

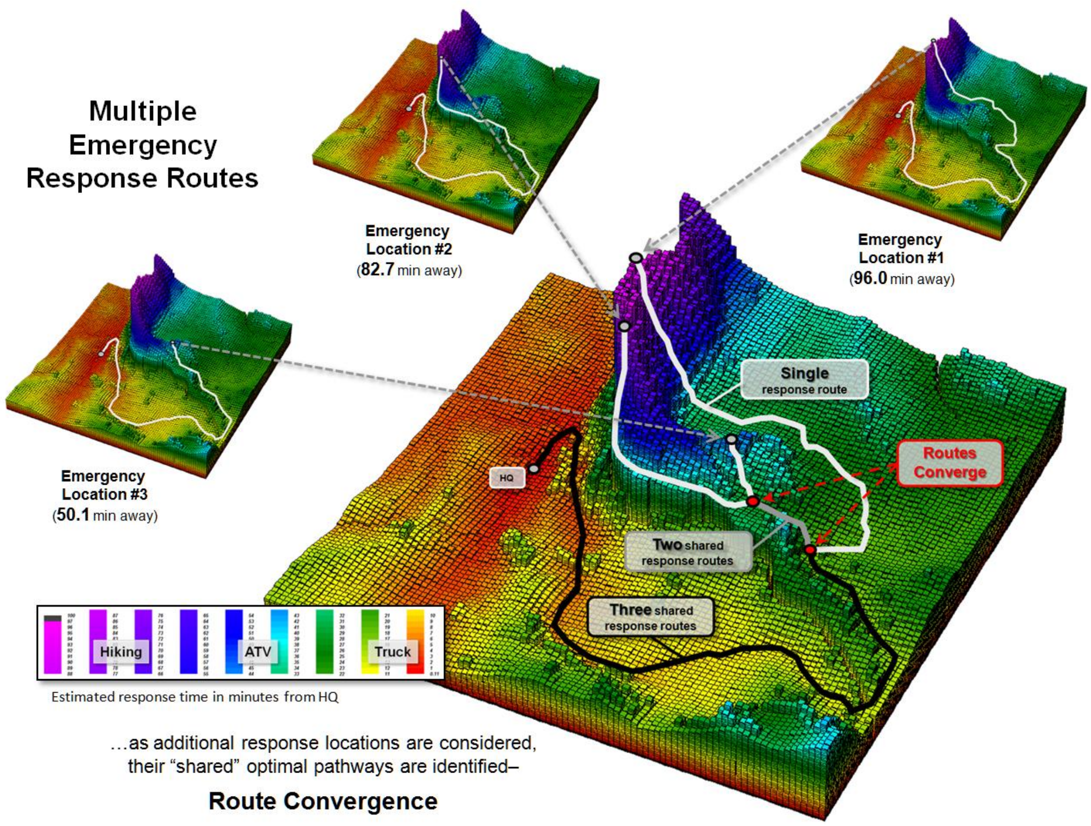

Figure 1. Multiple optimal paths tend to converge to take advantage of "common access" routes over the travel-time surface.

However as the wavefront encounters varying barriers to movement, the concentric rings are distorted as they bend and wiggle around the barriers to locate the shortest effective path. The conditions at each grid location are evaluated to determine whether movement is totally restricted (absolute barriers) or, if not, the relative difficulty of the movement (relative barrier). The end result is a map surface identifying the "shortest but not necessarily straight line" distance from the starting location to all other locations in a project area.

The emergency response surface shown in figure 1 identifies the minimum travel-time via a combination of truck, ATV and hiking from headquarters (HQ) to all other locations. Travel-time increases with each wavefront step as a function of the relative difficulty of movement that ultimately creates a warped bowl-like surface with the starting location at the bottom (HQ= 0.0 minutes away). The blue tones identify locations of very slow hiking conditions that result in the "mountain" of increasing travel-time to the farthest away location (Emergency Location #1= 96.0 minutes away).

The quickest route is rarely a straight line a crow might fly, but bends and turns depending on the intervening conditions and how they affect travel. The ***Optimal Path*** (minimum accumulated travel-time route) from any location is identified as "*the steepest downhill path over the accumulated travel-time surface*." This pathway retraces the route that the wavefront took as it moved away from the starting location while minimizing travel-time at each step.

The small plots in the outer portion of Figure 1 identify the individual optimal paths from three emergency locations. The larger center plot combines the three routes to identify their convergence to shared pathways— grey= two paths and black= all three paths.

