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# Analysis of Vehicle Use Patterns during Military Field Exercises to Identify Potential Roads

Chunxia Wu
*University of Tennessee - Knoxville*

To the Graduate Council:

I am submitting herewith a dissertation written by Chunxia Wu entitled "Analysis of Vehicle Use Patterns during Military Field Exercises to Identify Potential Roads." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Biosystems Engineering.

Paul D. Ayers, Major Professor

We have read this dissertation and recommend its acceptance:

J. Wesley Hines, Shih-Lung Shaw, John B. Wilkerson

Accepted for the Council:

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Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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J. Wesley Hines_______

Shih-Lung Shaw_______

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Vice Chancellor and Dean of
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(Original signatures are on file with official student records.)

# ANALYSIS OF VEHICLE USE PATTERNS DURING MILITARY FIELD EXERCISES TO IDENTIFY POTENTIAL ROADS

A Dissertation

Presented for the

Doctor of Philosophy Degree

The University of Tennessee, Knoxville

Chunxia Wu

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# ABSTRACT

Military training is an intensive land use and can cause negative environmental effects. Many studies conducted under Integrated Training Area Management (ITAM) for quantifying the impact resulted from the military training exercise found that off-road vehicular activities during training exercises cause the major impact to the training land. Vehicle land use patterns at a certain location affect the impact severity: concentrated and repeated traffic create more serious damage to the land compared to the dispersed off-road vehicle movements. Those areas heavily disturbed by off-road traffic may require a longer period of time or special treatments for the land to return to its pre-disturbed status. Based on the impact severity and the shape of the disturbed area, some areas can be considered as potential roads, defined as the roads newly formed by concentrated off-road traffic during the military training exercises, or the roads currently exist but have not been mapped. Potential roads need to be rehabilitated, have traffic dispersed to return the land to its natural status, or to be included in the established road construction and maintenance programs.

As Global Positioning System (GPS) has been used for monitoring vehicles' activities during military training exercises; it enables the analysis of vehicle movement patterns. The vehicle movement patterns are characterized as the percentage of vehicle travel every day, vehicles' on and off road travel, the frequencies of vehicle's off-road velocity and turning radius. GPS vehicle tracking data collected during an eight-day reconnaissance training exercises in Yakima Training Center (YTC) in October 2001

were analyzed for vehicle movement patterns. Comparison of the on-road and off-road movement patterns indicates that potential roads may exist on the locations where the concentrated traffic or a high speed movement occurred.

Based on the analysis of the movement patterns, factors were extracted to characterize the special movement patterns that indicate the vehicles moved on a potential road. The YTC was divided into small study units, and a multicriteria method was developed to determine if a study unit is a portion of a potential road. The multicriteria method was evaluated by comparing the predictions to the site visit results on 34 selected road segments that met different criteria levels. Results show that locations met higher criteria levels have higher possibilities to be roads: the location met all five criteria has an approximately 91% possibility for road existence; those met four criteria has an approximately 55% possibility; and for those met criteria level two or three, there is an approximately 14% probability for road existence. The analysis of updated off-road shows the percentage of vehicle off-road movement drops from 20.0% to 15.8% after excluding the potential road moving data.

As an alternative method, a neural network approach for identifying the potential roads was introduced and compared to the multicriteria method. The neural network method obtained an approximately 85% accuracy when tested by on-road grids, successfully identified the high-way segment as road, and predicted approximately 31% off-road grids as potential road grids. Results show that the neural network method, although emphasized in factors different from the multicriteria method, has approximately 78% accuracy for identifying the potential road locations. The prediction

from the neural network method was found highly correlated to the one of the criterion: vehicles travel in different directions.

Simplified methods were also developed to identify potential roads by investigating the GPS point density, vehicle velocity, and the number of passes within a study unit. A simple linear relationship was found between the number of passes and the possibility for road existence. Although using vehicle velocity for identifying the potential roads may not be the best choose, velocity is still considered as one of the most important features to characterize vehicle movements and to locate special movement patterns. Considering the discrete situation in the predicted potential road areas, a kernel smoothing technique was introduced and applied to smooth the results to improve the continuity of the potential roads. The application found the kernel smoothing technique was able to obtain continuous potential road grids by selecting reasonable bandwidth.

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# CHAPTER 1 - INTRODUCTION

The United States (U.S.) Department of Defense (DoD) is responsible for administering more than 25 million acres of federally owned land (Public Land Law Review Commission, 1970). Approximate half of the lands are allowed to be used for army training (Council on Environmental Quality, 1989). Military training is an intensive land use and can cause negative environmental effects. In order to achieve optimum sustainable use of training lands, Headquarters, Department of the Army (HQDA), conservation staff tasked the U.S. Army Construction Engineering Research Laboratory (USACERL) with developing and implementing the Integrated Training Area Management (ITAM) program (Headquarters Department of the Army, 1998). A major objective of the ITAM program is to estimate training land carrying capacity, the amount of training that a given parcel of land can accommodate in a sustainable manner based on a balance of use, condition, and maintenance practices.

Studies under ITAM have been conducted to investigate the impact of military training activities on the training lands and ecosystems. Available research found off-road vehicular activities during military training exercises cause the major impact (vegetation removal, rutting, soil compaction, etc.) to the training land. The impact severity at a certain location depends on the vehicle use patterns: dispersed off-road

vehicle movement create relatively less damage to the land, while concentrated and repeated traffic create more serious damage.

Those areas heavily disturbed by off-road traffic may require longer time or special treatments for the land to return to its pre-disturbed status. Based on the disturbance and linear shapes, some disturbed areas could be considered as roads, termed potential roads. Potential roads are defined in this study as the roads formed by concentrated off-road traffic during the military training exercises, or the roads that currently exist but have not been mapped. Potential roads need to be rehabilitated, have traffic dispersed to return the land to its natural status, or to be included in the established road construction and maintenance programs. It is important to locate the potential roads and identify their conditions based on their disturbance severity after a training exercise. This study can help land managers get increased control over installation land use decisions and greater certainty in available options for military training.

Considering that the Global Positioning Systems (GPS) has been used for monitoring vehicle movement during the military training exercise, and will get more utilized due to the decreased cost of GPS, this study developed a method to identify potential roads based on the analysis of GPS vehicle tracking data. The sample GPS vehicle tracking data were collected in Yakima Training Center during an eight-day duration reconnaissance training exercise in October 2001. The following sections of this chapter introduce the study site, the road systems, the training exercise tracked by GPS vehicle tracking systems, relevant on/off road movement studies, an observed potential

road segment in the screen line area, and the special movement patterns associated with the observed potential road.

## *1.1 Yakima Training Center*

The Yakima Training Center (YTC) is an Army training base, located in the shrub-steppe zone east of the Cascade Mountains in central Washington, about 11 km North of the city of Yakima (Goran et al., 1983). The landscape is characterized by Northwest-Southeast trending ridges: ridge top high points around 1200 m above sea level; the lowest elevations in the canyons run into the Columbia River and west into the Yakima River. YTC offers comprehensive training and logistics support to U. S. Army, Navy, Air Force, Marine, active and National Guard/Reserve units, and allies and federal agencies.

The training center encompasses about 1100 square kilometers of rugged shrub and grassland steppe. Dominant native plants of the YTC are bluebunch wheatgrass (Agropyron spicatum) (Figure 1-1) and big sagebrush (Artemisia tridentata) (Figure 1-2); cheatgrass is also an important invader in the center. Because of limited moisture availability and frequent fires, the installation is treeless, except along some water-courses where there are occasional willows and cottonwoods. Soils in the YTC are mostly of basaltic origin with wind-deposited material forming the surface soil horizon in many areas. Annual precipitation averages approximately 200 mm; most effective precipitation occurs between October and May (Goran et al., 1983).

*Figure 1-1 Bluebuch wheatgrass land cover at YTC*

*Figure 1-2 Big sagebrush land cover at YTC*

## *1.2 Yakima Training Center Road System*

The total length of roads in the YTC is approximate 2600 km. A GIS road coverage of YTC was developed by YTC's Directorate of the Environment and Natural Resources (DENR) with a 30 meters reported accuracy (from Metadata of the road coverage file), shown in Figure 1-3. Roads in YTC were mapped by using Trimble GPS Basic+, Pro XL, and Geo-Explorer GPS receivers. These GPS receivers were mounted on the vehicles driving the roads and collected position each second or every 10 meters. The GPS position data was differentially corrected using post-processing techniques, so accuracy better than reported 30 meters can be expected for the road map.

YTC DENR defined five military road classes and classified the roads in the YTC road system. Detailed description of the military road classes is shown in (Table 1-1) (Haugen, 2002). Only class 2, 3, 4, and 5 roads exist within the YTC boundaries. The majority of the roads in YTC are military class 4 roads; approximately 60% of the total length. Figure 1-4 shows the percentage for each military class road in YTC.

## *1.3 Reconnaissance Training Exercise*

The 1/14 Cavalry of the 3rd Brigade of the United States Army conducted an eight-day reconnaissance training exercise at YTC in October 2001. The training exercise consisted of three troops (Alpha, Bravo, and Charlie). Each troop had approximately 20 vehicles, and was divided into five platoons (Headquarters, 1st, 2nd, 3rd and Mortar). A total of 60 wheeled vehicles were utilized in this training exercise, including five types of vehicles: Light Armored Vehicles (LAV), Henschel Defense

