Trails as Accessibility Management Tools in Mountain Areas

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Abstract:
In mountain areas a trail network is usually present and strictly interconnected to the forest road network, both allowing the access for transportation and recreation. Therefore trail network can be considered a ramification of forest road network, which integrates accessibility in forest area. If forest road can be travelled by different motorized vehicles, from trucks and trailer to small 4WD cars, trail network can be mainly walked or travelled by small ATV. From this point of view trails represent a basic infrastructure for rescue interventions during which a widespread presence of operators is required. In order to evaluate the role of a trail network in a mountain area a methodology has been set up to assist the decision on determining the access time of the rescue crews along the trail network from the main road network. The methodology is based on a detailed GPS survey of the trail network considering the barriers for the pedestrian and motor vehicle accessibility. The resulting trail network is thus used to support the evaluation of the time/cost-distance according to the pedestrian or motor vehicle accessibility. Furthermore to increase the accuracy of the methodology, the evaluation of the off-trail pedestrian accessibility is also investigated according to the terrain geomorphology and the forest type. The resulting GIS model is a tool based on the GIS cost surface raster analysis. The methodology has been applied in a forest area in the North-eastern of Italy and the experimental design has been analyzed in order to identify the most difficult area to be reached and to evaluate the most reliable access for rescue crews.

Keywords: trail network, GIS, rescue intervention, cost surface raster

1 Introduction

Historically the road and trail networks in forest area were developed specifically to provide access for resource extraction and transportation purposes, such as timber transportation, hunting, and tribal connections (Janowsky and Becker, 2003). The trail network is thus present and strictly interconnected to forest road network, forest roads and trails are essential for the socio-economic development of population living in hilly and mountain areas and they are considered necessary to exercise a rational and economic management of forests, mountain pastures and agricultural lands (Haggett, 1965; Cielo and Gottero, 2004; Polelli, 2009).

Over the last decades the renewable use and environmental services of natural area resources has increased and emphasized the use of forest road and trail networks to provide access for nature-based tourism and recreation activities (Coghlan and Sowa, 1997; Gray et al., 2003; Chirici et al., 2003) walking, biking or skiing. This shared network allows many people interested in mountaineering, wildlife viewing, mushroom picking to reach wild areas guaranteeing a multifunction aspect that however would lead also to an increase risk of accident. Indeed a well-organized and managed trail network is essential in order to guarantee accessibility and first aid activities in mountain territories.

1.1 Aims

This study has developed a GIS model to map a wild mountainous area according to the time cost distance for mountaineering Search and Rescue (SAR) to reach any trails and off-trails area from any public roads. The analysis has evaluated the current operation condition based on the transport of the SAR crews by a small 4WD car along the forest road and the pedestrian progress of the same crew along the trail network (Scenario 1). An improvement operation condition based on the use of ATV vehicle has been also considered (Scenario 2).

2 Material and methods

2.1 Study area

The study area is 90 km^2 wide and it is located in the Chiampo and Agno valley in the North-eastern part of Italy (N 45°43'00-45°35'00, E 11°08'00-11°18'00), characterized by an elevation ranging from 200 m to 2000 m a.s.l. and showing different environments. The lower area is characterized by a dense network of forest roads mostly of them with low road standard and path trails under forest cover mostly used by forest landowners, mushroom pickers, hunters and hikers. The mountainous area is characterized by small forest road with high vertical grade and alpine trails and it attends mainly for outdoor activities like alpinism, hikers and mountain bikers.
Data about SAR activities in the area (SAR of Recoaro-Valdagno, 2012) have highlighted an increment of operation from an average per year of 14 in 2002-2006 to 31 in 2007-2011. This trend on the increment of mountaineering accidents is also confirmed in other mountainous regions (Lischke et al., 2001; Hung and Townes, 2007; Heggie, 2008).

2.2 Forest roads and trail network

This study area has been interested by a previous study on forest roads (Pellegrini, 2012) that has created a basic forest road network geo-database with descriptive fields containing characteristics and information such width, gradient and maintenance condition. In order to improve the information about the access network, the forest road network has been thus integrated with trail network by ortho-photo interpretation, technical and topographic maps and field surveys (33% of the network). The resulting total length (439.2 km) of the access network is shown in Table 1.