The left side of figure 2 simulates responding to all accessible locations in the project area. The result is an "***Optimal Path Density***" surface that "*counts the number of optimal paths passing through each map location.*" This surface identifies major confluence areas analogous to water running off a landscape and channeling into gullies of easiest flow. The light-colored areas represent travel-time "ridges" that contain no or very few optimal paths. The emergency response "gullies" shown as darker tones represent off-road response corridors that service large portions of the backcountry.

These "*corridors of common access*" are depicted as increasingly darker tones that switch to red for locations servicing more than 256 potential emergency response locations. Note that 9,853 locations of the 10,000 locations in the project area "drain" into the headquarters location (the difference is the non-accessible flowing water locations).

This is powerful strategic planning information, as well as tactical response routing for individual emergencies (backcountry 911 routing). For example, knowing where the major access corridors intersect the road network can be used to identify candidate locations for staging areas. The right side of figure 2 identifies fifteen areas with high off-road access that exceeds an average of sixteen optimal routes within a 1-cell reach from the road. These "jumping off" points to the major response corridors might be upgraded to include signage for volunteer staging areas and improved roadside grading for emergency vehicle parking.

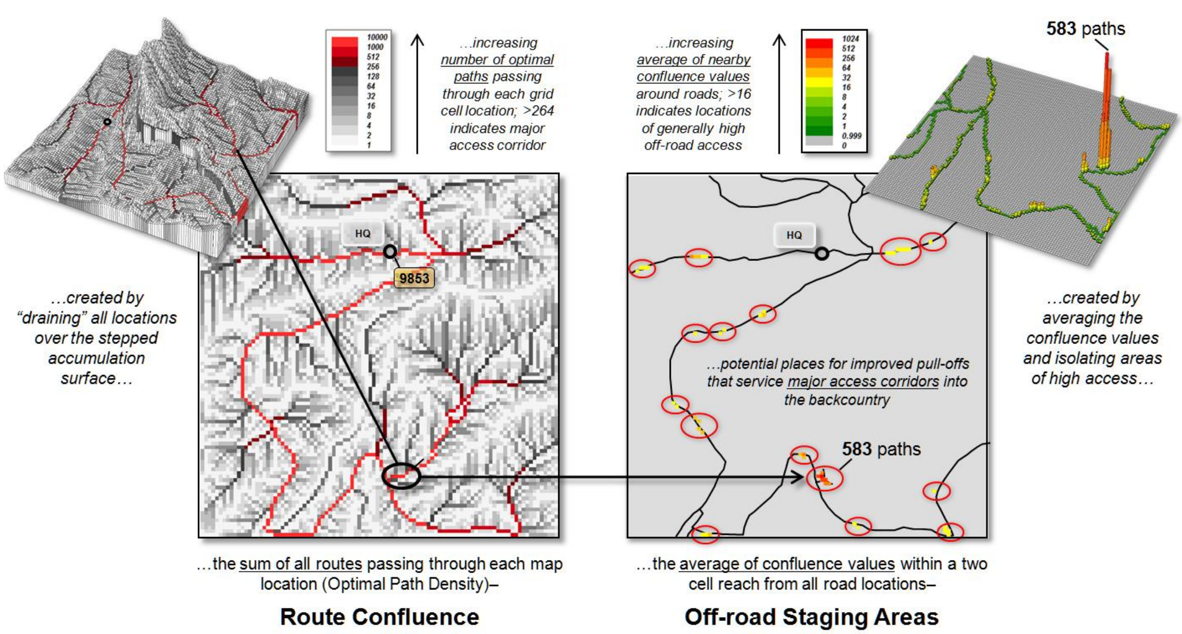

Figure 2. The sum of all optimal paths passing through a location indicates its relative rating as a "corridor of common access" for emergency response.

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In many ways, GIS technology is "more different, than it is similar" to traditional mapping and geo-query. It moves mapping beyond descriptions of the precise placement of physical features to prescriptions of new possibilities and perspectives of our geographic surroundings— an Optimal Path Density surface is but one of many innovative procedures in the new map analysis toolbox.

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Author's Note: *a free-use poster and short papers on Backcountry Emergency Response are posted at www.innovativegis.com/basis/Papers/Other/BackcountryER_poster/.*

Assessing Wildfire Response (Part 1): Oneth by Land, Twoeth by Air

(GeoWorld, August 2011)

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Wildfire initial attack generally takes three forms: *helicopter landing*, *helicopter rappelling* or *ground attack*. Terrain and land cover conditions are used to determine accessible areas and the relative initial attack travel-times for the three response modes. This and next month's column describes GIS modeling considerations and procedures for assessing and comparing alternative response travel-times.