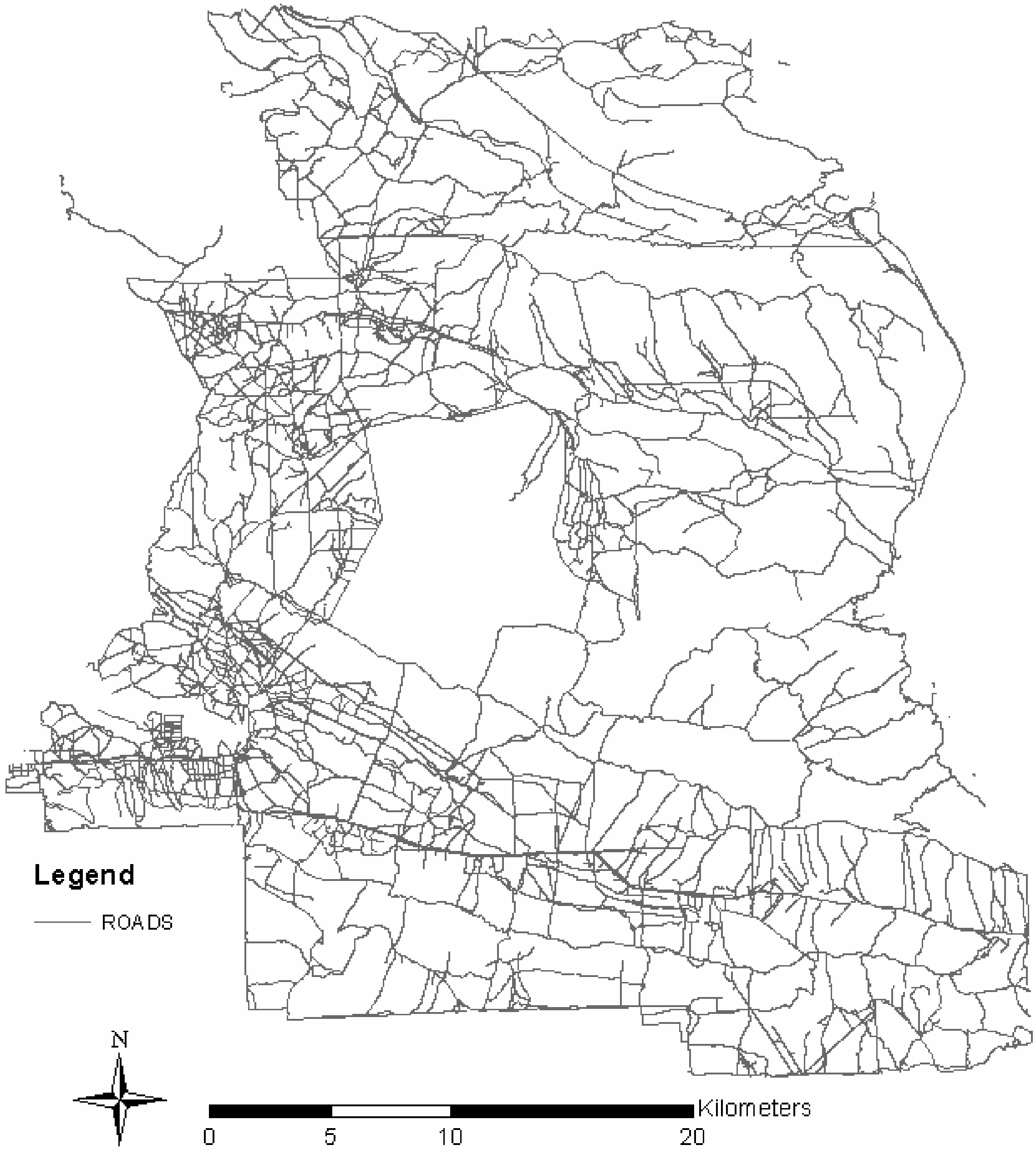


*Figure 1-3 Yakima Training Center road map*

*Table 1-1 Military road class descriptions**

| Military Road Class | Description |
|---|---|
| 1 | Primary, all weather, hard surface (e.g. freeway, state highway) |
| 2 | Secondary, all weather, hard surface (e.g. Local thoroughfare, county road) |
| 3 | Light duty, all weather, hard or improved surface (e.g. residential street, rural road, graveled road) |
| 4 | Fair or dry weather, unimproved surface (e.g. improved road with no maintenance unimproved dirt road; twin tracks; no tracks, but easily discerned vegetation change) |
| 5 | Trail, defined as extremely scary or difficult to negotiate in a civilian 4x4 truck, difficult to see (better seen from across the canyon than when driving), old firebreak, or cow/motorcycle path. |

* Descriptions from the meta-data of YTC GIS road map.

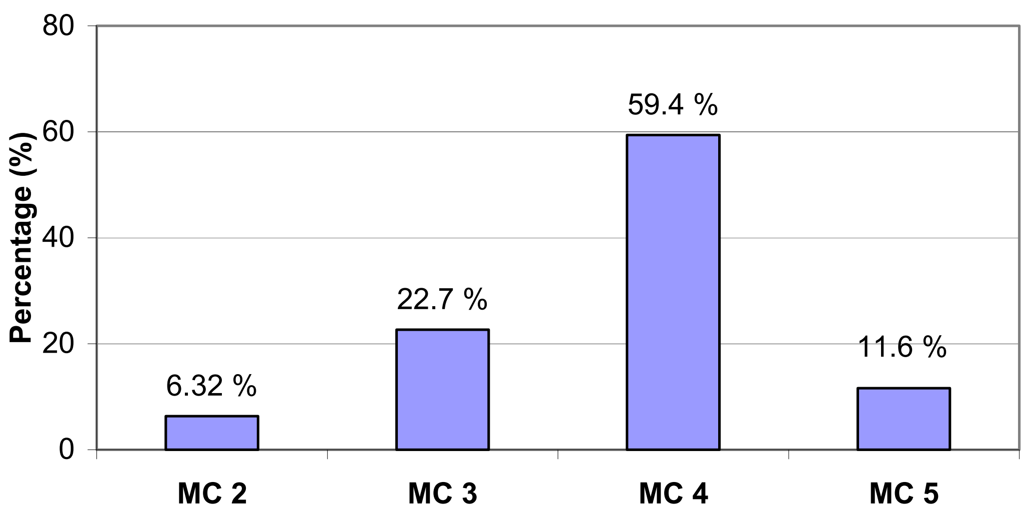


*Figure 1-4 Military Road Classes in YTC*

Systems Transportpanzers (FUCHS), High Mobility Multipurpose Wheeled Vehicles (HMMWV and CARGO HMMWV), and 5 ton Cargo Trucks (FMTV). Details of the distribution of involved vehicles are shown in Table 1-2 (Haugen, 2002).

### 1.3.1 Reconnaissance training missions

The reconnaissance training exercise included three missions: zone reconnaissance, screen line, and area security. The three troops conducted the three missions at certain locations (Figure 1-5) in different orders for approximately two to three days each. Different missions could have different vehicle movement patterns during the training exercise. Specific tasks of the three missions are described as follows (Department of the Army Headquarters, 2000).

*Table 1-2 Vehicles in the U.S. Army 3rd Brigade 1/14 Cavalry (Haugen, 2002)*

| Troop | Platoon | Vehicles |
|---|---|---|
| Alpha | Headquarters | 2 HMMWV, FUCH, FMTV |
| | 1st | 4 FUCH |
| | 2nd | 2 HMMWV, 2 CARGO HMMWV |
| | 3rd | 2 HMMWV, 2 CARGO HMMWV |
| | Mortar | 2 HMMWV, 2 FMTV |
| Bravo | Headquarters | 2 HMMWV, FMTV, FUCH |
| | 1st | 4 FUCH |
| | 2nd | 4 LAV |
| | 3rd | HMMWV, 3 CARGO HMMWV |
| | Mortar | 3 HMMWV, FMTV |
| Charlie | Headquarters | 3 HMMWV, LAV, FMTV |
| | 1st | 2 HMMWV, 2 LAV |
| | 2nd | 3 LAV, HMMWV |
| | 3rd | 2 LAV, 2 HMMWV |
| | Mortar | 2 HMMWV, FMTV |

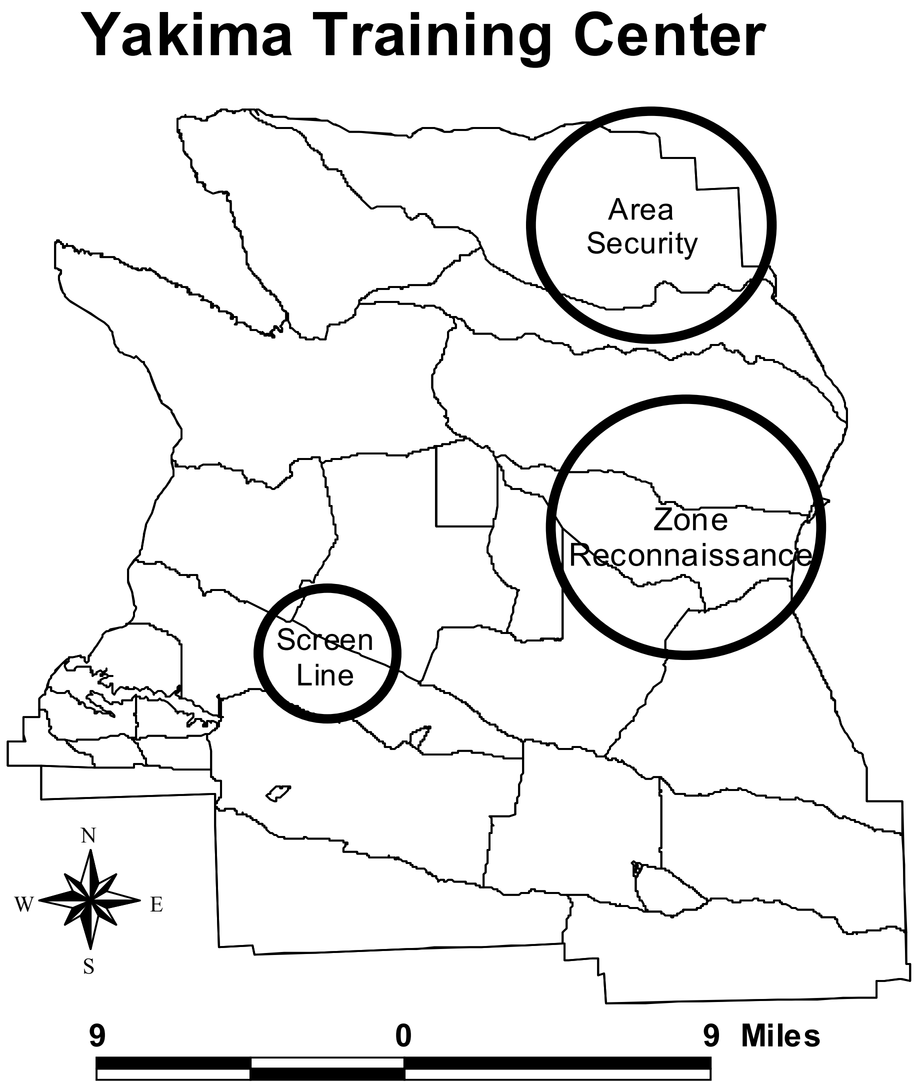


*Figure 1-5 Locations for different missions in YTC*

***Area security (AS)***

Area security mission provides reconnaissance and security in support of designated personnel, facilities, unit convoys, main supply routes, lines of communications, high value assets, equipment, and critical points.

***Screen line (SL)***

A screening force provides early warning to the main body and impedes and harasses the threat with direct and indirect fires, conducted on the front, flanks, and rear of a stationary force and to the flanks and rear of a moving force; establishes a series of operating positions and conducts patrols to ensure adequate reconnaissance and surveillance of the assigned sector; the platoon may suppress threat reconnaissance units with indirect fires in coordination with other combat elements

A screen mission has certain critical tasks that guide planning: 1) maintain continuous surveillance of all battalion-size avenues of approach into the sector under all visibility conditions; 2) destroy or repel all reconnaissance elements within capabilities; 3) locate the lead company of each suspected advance guard battalion and determine its direction of movement; and 4) maintain contact with the lead company of the advance guard battalion while displacing, and report its activity.

***Zone reconnaissance (ZR)***

Zone reconnaissance is the directed effort to obtain detailed information concerning all routes, obstacles, terrain, and enemy forces within a zone defined by boundaries. Obstacles include chemical and radiological contamination. A zone reconnaissance is assigned when the enemy situation is vague or when information

concerning cross-country trafficability is desired. It is appropriate when previous knowledge of the terrain is limited or when combat operations have altered the terrain.

Zone reconnaissance is a deliberate, time-consuming process. During a zone reconnaissance, the troop accomplishes the following critical tasks: 1) reconnoiter all terrain within the zone; 2) inspect and classify all bridges within the zone; 3) locate fords or crossing sites near all bridges in the zone; 4) inspect and classify all overpasses, underpasses, and culverts; 5) locate and clear all mines, obstacles, and barriers in the zone within its capability; 6) locate a bypass around BUAs, obstacles, and contaminated areas; 7) find and report all enemy forces within the zone; and 8) report reconnaissance information.

### 1.3.2 GPS vehicle tracking data

GPS based Vehicle Tracking Systems (VTS) (Haugen, 2002) had been developed and utilized for monitoring vehicles' movement during the reconnaissance training exercise in October 2001. The vehicle tracking systems utilized autonomous Garmin GPS35-HVS GPS receivers (with $PGRMF NMEA output sentence) for recording vehicles' position and dynamic properties during the training exercise. Twenty VTSs were installed on the selected vehicles (Table 1-3), and programmed to log data every one second for the entire training exercise, which results in large quantity of vehicle position data. Haugen (2002) eliminated the non-moving data based on the Speed Over Ground (SOG), one of the output parameters from GPS receiver. Elimination of the non-move vehicle tracking data points significantly reduced the size of the vehicle tracking files (approximately 92% data was eliminated).