Table 1: Description of the access network including roads and trails

Classes	Function	Surface	Length (km)	Adapt
C	Public access	Paved	45.5	All vehicles
MF	Multi-function	Paved	118.7	All vehicles
		Total	*164.2*	
MF	Multi-function	Unpaved	89.3	4WD vehicles and pedestrian
FOR	Exclusive for forest operation and recreation	Unpaved	102.2	4WD vehicles and pedestrian
S	Access to pastures or recreation activities	Natural	83.5	Only pedestrian
		Total	*275.0*	

The study considers however the main road network, so paved roads, suitable for ordinary rescue and safety operations and therefore it is considered as the starting point of the specialized mountaineering SAR crews which are the only ones who can operate along unpaved roads (62.6% of the full access network of the study area).

2.3 Experimental design for speed analysis

Study layout

Travel time analysis of different vehicles and SAR crews were based on field surveys aiming to test the speed of 4WD vehicles and SAR crews under different conditions. Tests were carried on with the cooperation of members of the Recoaro-Valdagno SAR Station.

The study of the speed considered four situations: evaluating the driving speed of small 4WD vehicles including a 4WD car and a ATV vehicle on small and steep forest road not adapted to 2WD vehicles; evaluating the driving speed of small a ATV vehicle on trail; evaluating the walking speed of a SAR crew on trail.

The study of small 4WD vehicles verified the speed on-road according to three road surface conditions (road surface in good condition; road surface failure starting; complete failure of road surface), road grade (from 0 to 30%) and travel width (from 1.8 to 2.5 m). Two 4WD small vehicles were tested: FIAT Panda 4WD as a small 4WD car and Yamaha Raptor 660 as a small ATV vehicle. The following speed hypothesis was thus formulated for both the vehicles: small 4WD vehicle speed = f (road grade (RG); travel width (TW); road surface conditions (RC)).

The study of the speed of the ATV vehicle on trails considered the trail grade (from 0 to 35%) and trail surface condition (regular; partially irregular; irregular). A minimum width of 1.6 m was considered. The following speed hypothesis was thus formulated: ATV vehicle speed on trail = f (trail grade (TG); trail surface conditions (TC).

The study of the SAR crew walking speed on trails considered only the trail grade (from 0 to 30%). The following speed hypothesis was thus formulated: SAR crew speed on trail = f (trail grade (TG)).

The experimental design for the travel time analysis on off-trail situation verified the speed of SAR crew according to the terrain grade (from 0 to 100%) and two types of land cover (permanent grassland and meadow or forest cover). The following speed hypothesis was thus formulated: SAR crew speed off-trail = f (terrain grade (TG); type of land cover (LC)).

Speed data collection

The use of GPS and D-GPS to record route or tracks, speed and fuel consumptions also under forest cover is well known in the last years (Devlin et al., 2007; Devlin et al., 2008; Devlin and McDonnell, 2009; Holzleitner et al., 2011). Different studies reported that speed and acceleration accuracy decrease as canopy condition changes from open to dense canopy. However the vehicle speed did not appear to affect the accuracy of the acquired data (Veal et al., 2001).

For these reasons the speed of vehicles was collected by a D-GPS antenna (PROXH TRIMBLE®) and a mapping-grade GPS handler (NOMAD TRIMBLE®) with a specific GPS software (TERRASYNC®). The GPS was set in order to record the speed (km h^{-1}) every one second from starting point to the closing point. The recorded data were therefore post-processed by a differential correction by *rinex* data available from a base GPS station within a distance of 15 km. In order to add more accuracy the acquired data were filtered by a PDOP (indicating a lower probability of accuracy) lower than 6 (Sigrist et al., 1999). In the case of the 4WD vehicle the antenna was fixed at the high of 2 m from the terrain on the centre of the roof, while in the case of the ATV the antenna was collocated on the rear part of the vehicle also at an high of 2 m from the terrain.

The walking speed of the SAR crew on-trail and off-trail were derived by the GPS data collected by a consumer-grade GPS (GARMIN® 62CS). The choice of this solution was determined because of the user-friendly characteristics of the GPS and because of the SAR operators were familiar with this type of GPS. Also, as reported by Wing (2011) the accuracy of consumer grade GPS could be adequate also under dense canopy conditions. The walking speed was therefore extracted by the difference in the travelled distance and altitude in an interval of 20 s in order to get more accuracy according to the consumer GPS accuracy (± 5.4m).

GPS-data was recorded in World Geographic System 1984 (WGS84) and projected in UTM 32 N. The GPS data were converted into shapefile in point format including all the attributes collected by the GPS.