The discussion is based on a recent U.S. Forest Service project undertaken by Fire Program Solutions (see Author's Notes). I was privileged to serve as a consultant for the project that modeled the relative response times for all of the Forest Service lands from the Rocky Mountains to the Pacific Ocean—at a 30m grid resolution, that's a lot of little squares. Fortunately for me, all I needed to do was work on the prototype model, leaving the heavy-lifting and "practical adjustments" to the extremely competent GIS specialist, wildfire professionals and USFS helitack experts on the team. The objectives of the project were to model the response times for different initial attack modes and provide summary maps, tables and recommendations for strategic planning and management of wildfire response assets.

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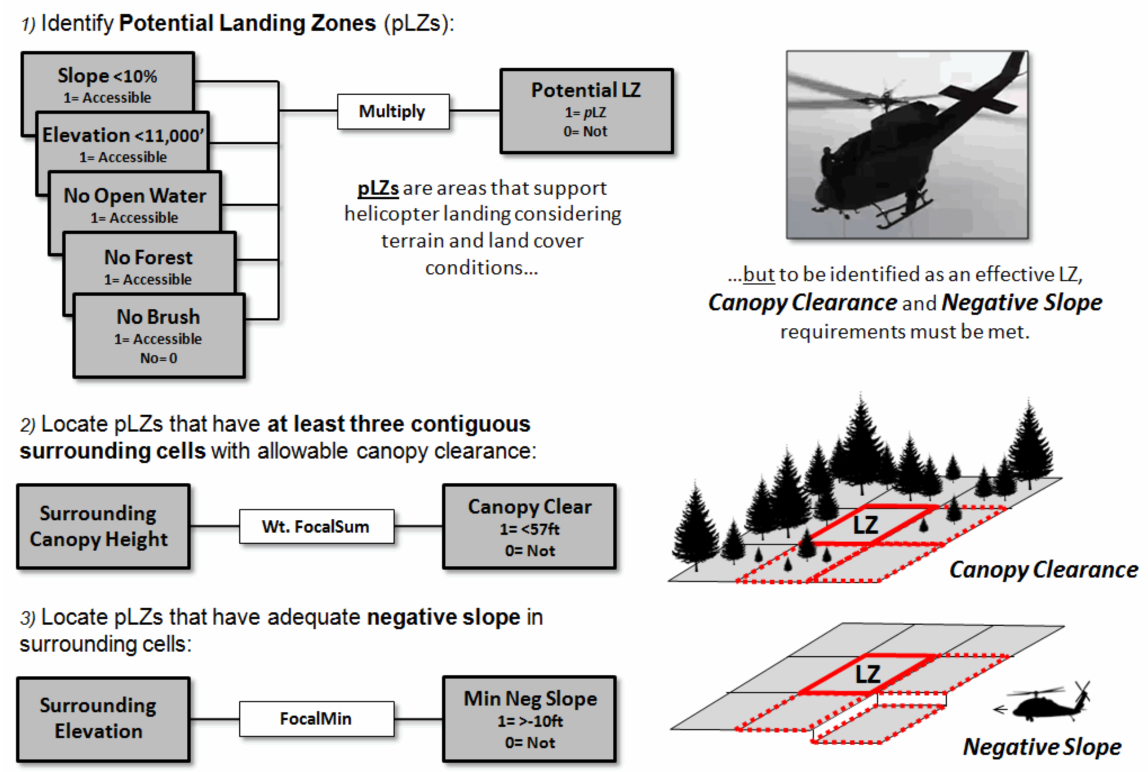

Figure 1. Generalized outline of a grid-based model for identifying Potential Landing Zones (pLZs) that are further evaluated for helicopter approach/departure considerations of Canopy Clearance and Negative Slope.

The most challenging sub-model involved identifying helicopter landing zones (see figure 1). A simple binary suitability model is used to identify Potential Landing Zones (pLZs) by assigning a map value of 1 to all accessible terrain (gentle slopes and sub-alpine elevations) and land cover conditions (no open water, forest or tall brush); with 0 assigned to inaccessible areas. Multiplying the binary set of maps derives a binary map of pLZs with 1 identifying locations meeting all of the conditions (1*1*1*1*1= 1); 0 indicates locations with at least one constraint.

Interior locations of large contiguous pLZs groupings make ideal landing zones. However, edge locations or small isolated pLZs clusters must be further evaluated for clear helicopter approach/departure flight paths. At least three contiguous cells surrounding a pLZ must have forest canopy of less than 57 feet to insure adequate *Canopy Clearance*. In addition, it is desirable to have a *Negative Slope* differential of at least 10 feet to aid landing and takeoff.