*Table 1-3 Vehicles tracked during the training exercise*

| Vehicle Tracking System Number | Vehicle Type | Troop | Platoon |
|---|---|---|---|
| 1 | FUCHS | ALPHA | $1^{ST}$ |
| 2 | FUCHS | ALPHA | $1^{ST}$ |
| 3 | CARGO HMMWV | ALPHA | $3^{RD}$ |
| 4 | CARGO HMMWV | ALPHA | $3^{RD}$ |
| 5 | HMMWV | ALPHA | $2^{ND}$ |
| 6 | CARGO HMMWV | ALPHA | $2^{ND}$ |
| 7 | HMMWV | BRAVO | $3^{RD}$ |
| 8 | CARGO HMMWV | BRAVO | $3^{RD}$ |
| 9 | LAV | BRAVO | $2^{ND}$ |
| 10 | LAV | BRAVO | $2^{ND}$ |
| 11 | FUCHS | BRAVO | $1^{ST}$ |
| 12 | FUCHS | BRAVO | $1^{ST}$ |
| 13 | HMMWV | BRAVO | MTR |
| 14 | LAV | CHARLIE | $3^{RD}$ |
| 15 | LAV | CHARLIE | HDQ |
| 16 | LAV | CHARLIE | $1^{ST}$ |
| 17 | LAV | CHARLIE | $1^{ST}$ |
| 18 | LAV | CHARLIE | $3^{RD}$ |
| 19 | LAV | CHARLIE | $2^{ND}$ |
| 20 | LAV | CHARLIE | $2^{ND}$ |

### 1.3.3 Vehicle on-road/off-road movement

Vehicles traveled on and off roads during training exercises. Characterizing when and on what road vehicles traveled during training exercises helps for monitoring road use and scheduling road-maintenance. GPS vehicle tracking data combined with the YTC GIS road data enable to determine vehicles' on-road and off-road usage during the training exercise. A road buffer study by Haugen (2002) suggested a 10-meter buffer width to select GPS data for on-road travel study, and a 30-meter buffer for off-road travel analysis. Vehicles' positions within the 10-meter road buffer were considered as on-road travel; those outside of 30 meters road buffer were considered as off-road. Figure 1-6 shows the locations where the vehicles' off-road movements occurred. Haugen (2002) analyzed the frequency of the vehicle velocity and the turning radius to characterize the on-road and off-road movement. Frequencies of velocity and turning radius varied among the tracked vehicles during the training exercise. The maximum operating velocity when vehicles traveled off-road generally varied between 15m/s and 18 m/s and the most frequent vehicle velocities ranged from 2 m/s to 4 m/s. On average, vehicles spent 16% of their off-road driving time at turning radii less than 20 meters.

An interesting off-road vehicle movement pattern was observed in screen line area. In this particular area (Figure 1-7), concentrated and repeated vehicle traffic from different troops occurred during different days, while no road was mapped on current road map. This area was considered as a potential road that was defined as the roads currently exist but have not been mapped on the current map, or as the roads newly formed by concentrated vehicle off-road traffic during a military training exercise.

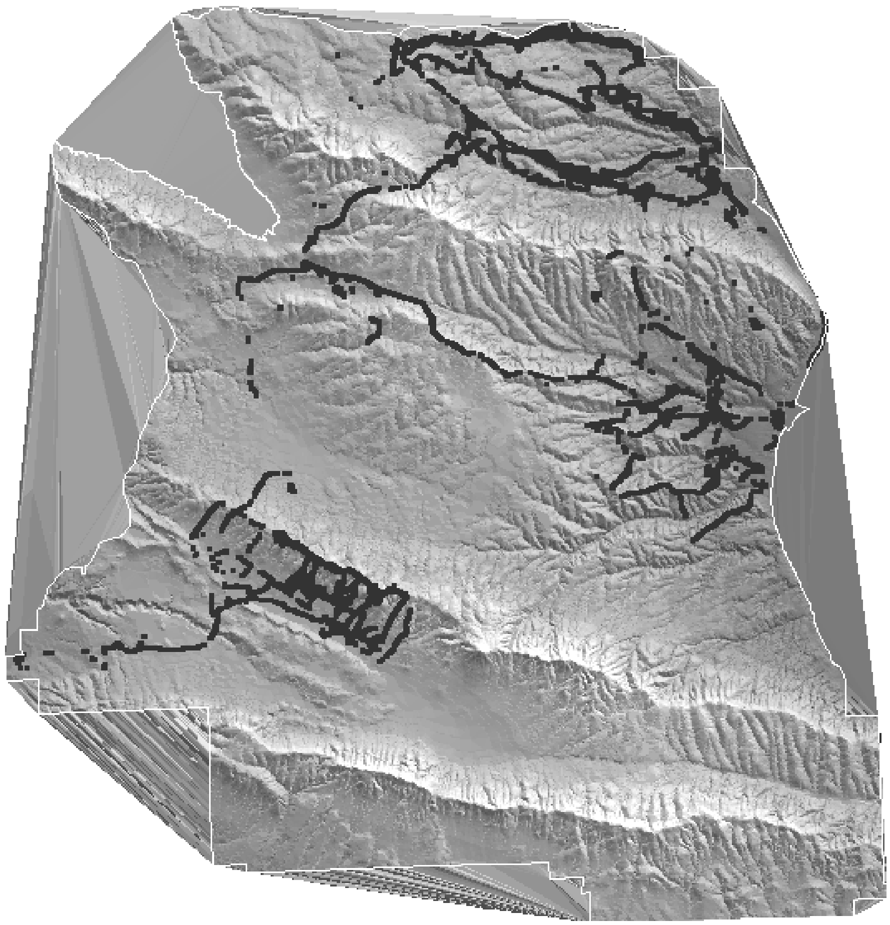

*Figure 1-6 Vehicles' off-road locations in YTC*

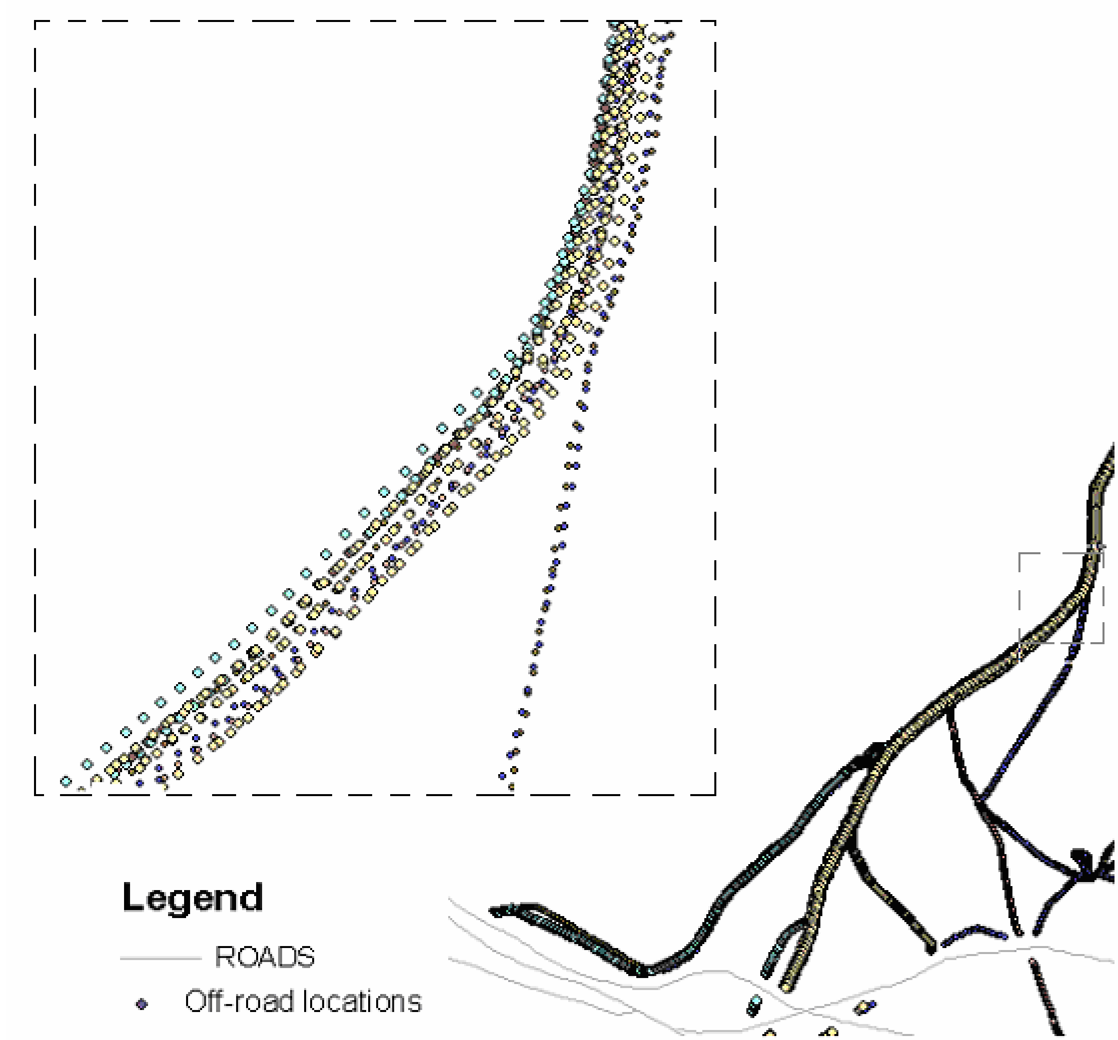


*Figure 1-7 Special vehicle movement pattern in the screen line area*

A site visit conducted by Ayers in June 2003 observed a military class 4 road (Figure 1-8 ) on the area where the special off-road movement pattern occurred. Confirmation of the potential road in the screen line area necessitates the identification of potential roads within the entire training center to support the training land management. The potential road identified in the area where repeated traffic was observed based on the GPS vehicle tracking data indicates that the GPS vehicle tracking data could be used to identify potential roads.

*Figure 1-8  An observed potential road in screen line area*

# CHAPTER 2 - OBJECTIVES

The goal of this study is to analyze vehicles' movement patterns during military training exercises to identify potential roads: roads not mapped or roads newly formed by concentrated military vehicle off-road traffic.

The specific objectives include:

1) Analyse GPS vehicle tracking data to extract the factors to describe vehicles' movement patterns during the training exercise;
2) Build criteria based on the extracted factors, identify potential road areas that meet a certain criteria level;
3) Cluster the contiguous areas with the same criteria level, identify the areas with characteristics of the road as potential roads;
4) Conduct site visits for selected potential road areas to evaluate and validate the potential road identification method; and
5) Explore alternate potential road identification techniques.

# CHAPTER 3 - LITERATURE REVIEW

Military vehicular activities during training exercises produce intensive impact on training land. Concentrated off-road traffic generated more serious impacts on the training land that requires a longer period of time for recovery compared to the areas with vehicle's single pass or dispersed traffic. Potential roads may exist in those areas that concentrated traffic occurred and need to be identified to assist the training land management and training activities arrangement. GPS vehicle tracking data enable the study under GIS environment for identifying potential roads based on analysis of vehicles' movement patterns. Multiple knowledge discovering and decision-making techniques can be applied to assist the extraction of potential roads.

## *3.1 Training Area Impact*

Military training activities can cause negative environmental effects, although they may be potentially beneficial in some fire-adapted ecosystems (Trame and Harper, 1997). Studies under ITAM have been conducted for monitoring, maintaining training land condition and quantifying the environmental impact of training activities. Training activities may vary from exercise to exercise; however, most of training exercises involve mechanized and armored units, engineering units, and combat service support units. These units usually are equipped with different military off-road vehicles that are able to

conduct training maneuvers almost anywhere on the terrain and cause environmental damage (Trame and Harper, 1997).