All the tracks were hence surveyed in terms of standard characteristics. The forest roads were surveyed in uniform segments according to road grade, horizontal alignment, width and road surface condition. The trail tracks suitable for the ATV were also subdivided in uniform segments according to trail grade and surface conditions. The trail path and the off-trail paths for the pedestrian SAR crews were hence surveyed in terms of path alignment and, focusing on the off-trail condition, also in terms of land cover. All the travelled tracks were surveyed by the D-GPS with at least 120 measurements for each surveyed point. Each segment was thus fixed by measuring slope distance, grade, azimuth and by calculating horizontal and vertical distance. The surveys were hold using a laser rangefinder (Trupulse® 360B - Laser Technology®) with an accuracy of ± 0.3 m to 1.00 m in distance, ± 0.25° in inclination and ± 1° in azimuth.

Using ArcGIS® 10 (ESRI), the recorded points were thus analyzed in order to assign the direction of travel. The speed data were snapped to the previously surveyed tracks. For all the situations the maximum distance of snapping from the speed point to the track feature was limited to 5 m, the rest of the points were thus filtered. As a consequent for each homogeneous segment the average speed of the snapped point was calculated and linked to the characteristics of the track segment.

Statistical analysis

For each speed study, the statistical analysis considered the development of a linear model with all the studied factors and covariates, the evaluation of their non-linearity and the choice of the model by removing variables that were not significant at 0.05 level. The regression linear model assumed the use of logarithmic transformed variables in order to express nonlinear models in linear model form. Therefore, the speed models were tested in order to obtain the best possible symmetrical distributions of residuals of the regression models and to achieve the best values for the coefficients. The homogeneity of variance was tested by Levene's test (<0.05). Statistical analysis was carried out using STATGRAPHICS® 16.1.

2.4 GIS procedure for travel time calculation

The SAR crew access time is calculated by along the secondary road network and all the unpaved roads by motor vehicles such as small 4WD cars and ATVs. Therefore for the off-trail area the travel time is calculated from the secondary forest road and trail network. The GIS model input are: road and trail network (including ordinary roads and secondary roads: forest roads and trails), Digital Elevation Model (DEM), Land Use Cover map (including forest type map), type and speed model of the SAR vehicles; speed model of the SAR crews for trail and off-trail movements.

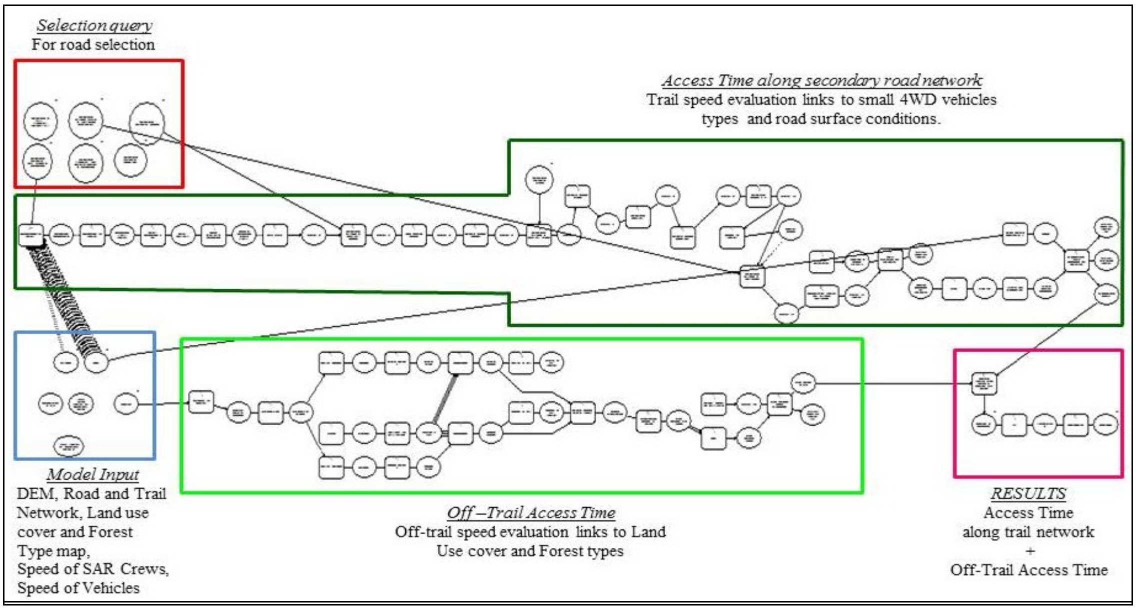

Figure 1: Model elements of the mountain rescue access time tool

Figure 1 shows the GIS model elements of the mountain rescue access time tool. The first core of the model is composed in two modules: one evaluates the access time calculation along the secondary forest road network and unpaved road while the other evaluates the access time cost calculation along off-trail network. The second core of the GIS model calculates the access time for off-trail movement. Both these modules are based on the speed models formulations based mainly on road, trail or terrain grade.