Two steps are required for evaluating canopy clearance (see figure 2). A reclassify operation is used to calculate a binary map with canopy heights of 57 feet or less assigned a value of 1; 0 for taller canopies. A neighborhood operation (*FocalSum* in ArcGIS) is used to calculate the number of clear canopy cells in the immediate vicinity of each pLZ cell (3x3 roving window). If all cells are clear, a value of 9 will be assigned, indicating an interior location in a grouping of pLZ cells.

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For derived values less than 9, an edge location or isolated pLZ is indicated. If there are more than four surrounding cells with adequate clearance, there has to be at least three that are contiguous and the pLZ is assigned a map value of 1 to indicate that there is a clear approach/departure; 0 for locations with a sum of less than 4.

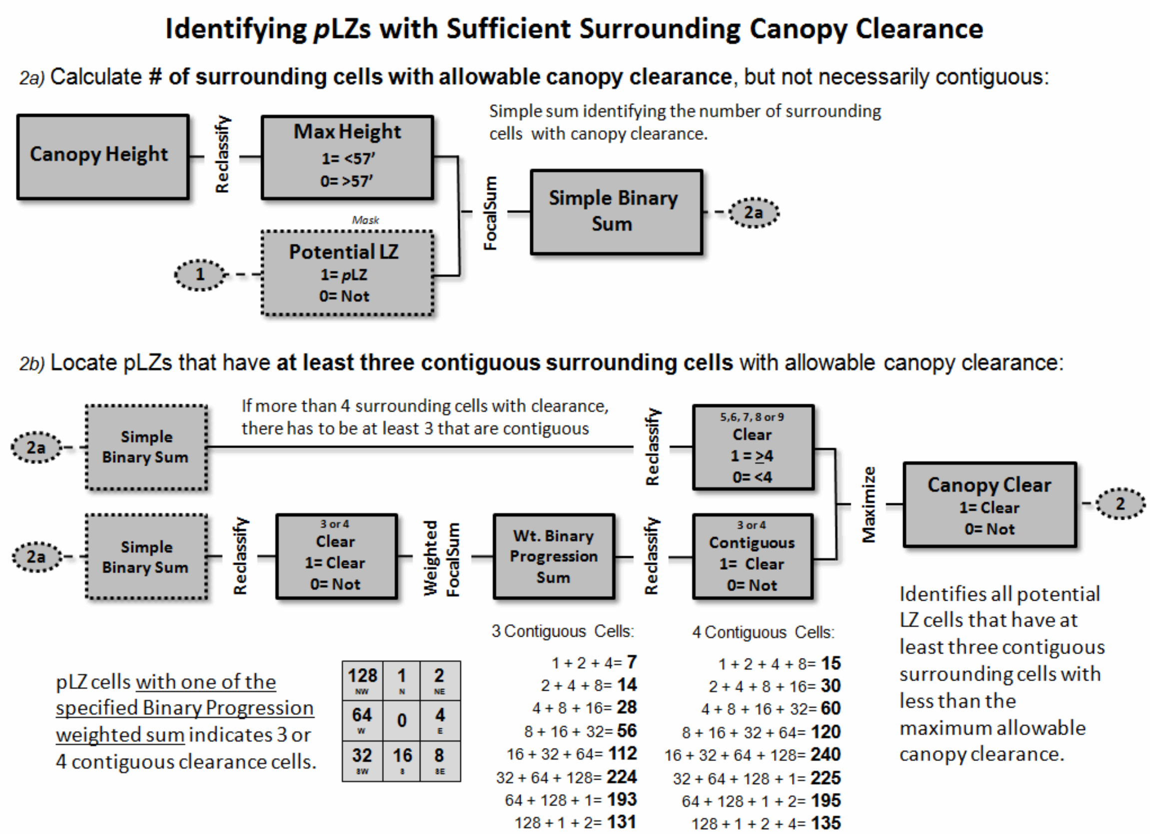

Figure 2. Procedure for identifying pLZs with sufficient surrounding canopy clearance.

Derived values indicating 3 or 4 clear surrounding cells must be further evaluated to determine if the cells are contiguous. First, locations with a simple binary sum of 3 or 4 are assigned 1; else= 0. A binary progression weighted window—1,2,4,8,16,32,64,128—is used to generate a weighted focal sum of the neighboring cells. The weighted sum results in a unique value for all possible configurations of the clear surrounding cells (see the lower portion of figure 2). For example, the only configuration that results in a sum of 7 is the binary progression weights of 1+2+4 indicating contiguous cells N,NE,E.

The weighted binary progression sums indicating contiguous cells are then reclassified to 1; 0=else. Finally, the minimum value for the "greater than 4 Clear" and "3 or 4 Clear" maps is taken resulting in 1 for locations having sufficient contiguous canopy clearance cells; else=0.