Many studies for evaluating the environmental impact resulted from military training activities found that most damage occurs from off-road movement (Michigan Department of Military Affairs [DMA] 1994). As described below, studies conducted to investigate the environmental impact of vehicles' off-road traffic found a common result that vehicular off-road traffics caused soil disturbance. Soil disturbance is termed to describe the situation that the soil surface surrounding a track or rut that has been displaced, compacted, or has lost strength due to remolding. The soil disturbances resulted from off-road vehicular traffic can cause environmental damage by decreasing plant development and increasing erosion.

Studies by Cole and Landres (1995) found that vehicles' off-road movements generated direct impacts to soil characteristics including altered oxygen, water, and nutrient content, and make changes to pH and infiltration rate. These alterations lead to reductions in germination, growth, reproduction in native plants, and changes in species composition and community structure (Beije, 1987; Cole and Landres, 1995). Similar results were also found in a study at Fort Benning (Goran, et al., 1983).

Webb and Wilshire (1983) reported that the impacts produced by off-road vehicle traffics can result in soil compaction, rutting, and vegetation removal. Brown and Schoknecht (2001) found that single-passage tracks lead to the alteration of various soil attributes by initially causing compaction of the topsoil accompanied by the formation of shallow linear depressions. A study conducted in the Mojave Desert by Prose and

Wilshire (2000) found significant levels of soil compaction in the tank tracks. They also found that the infiltration rates in the tracks were lowered by 24 to 55 percent, and vegetative species composition was altered after the tank maneuvers. Smith and Dickson (1990) found that the increase of ground pressure increases soil bulk density at the surface, a higher wheel load (at a given ground pressure) led to the compaction at a greater depth. The degree of compaction was found to be related to the soil moisture content at the time of tracking (Halvorson et al., 2001).

Studies also found that concentrated off-road vehicular traffic produces more damage to the environment than dispersed traffic for a given land condition. Pearson *et al.* (1990) found that the soil disturbance resulted from off-road vehicular traffic depended on the characteristics, timing and intensity of traffic. Braunack (1986) reported that additional passes of the tracked vehicle resulted in decreasing cone resistance and increasing rut depths. A study by Goran *et al.* (1983) observed impacts from tracked vehicle activity at 12 training installations. They found that the impacts from the vehicles varied from installation to installation, but in general, one-time only traffic generally resulted in minor disturbance and light damage to surface vegetation. They also found that frequent, repeated use of an area tended to result in general degradation of flora, fauna, and soils.

Studies by Grantham *et al.* (2001) and Abele *et al.* (1984) evaluated tracked vehicle impact as a function of multiple straight passes. The study by Grantham *et al.* (2001) found that an increase in vehicle passes induced significant damage to vertical vegetation structure, an increase in eroded soil mass, and a decrease in soil surface

stability. The study by Abele *et al.* (1984) found that multiple passes with the wheeled Rolligon vehicles caused longer lasting disturbance than the light tracked vehicles, most likely due to higher ground contact pressure and wider area of disturbance. The vegetative damage also was found increased with the number of vehicle passes and increasing ground contact pressure on the vehicle's tires or tracks.

Fuchs *et al.* (2003) conducted a study to determine the impacts of military tracked vehicles on sediment loss from runoff, surface plant cover, and surface microtopography in a desert military training environment. Four tracks under different conditions were studied: one pass track and three passes track under wet seasonal conditions; one pass track and three passes track under dry seasonal conditions. They found comparatively intense rainfall events often generated significantly greater sediment losses from three passes tracks, and detrimental effects of three passes tracks can last many years, particularly when disturbances were imposed under dry seasonal conditions.

Although many studies documented the impact of repeat or concentrated off-road traffic, few of them addressed how often the concentrated off-road traffic occurred and how to locate the areas where the concentrated traffic occurred during the military training exercises. An analysis, classification, and locating of different vehicle movement patterns during a training exercise is needed to support the land management.

### *3.2 Recovery of Impacted Area*

Recovery of the disturbances resulted from vehicular training exercises limits the training installation and affects the land maintenance strategies. A Land Condition Trend Analysis (LCTA) program was developed by the U.S. Army Construction Engineering

Research Laboratory (CERL) for natural resources inventories and monitoring at training installations (Diersing et al., 1992). Studies have been conducted to investigate the natural recovery of training land after training activities. Results showed that concentrated vehicle off-road traffic produced more serious damage to the vegetation and soil, and required longer time for recovery. In some cases, the required time is so long that it can be considered unable to recovery naturally. Special management and treatments for the disturbed areas need to be conducted for the land rehabilitation and to reduce the negative impact resulted from training activities.

Damaged or destroyed vegetation increases soil erosion due to its reduced soil holding capability. The vegetation recovery rate affects training exercise arrangement. An experimental study by Rogers and Schumm (1991) evaluated the effects of changing vegetative cover from 43% to 0% on a 10% slope on sediment yield. They found that the sediment yield increases rapidly as vegetative cover decreases from 43% to 15%, but with less than 15% vegetative cover the rate of increase of sediment yield diminishes markedly, which indicated that less than 15% vegetative cover is ineffective in retarding erosion.

Vegetation recovery of the training area after training exercise depends on the disturbed severity and the weather condition. Concentrated usage of a certain area introduces more damage and requires longer time for the land to return to its initial status. Training areas with a climate that encourages plant growth require a shorter recovery time than arid areas. Abele *et al.* (1984) conducted long-term studies of vehicle impacts and vegetative recovery in tundra regions for air cushion, wheeled, and tracked vehicles.

They found vegetation was to recover in less than 10 years, and surface depression and thaw depth were to recover after 10 years, but aesthetic vegetation differences are still visible. Studies by Charman and Pollard (1995) investigated the aerial photographs of off-road vehicle tracks taken in 1969, 1975, and 1989 to evaluate the natural recovery for different vegetations. The vegetation recovery rate was species specific for a given time period: some may take 4 to 18 years; some may take longer than 24 years. A study by Fuchs *et al.* (2003) suggested, depending on precipitation availability, a minimum of 3 years for most triple pass M1A1 tank impacts for suitable vegetation recovery and soil stability.

In order to shorten the recovery time and improve the recovery result, special treatment may be applied to the impact area to help land return to its natural status. Studies have also been conducted on the methods to help recover the areas disturbed by military vehicle traffic. A study by Berlinger and Cammack (1990) focused on disturbed rangelands revegetating at Fort Carson, Calorado. They recommended using pitting alone, instead of pitting, seeding, and fertilization combinations, to increase revegetation on the rangeland in highly impacted areas.

Foresaid studies demonstrated the impact resulted from off-road vehicle maneuvers during military training exercises. Studies showed that concentrated or repeated off-road vehicle traffic produced more serious impacts to the training land and required special strategies for land recovery. These areas heavily disturbed by concentrated off-road traffic are considered as potential roads (newly formed or previous unidentified road) based on their shapes and disturbance. Potential roads need to be

rehabilitated, have the traffic dispersed to return the lands to their natural status, or to be included in established road construction and maintenance programs. It is important to locate these potential roads and identify their conditions based on disturbance severity and traffic load after a training exercise. Although there are some studies focusing on vehicular off-road traffic environmental impacts in army training areas, few studies have been conducted exploring potential road identification. A feasible method needs to be developed to identify the potential roads resulting from concentrated off-road vehicular traffic during military training exercises.

### *3.3 Road Extraction*

In some installations, roads were identified manually using aerial photo and satellite imagery. The aerial and satellite imagery is considered as one of the standard data sources to extract topographic objects such as roads or buildings for GIS (Mayer et al., 1998). There are two common approaches to use these images for road extraction. One approach is to use satellite images as a backdrop in GIS for visual inspection, i.e. manually extracting road features; the other approach is semi-automatic or automatic road extraction. Manually extracting road features from aerial imagery is time consuming, ineffective, and requires special knowledge of the operators. Semi-automatic or automatic road extraction involves different complex algorithms; and the results usually contain high uncertainty.

Road extraction from aerial images has been an active and important area in the field of computer vision over the past two decades. Auclair-Fortier *et al.* (2000) provided a survey of works on road extraction in grey-level aerial and satellite images. They

presented four types of road characteristics: spectral, geometric, topologic, and contextual; three road detector characteristics: input image, external knowledge, and results; and the basic operations used in a road detection system: preprocessing, edge detection, road following, and grouping of road primitives. They pointed out that the diversity of road detection systems is probably due to the fact that none of them are reliable in all circumstances. Mena (2003) surveys the state of the art on automatic road extraction for GIS update from aerial and satellite imagery. He presented a bibliography of nearly 250 references related to road extraction for GIS update, which includes main approaches on general methods of road network extraction and reconstruction, road tracking methods, morphological analysis, dynamic programming and snakes methods, multi-scale and multi-resolution, stereoscopic and multi-temporal analysis, hyperspectral experiments, and other techniques. However, none of the 250 referenced papers addressed the potential road identification or road extraction particularly for military training base. Most of the articles referenced by Mena (2003) dealt with the extraction of constructed roads; these methods may not be efficient for extracting the potential roads newly formed in Army training base and may be difficult to be adopted by the range control manager.

Semi-automatic or automatic road extraction is a complicated process that involves different techniques and strategies. Karimi and Liu (2004) presented requirements for developing an automated procedure for extracting road data from high-resolution satellite images and preparing the extracted data for use in GIS. The procedure includes a region growing algorithm to obtain road features, an edge detection algorithm, an image enhancement algorithm, a vectorization algorithm, and a georeferencing

algorithm. Vosselman (1996) mentioned that the interpretation of aerial images for the purpose of mapping roads is an extremely difficult task to automate.

The difficulty of road extraction depends strongly on the context in which it is to be extracted (Hinz et al., 2000). The result depends on the context, the road class, and the technique used for road extraction. Hinz *et al.* (1999) found in an open rural area where background objects made road extraction locally difficult. Wessel and Wiedemann (2003) investigated the potential of an approach for automatic road extraction developed at Technische Universität München (TUM) from airborne synthetic aperture radar (SAR) imagery. They found automatic road extraction often fails to extract secondary roads: the results for secondary roads from the 2m E-SAR imagery are incomplete due to the low visibility, and the completeness of the extracted secondary roads in the high-resolution AeS-1 image is relatively low. Also, some of the secondary roads are missing in the manually extracted road data, because they are not visible in the SAR imagery. Time and weather condition difference can also result in different aerial images; it will affect the road extraction result and make the problem even more complex.

For military training areas, landscape and vegetation cover rate vary from installation to installation. Many military training areas located in arid area with desert like landscapes. In the areas with low vegetation cover rate, the differences between the areas impacted by dispersed off-road vehicle traffic and those impacted by concentrated traffics are only represented by the different compressed soil that can barely be distinguished from satellite images. As the land condition in the Yakima Training Center to be considered, military class 4 and class 5 roads will be difficult to be identified from

the aerial photos, so as for potential roads. Road extraction from aerial images yet may not be able to identify the areas that are in the process of being transformed to be a road. From training land management perspective, it is necessary to identify those areas in the processing of becoming roads in order to rehabilitate them.