The basic GIS analysis is based on path distance tool used in conjunction to model effectively the dispersion and movement processes (Burrough and McDonnell, 1998). The path distance tool is used to determine the minimum accumulative travel cost from a source to each cell location on a raster. Path distance tool calculates the accumulative cost over a cost surface and compensates it for the surface distance and for horizontal and vertical factors influencing the total cost of moving from one location to another.

The gradient of road and trails were partially based on the methodology of Guo and Kurt (2004) and Wing and Johnson (2001) by using a DEM with a medium resolution (5 m).

3 Results and discussions

3.1 Statistical results

Table 2 shows a summary of the results of the observed speeds that were acquired by GPS. The number of the observation indicates the observed speeds filtered by a maximum PDOP of 6 for the surveys based on D-GPS (*) and for the observation based on consumer grade GPS (**) the speeds were filtered by abnormal values. As Tobler (1993) reported a maximum speed for walking on footpath in hilly and mountainous terrain of 6 km h^{-1}, the walking speed was filtered by values higher than 7 km h^{-1} for movement along trail network and 5.5 km h^{-1} in off-trail movement. This last threshold was fixed higher than the value indicated by Ciolli et al. (2006) as the SAR crews are expected to walk faster if they are not in research activity.

Statistical analysis resulted therefore in speed models for all the different situation analysed (Table 3). The travel time is thus computed as the travelled distance (km) divided by the movement speed (km h^{-1}) according to the formulas reported on Table 4.

Table 2: Summary statistic of the observed speeds

	Speed			Grade			*Observed speeds
	Mean (km h^{-1})	q 0.05 (km h^{-1})	q 0.25 (km h^{-1})	Mean (%)	q 0.05 (%)	q 0.25 (%)	(n.)
Panda 4WD on road*	14.48	12.52	16.40	8.26	4.20	11.40	754
ATV on road*	18.16	14.00	22.01	8.26	4.20	11.40	715
ATV on trail*	14.22	11.30	17.38	11.06	6.99	14.77	375
Crew on trail**	4.86	4.20	5.60	14.71	10.85	19.00	618
Crew off trail**	3.22	2.10	4.37	28.69	9.40	43.23	155

Table 2: Statistical of time speed models (confidence level 0.95)

Speed model	Dependent variable	R^2 (adjusted) %	F *test* (*p*)	Obs. -	Terms / Predictor	Constant/Coefficient Estimate	Constant/Coefficient Std. error	95% confidence interval of the difference lower	95% confidence interval of the difference upper	F	*p*
Panda 4WD on forest road	LN(Speed)	41.7	133.74 (<0.001)	754	Constant	2.586	0.020	2.547	2.626	16517.9	<0.001
					RG*	-0.015	0.001	-0.017	-0.013	215.16	<0.001
					TW	0.060	0.006	0.049	0.071	109.25	<0.001
					RS1	0.086	0.010	0.067	0.106	40.04	<0.001
					RS2	0.014	0.010	-0.005	0.033		
ATV on forest road	LN(Speed)	39.3	116.73 (<0.001)	715	Constant	2.870	0.034	2.803	2.937	7078.95	<0.001
					RG*	-0.017	0.001	-0.019	-0.015	218.56	<0.001
					TW	0.139	0.012	0.114	0.163	124.83	<0.001
					RS1	0.071	0.011	0.050	0.092	24.38	<0.001
					RS2	0.045	0.011	0.024	0.066		
ATV on trail	LN(Speed)	54.9	153.10 (<0.001)	375	Constant	2.799	0.023	2.754	2.844	272.24	<0.001
					TG*	-0.022	0.002	-0.027	-0.019	162.16	<0.001
					TC1	0.189	0.016	0.158	0.219	142.65	0.016
					TC2	0.078	0.021	0.037	0.119		
SAR crew on trail	LN(Speed)	49.5	626.02 (<0.001)	618	Constant	1.916	0.016	1.885	1.947	14946.1	<0.001
					TG*	-0.024	0.001	-0.026	-0.022	626.02	<0.001
SAR crew off trail	LN(Speed)	57.6	241.33 (<0.001)	155	Constant	1.788	0.028	1.733	1.842	4179.02	<0.001
					TG*	-0.015	0.001	-0.016	-0.014	452.77	<0.001
					LC	0.046	0.017	0.012	0.080	7.01	0.009