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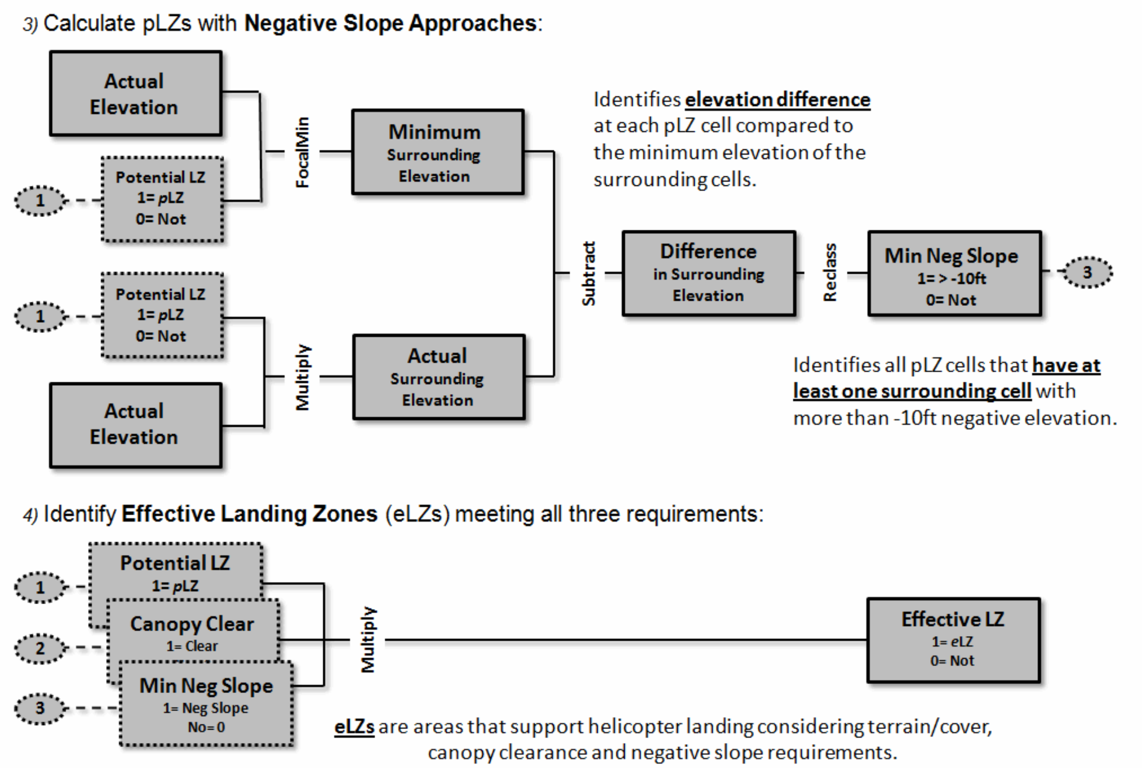

Figure 3. Procedures for identifying pLZs with sufficient negative slope (top) and combining all three considerations (bottom).

The top portion of figure 3 outlines the procedure for evaluating sufficient negative slope by determining the difference between the minimum surrounding elevation and each pLZ elevation. If the difference is greater than 10 feet, a map value of 1 is assigned; else= 0.

The final step multiplies the binary maps of Potential LZ, Canopy Clearance and Minimum Negative Slope. The result is a map of the Effective LZs as 1*1*1= 1 for locations meeting all three criteria.

In the operational model, the negative slope requirement was dropped as the client felt it was of marginal importance. The next section describes the analysis approaches for identifying ground response areas, helicopter rappelling zones and the translation of all three response modes into travel-time estimates for comparison.

Author's Notes: *For more information on Fire Program Solutions and their wildfire projects contact Don Carlton, DCARLTON1@aol.com.*

Assessing Wildfire Response (Part 2): Jumping Right into It

(GeoWorld, September 2013)

(*return to top of Topic*)

The previous section noted that wildland fire initial attack generally takes three forms: *helicopter landing*, *helicopter rappelling* or *ground attack* as determined by terrain and land cover conditions (also "*smoke-jumping*" but that's a whole other story). The earlier discussion described a spatial model developed by Fire Program Solutions (see Author's Notes) for identifying helicopter landing zones. The following discussion extends the analysis to modeling and comparing the response times for the three different initial attack modes for all locations within a project area.