### *3.4 GPS for Road Mapping*

Applications of Global Positioning System (GPS) abound in agriculture, surveying, mapping, transportation, military planning, and the geosciences. GPS-based vehicle tracking systems were used to quantify the environmental impact resulted from military vehicle maneuvers and to monitor the vehicular activities during the training exercises to estimate the environmental impact (Ayers, 1994; Ayers et al., 2000, Ayers et al., 2004; Haugen et al., 2000; Haugen et al., 2003; Haugen, 2002). GPS can also be used directly or indirectly for road mapping and road system update. The digital road map of the Yakima Training Center (YTC) was created by using GPS receivers (YTC DENR, 1999): GPS receivers were mounted on the vehicles driving the roads and collected position each second or every 10 meters. Mintsis *et al.* (2004) presented the application of GPS technology for railway mapping in Greece. Schroedl *et al.* (2004) introduced an approach to induce high-precision maps from traces of vehicles equipped with differential GPS receivers. Toth and Grejner-Brzezinska (2004) introduced an automated high-precision road centerline mapping system. Da Silva *et al.* (2003) presented the prototype of a low-cost terrestrial mobile mapping system (MMS) composed of a van, two digital video cameras, two GPS receivers, a notebook computer and a sound frame synchronisation system. The GPS receivers were used to record vehicle position at a

planned time interval to georeference the road images taken by the digital video cameras. This system provides an opportunity to merge distinct techniques to make topographic maps and to build georeferenced road image database. By expanding the method both at the hardware and software levels, engineers will be able to analyse the entire road environment on their office computers.

GPS has been used to monitor the disturbance patterns during the vehicle field operations or military training exercises. A study by McDonald *et al.* (2002) utilized the GPS to map disturbance patterns for forest harvesting machinery. They presented a method to transform sampled machine positional data obtained from a GPS receiver into a two-dimensional raster map of number of passes as a function of location to determine the area impacted by a machine as it traveled over a site. Studies by Ayers *et al.* (2000) and Haugen *et al.* (2000) evaluated the use of the GPS for tracking vehicles and determining their dynamic properties and found that GPS can accurately monitor a vehicle's position and dynamic properties including velocity, turning radius, and change in vehicle velocity. The autonomous Garmin GPS35-HVS GPS receivers were used to determine the vehicle dynamic characteristic and access locations during a military training exercise (Haugen, 2002). Although the GPS data collected during the training exercise is not from road mapping perspective, it can be manipulated to locate the concentrated traffic and to identify the potential roads. Related accuracy analysis by Ayers *et al*. (2004) for the GPS receivers used for tracking vehicles during the training exercise indicated that the GPS vehicle tracking data collected during the training exercise can be used to update the current YTC road map.

### *3.5 Spatial Decision Making*

Identifying potential roads resulted from concentrated off-road traffic during a military training exercise can be considered as a spatial decision problem, which is certainly related to the application of the Geographic Information System (GIS). GIS can be defined as computer hardware and software system designed to collect, manipulate, analyze, and display spatially referenced data for solving spatial problems. GIS, as a great tool for analyzing spatial related problems, provides a flexible environment in the process of the decision research and in the solution of complex spatial problems. Different decision-making and knowledge discovering techniques can be applied or integrated into GIS to help solve spatial decision problems.

#### 3.5.1 Multicriteria GIS decision making systems

Multicriteria analysis (MCA) is the technique supporting the solution of a decision problem by evaluating the possible alternatives from different perspective. MCA in its strict sense refers to a sequence of well-established procedural steps that allow to rank competing alternatives and to optimize the selection. There has been a rapid expansion in the development and description of decision-making methods; and many of these have applications in the spatial domain. Many studies demonstrated this function of GIS in decision making, and many researchers described the integration of GIS and MCA for spatial decision making. Jankowski (1995) introduced the methods for integrating GIS and multiple criteria decision-making methods. Hill *et al.* (2005) examined the case for inclusion of new methods in spatial systems for multi-criteria decision analysis (MCDA) for selecting suitable sites.

Geneletti (2004) described a methodological approach, based on the integrated use of GIS and Decision Support Systems (DSS), to identify nature conservation priorities among the remnant ecosystems within an alpine valley. In this study, the ecosystems are first assessed by means of landscape ecological indicators, and then ranked by using multicriteria analysis techniques; most conflicting sites based on different evaluation perspectives were highlighted for different conservation strategies. The effectiveness of spatial decision-support techniques in land-use planning for nature conservation was exemplified and discussed in Geneletti's paper. A study by Ellis and Johnston (1999) summarized elements of research on the effectiveness of using qualitative spatial representation (QSR) in 2D and 3D display modes to determine its usefulness for situational awareness and decision making. The study included several procedures: 1) create spatial query functions based on QSR that capture knowledge about objects in space; 2) build the query functions into a graphical user interface environment as simulated user accessible support functions; and 3) test the support functions.

As GPS has been widely used for vehicle tracking in military training installations; and GIS gets more involved in Army training land management, the study on analyzing GPS data by using GIS techniques to help land manager decision making becomes possible and necessary. Based on the reviewed literatures, a method adapted from the multicriteria analysis to classify the off-road areas based on their traffic intensities was considered a good approach for identifying the potential roads.

### 3.5.2 GIS & artificial technologies

Artificial technologies for knowledge discovering can also be integrated into GIS to assist spatial decision making. Some studies demonstrated the advantages to apply Artificial Neural Networks (ANNs) (Skabar, 2003; Mas et al., 2004), Fuzzy Logic (Jiang and Eastman, 2000; Girvetz and Shilling, 2003), and Genetic Algorithm (Zhou and Civco, 1996; Brookes, 2001) in GIS for solving spatial problems.

Skabar (2003) described a data-driven approach by which ANNs can be trained to represent a function characterizing the probability that an instance of a discrete event will occur over some grid element of the spatial area under consideration. Skabar demonstrated the application of the technique to the task of mineral prospectiveity mapping in the Castlemaine region of Victoria using a range of geological, geophysical, and geochemical input variables. The comparison of the map resulted from ANNs and the map produced using a density estimation-based technique indicated that the maps can be reliably interpreted as representing probabilities, and ANNs approach had its advantages, especially in high dimensional input spaces. A study by Mas *et al.* (2004) utilized ANNs technique to predict the spatial distribution of tropical deforestation based on Ladsat images of 1974, 1986, and 1991. A multi-layer perceptron neural network was trained to estimate the propensity to deforestation as a function of the explanatory variables and was used to develop deforestation risk assessment maps. Results showed the capability of the ANNs technique for predicting land cover changes.

Jiang and Eastman (2000) reviewed two main Multi-criteria evaluation approaches employed in GIS (Boolean and Weighted Linear Combination (WLC)), and

proposed the application of fuzzy techniques to resolve the conceptual differences between the two approaches. By introducing a case study of industrial allocation in Nakura, Kenya, Jiang and Eastman (2000) illustrated a new aggregation operator (the Ordered Weighted Average) that accommodates and extends the Boolean and WLC approaches. Girvetz and Shilling (2003) developed an Ecosystem Management Decision Support program (EMDS) to integrate a user-developed fuzzy logic knowledge base with a grid-based GIS to evaluate the degree of truth for assertions about a road's environmental impact. They found a high level of agreement between the evaluation for the assertion "the road has a high potential for impacting the environment" and ground observations of a transportation engineer, as well as occurrences of road failure.

Zhou and Civco (1996) presented a genetic learning neural networks approach, an artificial neural network approach using a genetic algorithm as its learning mechanism, for suitability analysis in GIS. They found the genetic learning neural networks can provide an alternative for and improvement over traditional suitability analysis methods in GIS. Brookes (2001) described a computer system using a genetic algorithm search heuristic combined with a region-growing algorithm to solve optimal patch design problems in raster GIS. The implementation of the system on a hypothetical problem proved that the system is efficient and effective.

## *3.6 Summary of Literature Review*

Military training activities, especially off-road vehicle maneuvers, produce intensive impact on training land. Available research has shown concentrated off-road vehicle movement created more serious damage and required longer period time for

recovery. The recovery rate and the required recovery time depend on the impact severity, vegetation cover, and climate condition of the specific disturbed area. These areas heavily disturbed by intensive off-road vehicle maneuvers during training exercises require special treatments to help the land return to its natural status. The special treatments may include restoring, revegetating, or constructing. Based on the impact severity and the shape of the disturbed area, potential roads may exist and need to be identified to update the current road system for better training land management and maintenance.

Aerial imagery has been used in some installations for manually extracting roads; it is time consuming and un-effective. Many studies have been conducted in semi-automatic or automatic road extraction from aerial imagery. The procedures are complicated and the efficiency and effectivity varies with different image solutions, road extracting algorithms, road conditions and the road context. The techniques for extracting road features from imagery will not be adopted in this particular study; however, they can be helpful in the future to evaluate the potential road identification method identified in this study, if the satellite imagery for YTC is available.

The development of GPS, GIS technology and digital data manipulation techniques allow researchers from different fields to make more efficient use of resource information and to help decision making. As the GPS has been used for vehicle tracking in military training installations; and GIS gets more involved in Army training land management, the study on analyzing GPS data by using GIS techniques to help land manager decision making becomes possible and necessary. GPS vehicle tracking data

collected in the YTC during a reconnaissance training exercise and relevant studies enable the study for potential roads identification based on analysis of vehicles' land use patterns. Since available studies indicated that the integration of GIS and multicriteria analysis was efficient and effective in solving spatial decision problems, this study will focus on the analysis of GPS vehicle tracking data to develop a multicriteria method for identifying the potential roads. Referenced artificial techniques can be applied for developing an alternative method or to evaluate the multicriteria method.

# CHAPTER 4 - VEHICLE MOVEMENT PATTERNS DURING A MILITARY TRAINING EXERCISE

As described in Chapter 3, Global Positioning System (GPS) can be used for monitoring vehicles' activities during military training exercises. This Chapter introduces the analysis of GPS vehicle tracking data collected at the Yakima Training Center (YTC) in October 2001 for vehicle movement patterns. Vehicle movement patterns were characterized as the percentage of vehicle travel every day, vehicles' on and off road travel, the frequencies of vehicle's off-road velocity and turning radius. Comparison of the similarity of on-road movement and off-road movement indicates that potential roads may exist where the concentrated traffic or a certain special movement pattern occurred. The study on the vehicle movement patterns demonstrated the capability of manipulating GPS vehicle tracking data to identify potential roads resulted from military training exercises.

## *4.1 GPS for Identifying Movement Patterns*

GPS has been widely used for vehicle tracking (Han et al., 2004; Haugen et al., 2003; Keong, 1999), animal movement monitoring (Turner et al., 2001), yield mapping (Shannon et al., 2002), and automated guidance (Bell, 2000; Guo and Zhang, 2004).

Quantification of and standards for GPS accuracy depend on individual applications; some require high absolute accuracy, while others need high relative accuracy.

GPS vehicle tracking data can be used for estimating the traffic areas for forest harvesting machinery (McDonald et al., 2002) and estimating vegetation removal from military vehicular activities (Haugen et al., 2000). Accuracy and efficiency of the estimation on the impact area resulted from vehicular off-road activities depends on the GPS receivers' dynamic accuracy. McDonald *et al.* (2002) investigated the influence of three different error sources on estimating the number of passes from GPS position data: path sampling rate (receiver sampling frequency), output raster resolution, and GPS receiver errors. They found that the estimate of number of passes at a specific point was heavily dependent on the presence of errors, although the total accuracy of traffic maps across a site (the summed areas receiving one, two, three, etc. passes) was not greatly affected by the error sources; and the GPS position errors affected the accuracy when the GPS data were applied in defining the number of passes at a given area. The following studies addressing GPS accuracy from different aspects indicated that the GPS vehicle tracking data can be used for describing different vehicle movement patterns; but the uncertainties involved may be too complicated to be quantified, which is not unusual in spatial problems.

GPS receivers' accuracy, especially dynamic accuracy, varies from receiver to receiver. GPS dynamic accuracy measurement is difficult, because more variables affect GPS dynamic performance and are difficult to control (Buick, 2002). Even for the same GPS receiver, the measured dynamic accuracy can be different due to the test location,

test time period, the circumstance of the test station, the tested vehicle's travel direction, and maybe the analysis method for calculating the errors. Han *et al.* (2004) found that the dynamic performance of a GPS receiver was extremely variable from test to test. Different testing time periods and tested locations will have different GPS satellite constellations, signal levels, atmospheric errors, and correction accuracy, which will result in different accuracy. Wu *et al.* (2005) investigated the influence of travel directions on the GPS dynamic accuracy and found that due to the GPS satellite geometry, the GPS dynamic accuracy is expected to be better when vehicle is traveling in North-South direction than in the East-West direction in the mid-latitude area.