*Absolute value

Table 3: Resulting speed model for the different types of access (confidence level 0.95)

Panda 4WD on forest road	$Speed = 13.279 * e^{(0.086*RS1-0.014*RS2+0.0600257*TW - 0.015*\|RG-1.7\|)}$ RS1=1 and RS2 = 0 (road surface in good condition) RS1=1 and RS2 = 0 (road surface failure starting) RS1=0 and RS2 = 0 (road surface in poor condition) TW = travel width (m); RG = road grade (%)
ATV on forest road	$Speed = 17.641 * e^{(0.071*RS1-0.045*RS2+0.139*TW - 0.017*\|RG+0.5)}$ RS1=1 and RS2 = 0 (road surface in good condition) RC1=1 and RC2 = 0 (road surface failure starting) RC1=0 and RC2 = 0 (road surface in poor condition) TW = travel width (m); RG = road grade (%)
ATV on trail	$Speed = 16.428 * e^{(0.189*TC1-0.078*TC2-0.022*\|TG-1.1\|)}$ TC1=1 and TC 2 = 0 (Regular trail surface condition) TC 1=1 and TC 2 = 0 (Partially irregular trail surface condition) TC 1=0 and TC 2 = 0 (Irregular trail surface condition) TG = terrain grade (%)
CREW off-trail	$Speed = 5.976 * e^{(0.046*LC- 0.015*\|TG+5.0\|)}$ LC = 1 if permanent grassland and meadow or LC = -1 if forest area TG = terrain grade (%)
CREW on trail	$Speed = 6.795 * e^{(-0.024*\|TG+5.8\|)}$ TG = terrain grade (%)

The formula reports also a corrective coefficient as the distributions of the speed were roughly symmetrical (Figure 2 and Figure 3). The corrective coefficients were empirically derived by the intersection between the simple regression models for down-hill speeds and up-hill speeds.

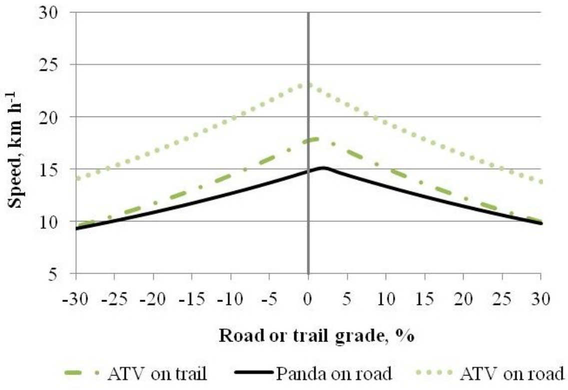

Figure 2: Speed models of the small 4WD car and ATV on narrow forest road (2.0 m travel width) and with a road surface failure starting and speed of ATV on trail with a partially irregular surface

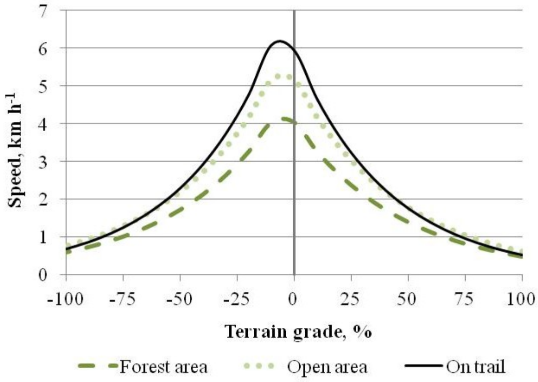

Figure 3: Speed models of SAR crews on trail and off trail in forest area and in permanent grassland and meadow

3.2 GIS model results

The GIS model results show the accumulative travel time cost of SAR crew from any parts of the ordinary road network or paved roads.