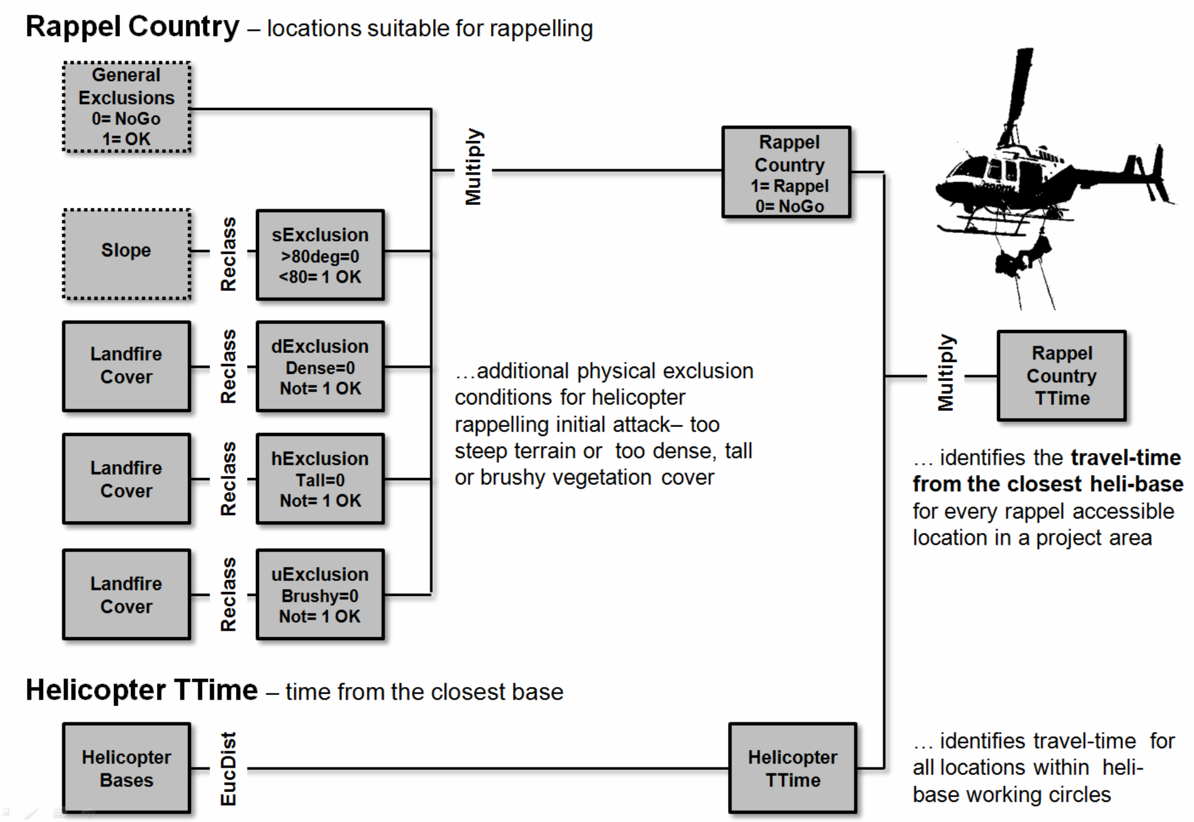

Figure 1. Major steps and considerations in modeling wildfire Helicopter Rappel Attack travel-time.

Figure 1 identifies the major steps in determining "Rappel Country" …there are some among us so heroic (crazy?) that they rappel out of a helicopter just to get to a wildfire before the crowd. Rappel country is defined as the areas where rappelling is the most effective initial attack mode based on project assumptions. In addition to general exclusions (e.g., open water, 10,000 foot altitude ceiling), rappelling must consider four other highly variable physical exclusions—extremely steep terrain (>80 degrees), very dense and/or tall forest canopies and dense tall brush. The simple binary model in the upper portion of figure 1 is used to identify locations suitable for rappelling (1= OK; 0= NoGo) where the fearless can jump from a hovering helicopter and slide down a rope between the trees up to a couple of hundred feet to the ground.