The Garmin GPS35-HVS GPS receivers were used as the major components to construct the Vehicle Tracking Systems (VTS) to track the vehicles' activities during the reconnaissance training exercise at the YTC in October 2001 in Washington State. The Garmin GPS35-HVS GPS receiver is a 12-channel receiver which allows tracking up to 12 satellites at a satellite update rate of one second. Studies by Ayers *et al.* (2000) and Haugen *et al.* (2000) evaluated the use of the GPS35-HVS GPS for tracking vehicles and determining vehicles' dynamic properties; they found that GPS can monitor a vehicle's position and dynamic properties including velocity, turning radius, and change in vehicle velocity with a certain uncertainty. Haugen *et al.* (2000) found that the GPS receiver can locate a static position within 2.4 meter 50% of time, and 6.9 m 95% of the time; under dynamic situation, the GPS receiver was measured with a time lag 1.6 seconds. A 24-hour static test for the same type of GPS receivers at different times and different locations was conducted by Ayers *et al.*, (2004). Results showed static accuracy varied

slightly from receiver to receiver: the 2DRMS values of the receivers ranged from 7.7 to 11.0 meters. Considering the uncertainties from the YTC GIS road map and the GPS position errors, an approximately 10 meters tolerance was assigned to each GPS position when conducting the analysis of vehicle movement patterns.

## *4.2 Vehicle Movement Patterns*

Previous studies by Ayers *et al.* (2000; 2004), Haugen *et al.* (2000; 2003) and Wu *et al.* (2005) evaluated the use of the GPS for tracking vehicles' activities during military training exercises; they found GPS vehicle tracking data enables the analysis of vehicle movement patterns during military training exercises. Vehicle movement patterns during the reconnaissance training exercise in YTC were characterized as the percentage of vehicle travel every day, vehicles' on and off road travel, frequencies of vehicle's off-road velocity and turning radius.

The road buffer study by Haugen (2002) suggested a 10-meter road buffer for selecting the vehicle on-road travel data, and a 30-meter buffer for the off-road travel data. Studies by Haugen *et al.* (2003) analyzed the quantity of the travel per day of the training activity, quantity of travel on and off roads, frequencies of vehicle's off-road velocity and turning radius; and estimated the vegetation removal from vehicle off-road travel. The analysis by Haugen *et al.* (2003) gave an overview of the training exercises: the vehicles were in motion an average of 8.4% of the training exercise time; the daily average distance traveled on roads was 33.5 km, the daily average distance traveled off roads was 7.7 km; and the vehicles spent 16% of their off-road traveling time at turning radii less than 20 m. Haugen (2002) also assessed the vegetation removal by five Light

Armored Vehicles (labeled number: 10, 16, 17, 19, and 20) at approximately 43,000 square meters. The total distance traveled off-road by all vehicles during the 8-day reconnaissance training exercise in YTC is approximately 300 miles based on the 30-meter road buffer. The following sections, dedicating to introduce the parameters characterizing the spatial off-road vehicle movement patterns relevant to potential road identification, explore the details of the vehicle movement patterns from the traffic density perspective.

### 4.2.1 GPS data density

GPS vehicle tracking data collected during the training exercise contain the positions for each vehicle. Concentrated traffic area can be extracted by overlaying all vehicles' GPS data on top of each other and selecting the areas with higher GPS data density. The close proximity of GPS points is believed to be an important feature to describe vehicles' movement patterns during the training exercises; it can be estimated by counting how many GPS points surrounding the target point within a 10-meter search radius. The close proximity of GPS data is also defined as GPS data density in this study for characterizing the situation that the vehicles moved closely in a certain location or the vehicle(s) used the area repeatedly. The 10-meter search radius was selected based on the GPS35-HVS GPS receivers' accuracy (approximately 4 m for CEP and 8.5 m for 2DRMS), the various locations for mounting the GPS receivers on different vehicles, and vehicles' traveling velocities (average off-road speed is approximately 2.9 m/s). Those GPS points fall inside the 10-m radius search area were considered having proximity to each other. A new attribute field (with value equals to 1) was added to the on-road (or

off-road) moving data attribute table for identifying the GPS point population for each point. By using Neighborhood Statistics function in ArcGIS Spatial Analyst (ESRI, 2002) a raster map can be generated with the cell value equals to the number of points surrounding for each location. Assigning the cell value to each point which falls inside the cell gives the point a value indicating how many points surrounded within a 10 meters search radius. Summarizing the point data set based on the extracted values provides frequencies of the number of surrounding points.

The GPS data density distributions for off-road and on-road moving data are shown in Figure 4-1 and Figure 4-2 respectively. As can be seen from Figure 4-1 and Figure 4-2, the most common density for off-road moving data is 5--15 points per study unit (approximate 314 square meters, an area for a circle with 10-meter radius); and 35--70 points per study unit for on-road moving data. Clearly, the GPS data density for on-road moving data is substantially higher than off-road moving data. The frequencies difference of GPS data density for both off-road and on-road moving data was compared

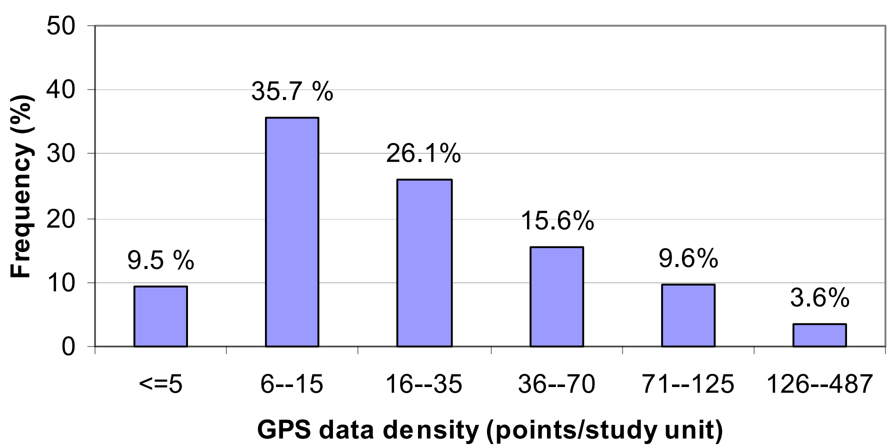


*Figure 4-1 Frequency distribution of GPS point density for off-road moving data*

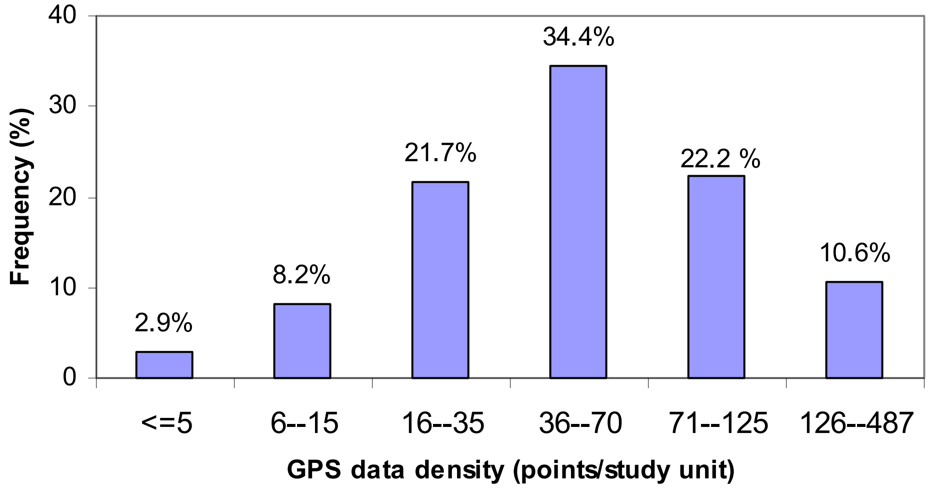


*Figure 4-2 Frequency distribution of GPS point density for on-road moving data*

and shown in Figure 4-3. About 72% of the GPS off-road moving data fall inside the areas with the GPS data density less than 30 points per study unit, while more than 74% of the on-road moving data fall inside the areas with the density higher than 30 points per study unit.

The comparison shows the capability of the GPS data density as a feature to distinguish the vehicle on-road movement from off-road movement, so as to identify locations where potential roads possibly exist. Figure 4-3 also shows approximately 25% of off-road moving data fall inside the areas with density greater than 40 points per study unit. These locations with high GPS data density were considered as the areas with high possibility for special vehicle movement patterns (e.g. vehicles traveled on an unmapped road or conducted repeat off-road movement); these areas will be investigated for identifying potential roads. Figure 4-4 shows the locations in the screen line area with GPS data density greater than 40 points per study unit. Figures showing high point density areas in area security and zone reconnaissance can be found in Appendix I.