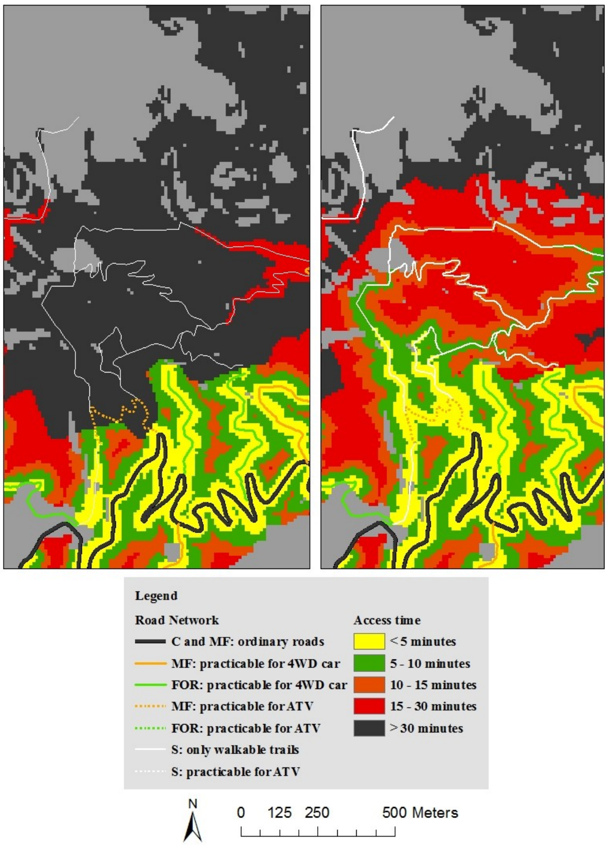

Figure 4: Details of the accumulative travel time cost for Scenario 1 (left) and Scenario 2 (right)

As shown on the maps of Figure 4, two scenarios were considered: the Scenario 1 corresponds to the current situation in which SAR crew uses small 4WD cars, while in Scenario 2 the SAR crew can travel along the secondary forest roads and appropriate trails by ATVs instead of the small 4WD cars. The results confirm the possibility in the use of ATVs in order to speed up rescue operations. The evaluation of the two scenarios highlights that with the use of ATVs in SAR operations are faster.

In particular, the area reachable by the small 4WD car within 30 minutes is 26% of the total area, while it decreases to 21% with the use of the ATVs. The use of ATV allows SAR crew to travel with a vehicle also in a part of the trail network (Figure 5). Results show that in Scenario 1 the use of the small 4WD is possible only for 60% of the whole access network including the trail network while in the Scenario 2 the use of ATV allow the SAR crew to travel with a vehicle for the 77% of the entire access network.

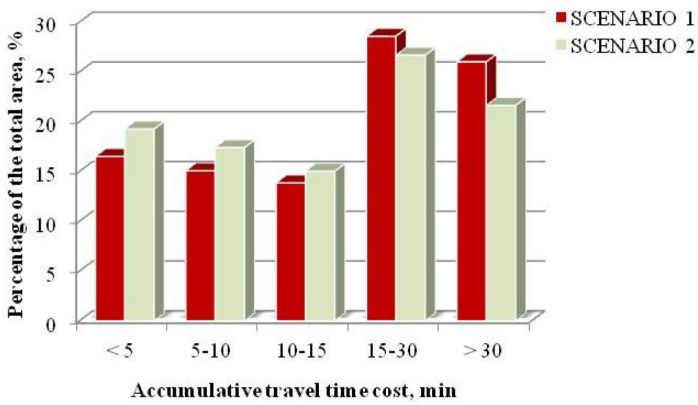

Figure 5: Accumulative travel time cost in Scenario 1 and Scenario 2

4 Conclusions

A better knowledge of trail network characteristics through field surveys could surely improve model results; anyway future applications are also possible in order to include other factors influencing the speed progress. Moreover a future work will focus on the study of specific ATV vehicles for SAR operations as in the time of the study were not present in the test area. Also the use of a more precise terrain and canopy data based on LiDAR technology could improve the accuracy of results (Pirotti et al. 2012) and consequently verify the validity of the model.

However this GIS application confirms that the use of GIS methodology combined with field data allows to create useful tools in order to value the accessibility of the forest area. The mountain rescue access time GIS tool sounds to be useful in order to support the decision SAR strategy in order to improve safe and faster interventions and to verify the vehicle alternative.

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