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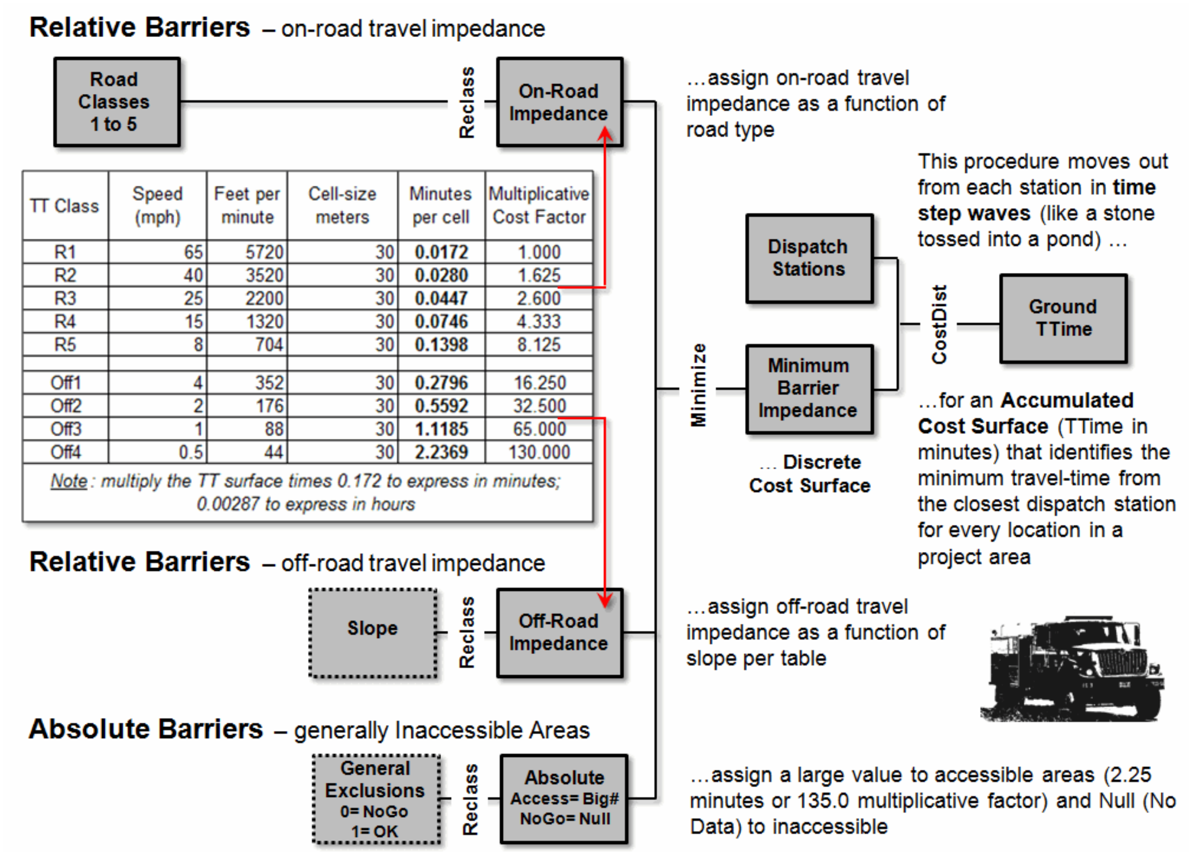
The lower portion of the figure uses a simple distance calculation to identify the travel-time within a 75 mile working circle about a helibase assuming a defined airspeed, round trip fuel capacity and other defining factors. By combining the binary map of rappel country and the helicopter travel-time surface, an estimated travel-time from the closest helibase to every Helicopter Rappelling Accessible location in a project area is determined.

In a similar "binary multiplication" manner, the helicopter travel-time to each Effective Landing Zone can be calculated. However, the landing crew must hike to a wildland fire outside the landing zone. This secondary travel is modeled in a manner similar to that used for the off-road movement of the ground response model described below. The helicopter flight time to a landing zone and the ground hiking time to the fire are combined for an overall travel-time from the closest helibase to every Helicopter Landing Accessible location in a project area.



TT Class	Speed (mph)	Feet per minute	Cell-size meters	Minutes per cell	Multiplicative Cost Factor
R1	65	5720	30	**0.0172**	1.000
R2	40	3520	30	**0.0280**	1.625
R3	25	2200	30	**0.0447**	2.600
R4	15	1320	30	**0.0746**	4.333
R5	8	704	30	**0.1398**	8.125
Off1	4	352	30	**0.2796**	16.250
Off2	2	176	30	**0.5592**	32.500
Off3	1	88	30	**1.1185**	65.000
Off4	0.5	44	30	**2.2369**	130.000

Note: multiply the TT surface times 0.172 to express in minutes; 0.00287 to express in hours

Figure 2. Major steps and considerations in modeling wildfire Ground Attack travel-time.

Figure 2 outlines the major steps in modeling the combined on- and off-road response time for a ground attack crew. On-road travel is determined by the typical speed for different road types. The calculations for deriving the travel-time to cross a 30m grid cell are shown in the rows of the table for five classes of roads from major highways (R1) to backwoods roads (R5). Note that the slowest travel taking .1398 minute to traverse a backwoods road cell is over eight times slower than the fastest (only .0172 min/cell).

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Off-road travel is based on typical hiking rates under increasingly steep terrain with the steepest class (2.2369 min/cell) being 130 times slower than travel on a highway. In addition, some locations form absolute barriers to ground movement (e.g., very steep slopes, open water).