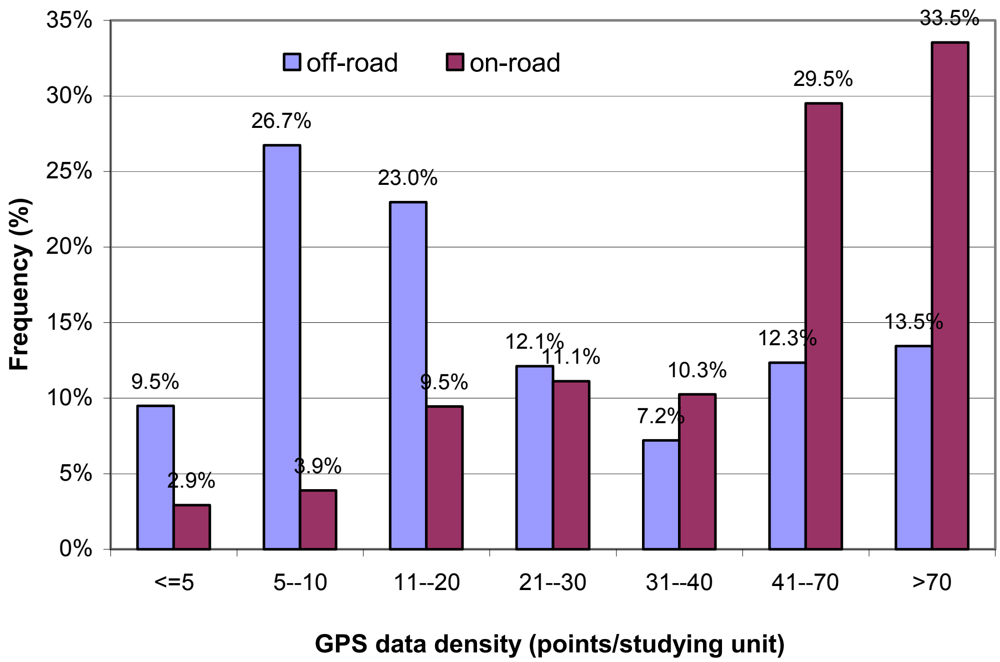


*Figure 4-3 Comparison of GPS data density for on-road and off-road data*

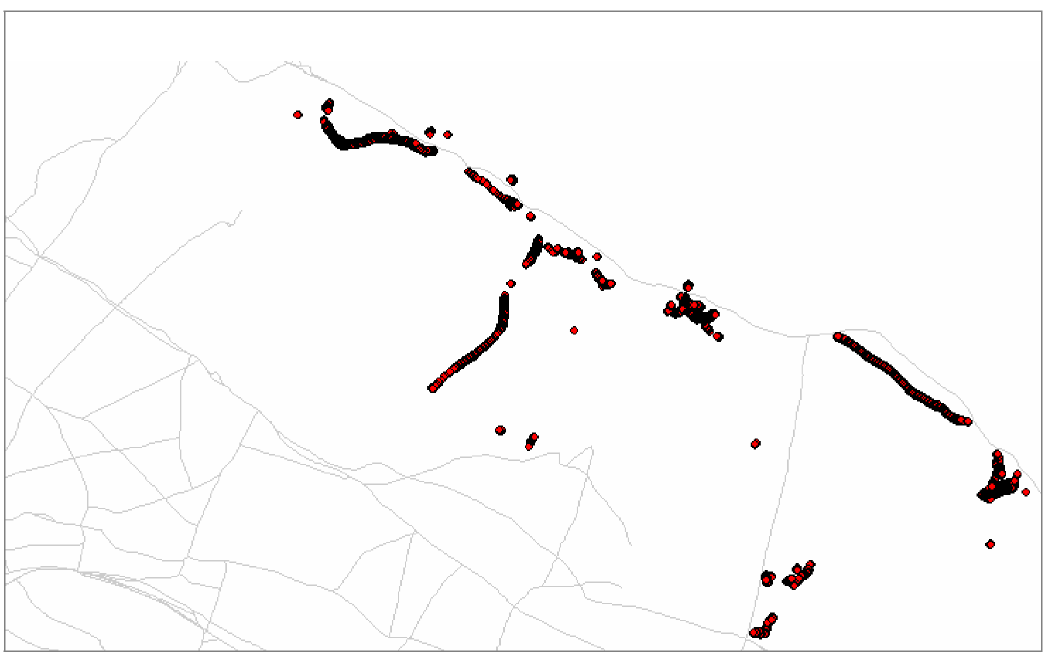

*Figure 4-4 Locations in screen line area with GPS data density greater than 40*

The frequencies of off-road moving data density for different missions were analyzed and compared. Figure 4-5 shows that more GPS data fall inside the areas with lower GPS data density (less than 10 points per study unit) for area security mission; while more GPS data point surrounded by more than 40 points for screen line mission. The different distribution indicated the difference of the vehicle land use patterns when conducting screen line mission and area security mission: the traffic in screen line area is more concentrated than in area security, which is reasonable considering that the screen line mission can be more structured than area security mission.

### 4.2.2 Velocity distribution

Vehicle velocity is an important property for characterizing vehicle on-road and off-road travel, since vehicle on-road travel normally can have a higher speed than off-road travel. The study by Haugen *et al.* (2003) analyzed the frequencies of velocities for off-road travel during the training exercise (Figure 4-6). Figure 4-6 shows the frequencies of velocities for each vehicle when traveling off-road: vehicles traveled in relatively low velocities for most of the time. A similar analysis for integrated vehicles' off-road moving data was also conducted; the results are shown in Figure 4-7 and Figure 4-8. These two figures show that more than 70% of off-road moving data has a velocity lower than 3 m/s, and less than 10% data has a velocity higher than 6 m/s.

On-road moving data for all vehicles were also integrated and analyzed for the frequencies of travel velocities. Figure 4-9 shows approximately half of the data with a velocity higher than 6 m/s. A comparison of the on-road and off-road velocities is shown in Figure 4-10. Substantial differences of frequencies on the velocities greater than

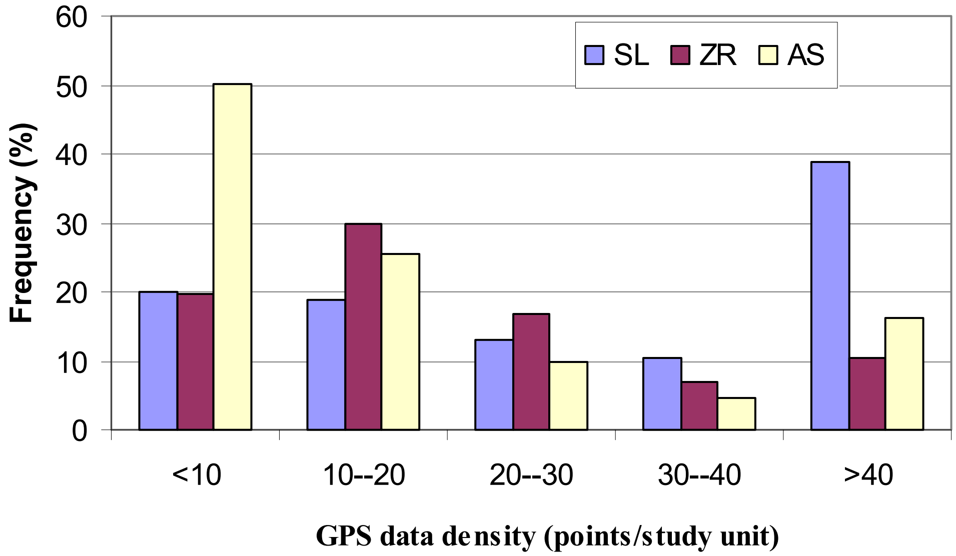


*Figure 4-5 Comparison of GPS point density distribution for different missions*

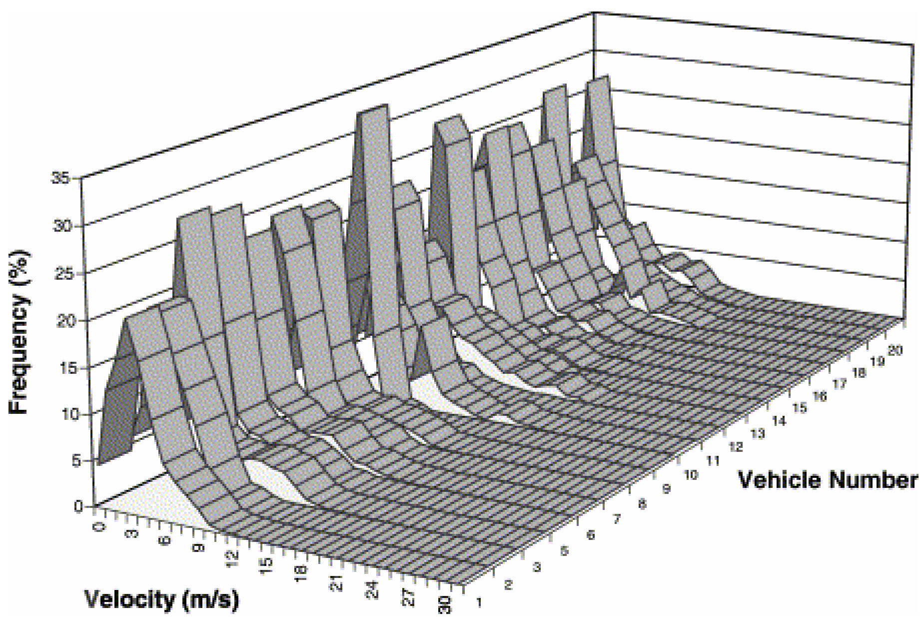


*Figure 4-6 Frequencies of different vehicles' off-road velocities (Haugen, 2003)*