The three types of impedance are combined such that the minimum friction/cost value is assigned to each location. A null value is assigned to locations with absolute barriers. This composited friction (termed a *Discrete Cost Surface*) is used to calculate the effective distance for every location to the closest dispatch station. The procedure moves out from each station in *time step waves* (like a stone tossed into a pond) that considers the relative impedance as it propagates to generate an *Accumulated Cost Surface* (TTime in minutes) identifying the minimum travel-time from the closest initial dispatch location to every location in a project area (see Author's Notes).

The three separate travel-time surfaces can be compared to identify the attack mode with the minimum response time (see figure 3) and the differential times for alternative attack modes. In operational situations, this information could be accessed for a fire's location and used in dispatch and tactical planning.

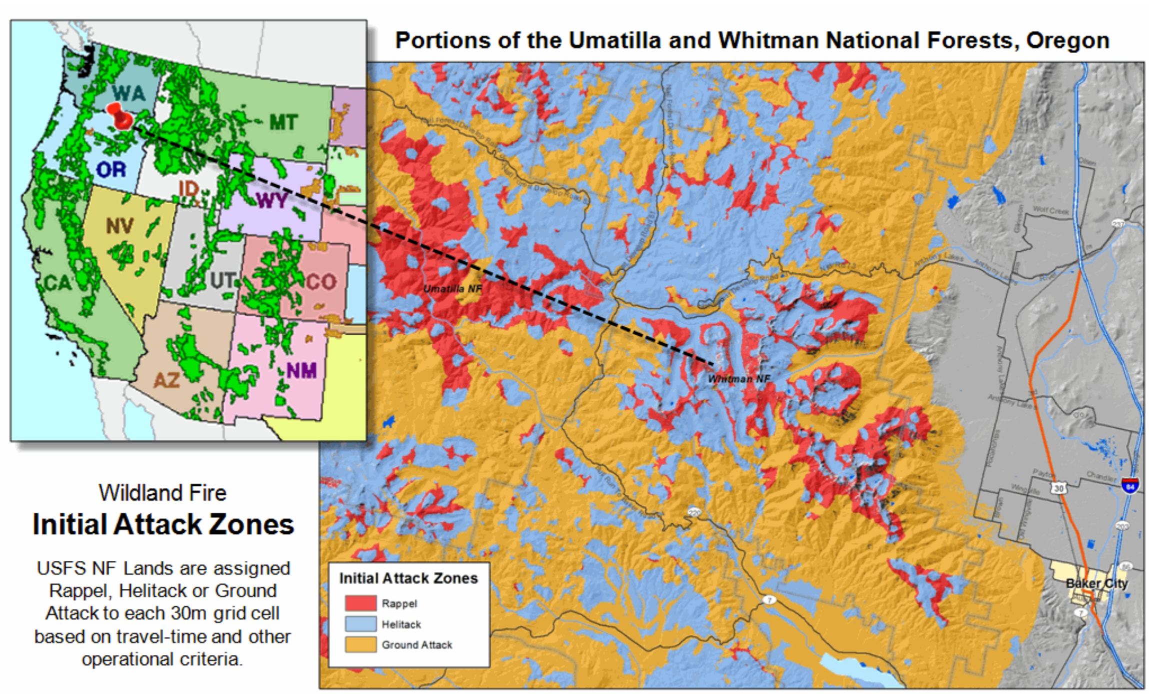

Figure 3. An example of a map of the "best" initial attack mode for a fairly large area draped over a Google 3D image.

In the "Rappel Country" project the information is used for strategic planning of the arrangement of helibase locations with rappel initial attack capabilities. Tabular summaries for travel-time from existing helibases by terrain and land cover conditions were generated. In addition, rearrangement of helibase location and capabilities could be simulated and evaluated.

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From a GIS perspective the project represents a noteworthy endeavor involving advanced grid-based map analysis procedures over a large geographic expanse from the Rocky Mountains to the Pacific Ocean that was completed in less than four months by a small team of domain experts and GIS specialists. The prototype analysis originally developed was interactively refined, modified and enhanced by the team and then applied over the expansive area.

As with most projects, database development and model specification/parameterization formed the largest hurdles—the grid-based map analysis component proved to be a "piece-of-cake" compared to nailing down the requirements and slogging around in millions upon millions of geo-registered 30m cells …whew!

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Author's Notes: *For more information on Fire Program Solutions, LLC and their wildfire projects contact Don Carlton, DCARLTON1@aol.com; for an in-depth discussion of travel-time calculation, see the online book Beyond Modeling III, Topic 25, Calculating Effective Distance, posted at www.innovativegis.com/Basis/MapAnalysis/Default.htm.*

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