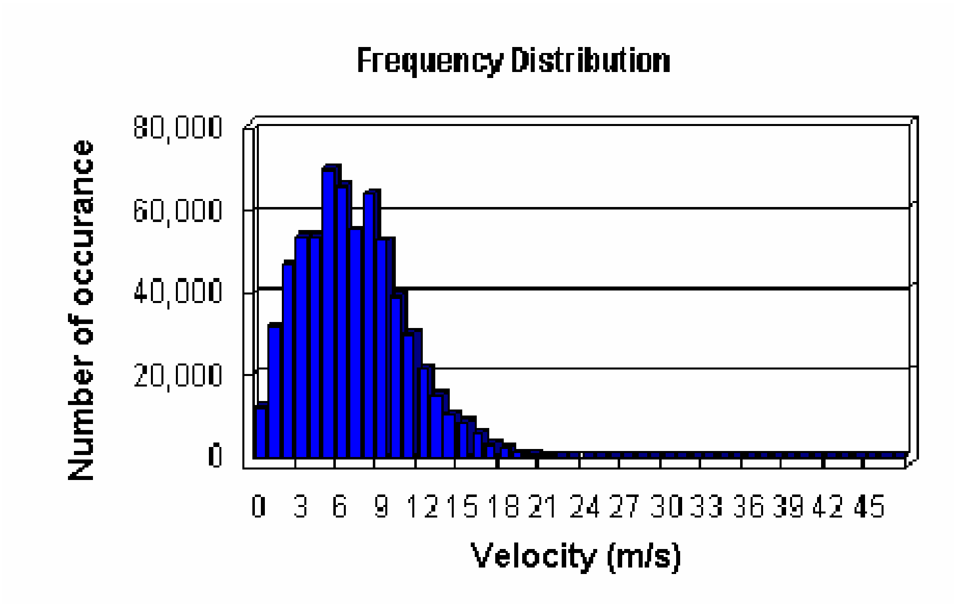


*Figure 4-7 Frequency distribution of vehicle on-road velocities*

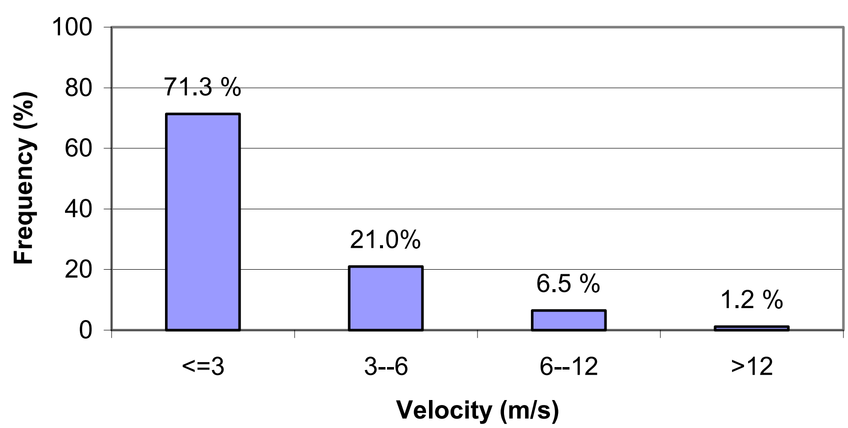


*Figure 4-8 Frequency distribution of vehicle off-road velocities*

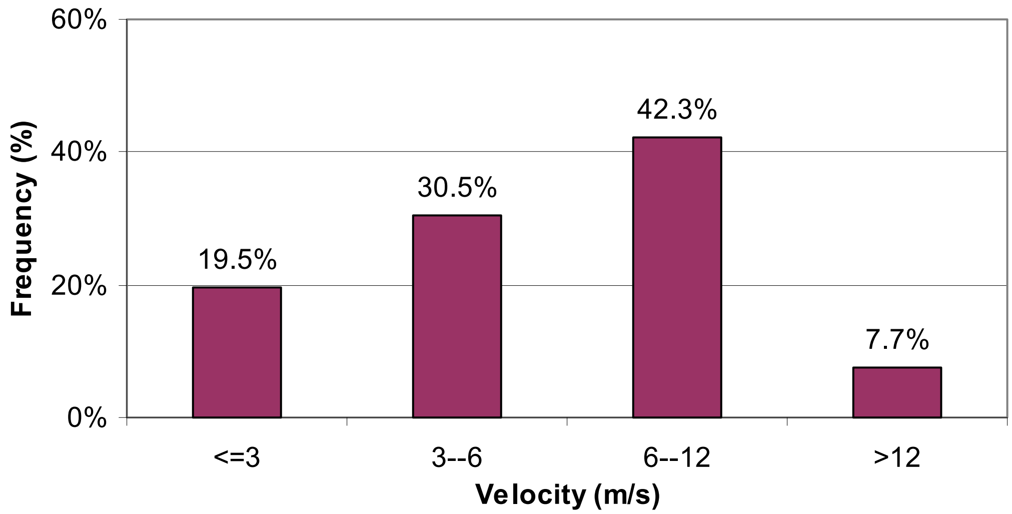


*Figure 4-9  Frequency distribution of velocities for on-road moving data*

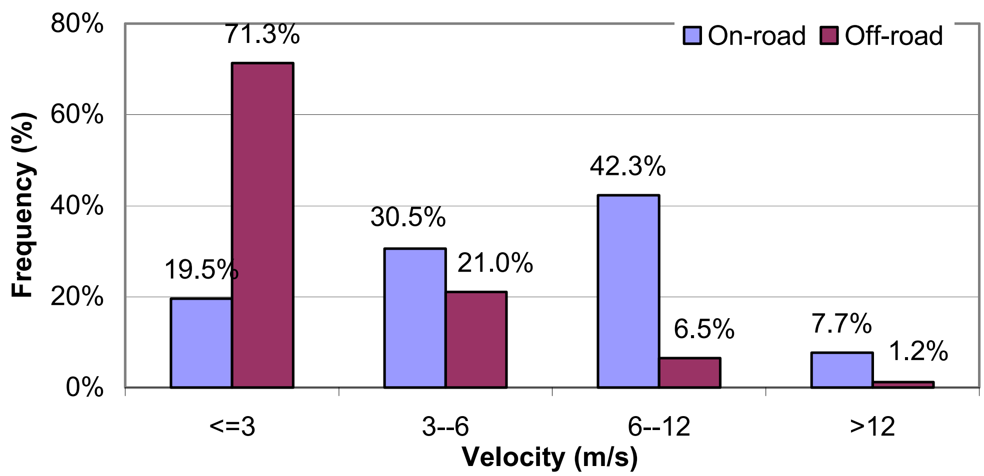


*Figure 4-10 Comparison of frequency distributions of on-road off-road velocities*

6 m/s for on-road and off-road moving data can be observed in Figure 4-10. A frequency analysis on different military classes' road was conducted and shown in Figure 4-11. As can be seen from Figure 4-11, vehicles were able to obtain a higher speed when traveling on the roads belonging to higher level military classes due to the relatively better road conditions.

The locations where off-road high speed traffic occurred were expected to have a higher possibility to be a portion of a road. Figure 4-12 shows the locations with velocity greater than 6 m/s in the screen line area. More figures showing off-road movement locations with high velocities for the area security and zone reconnaissance mission can be found in Appendix I. These areas where high speed off-road movements occurred need to be investigated for potential roads.

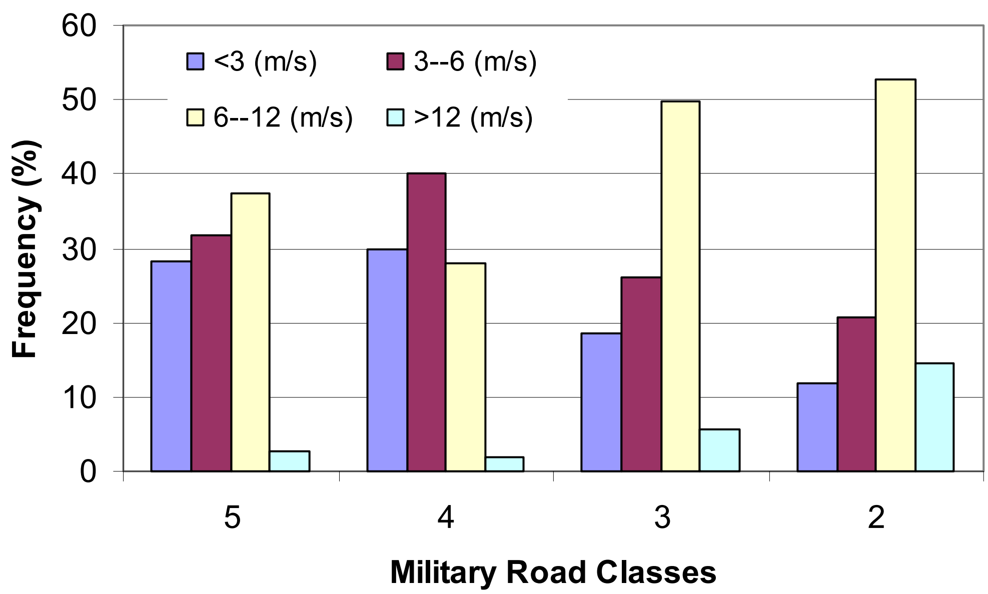


*Figure 4-11 Frequency distribution of velocities for different military classes' roads*

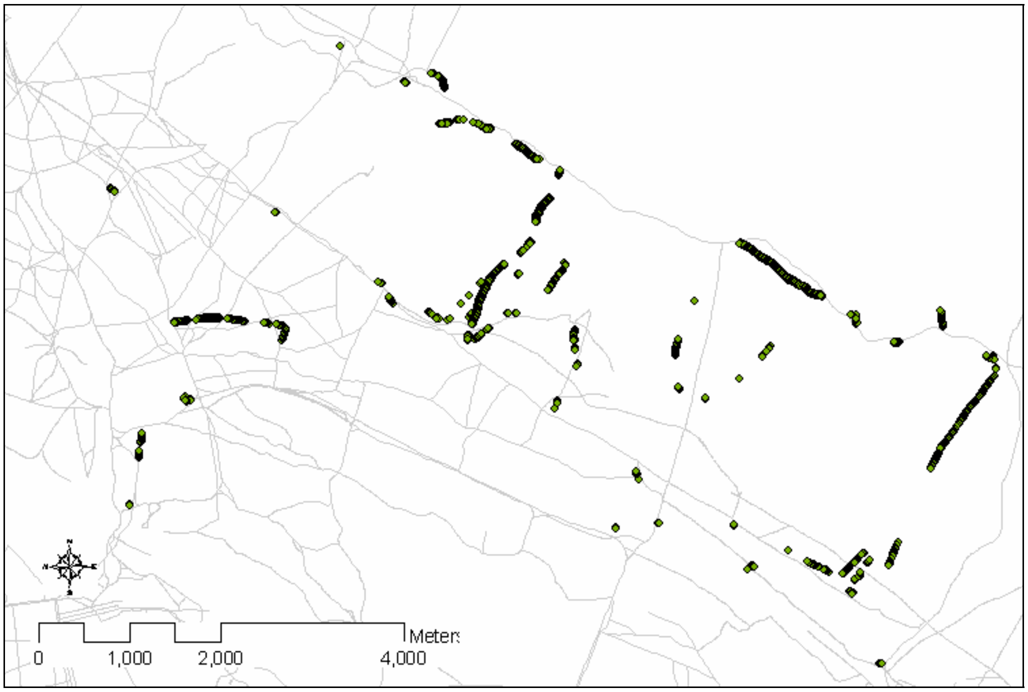


*Figure 4-12 Locations with velocity greater than 6 m/s in the screen line area*

### 4.2.3 Turning radii distribution

As an important feature of vehicle's dynamic properties, turning radius (TR) can help to describe vehicles' movement patterns. Roads usually have a certain level of straightness, especially for those constructed roads: obstacles were usually removed to straighten the road. As for the turning radii calculated based on continuous GPS points from on-road moving data, their values should be relatively higher, indicating the straight driving.

The turning radii were locally averaged within an area with a 10-meter search radius. As a result, a raster map was generated providing the locally averaged turning radius for each location. Assigning the cell value to each point falling inside the cell gives each point the turning radius averaged from all surrounding GPS points within the

search area. Figure 4-13 shows the frequencies of turning radius calculated for the on-road moving data: more than 80% of the moving data contains a turning radius greater than 80 meters. It is believed that the GPS data trace with an averaged turning radius greater than 80 meters can be locally considered as having a linear shape.

Other than a locally averaged turning radius that takes into account the surrounding points, an analysis on the frequency distribution of turning radii by Haugen *et al.* (2003) was based on the turning radius from each GPS point. Haugen *et al.* (2003) analyzed the frequency distribution of turning radii for off-road moving data for each tracked vehicle; the result is shown in Figure 4-14. As mentioned by Haugen *et al.* (2003), vehicles spent about 20% of the off-road travel conducting turns with turning radii less than 20 meters.

The off-road moving data were analyzed for an integrated (locally averaged) turning radius frequency distribution (shown in Figure 4-15). Compared to the 20% reported by Haugen *et al.* (2003), this integrated analysis resulted in a slightly lower percentage (18.5%) for the activities with small turning radii. Figure 4-15 also shows

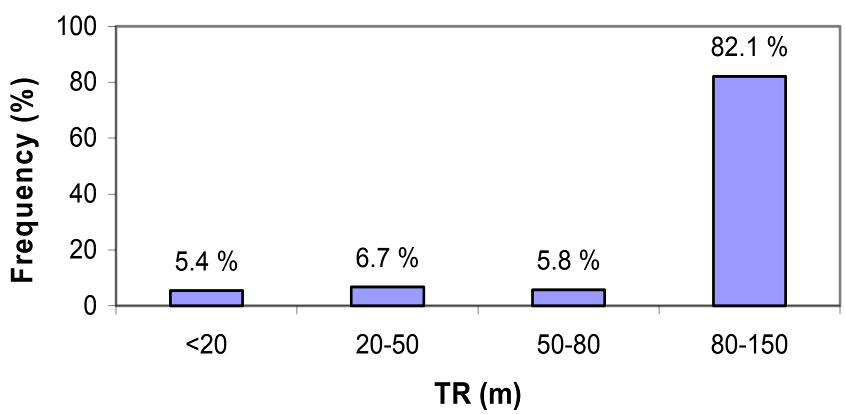


*Figure 4-13 Frequencies of turning radius for on-road moving data*

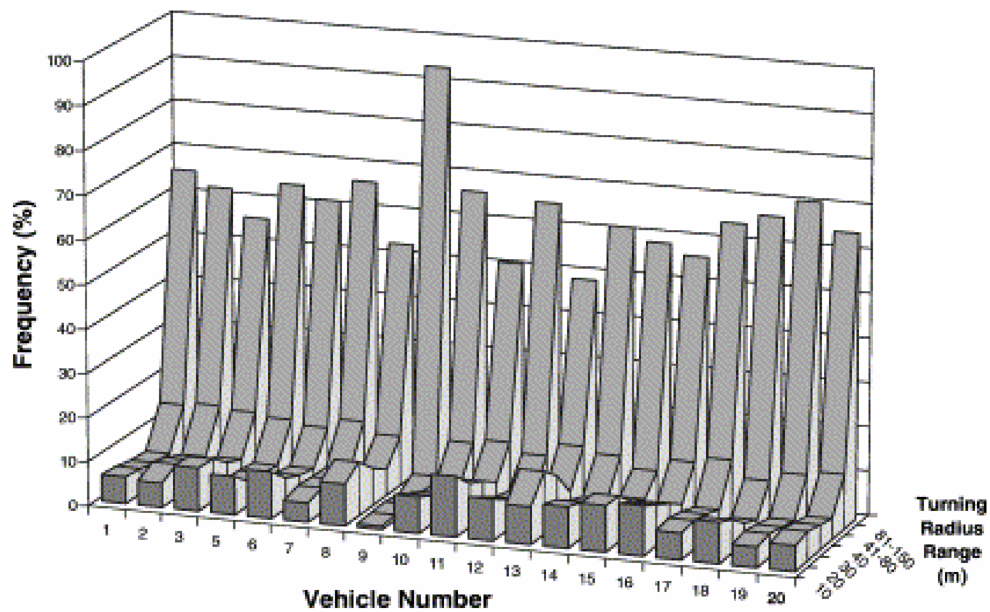


*Figure 4-14 Frequencies of turning radius for off-road moving data (Haugen, 2003)*

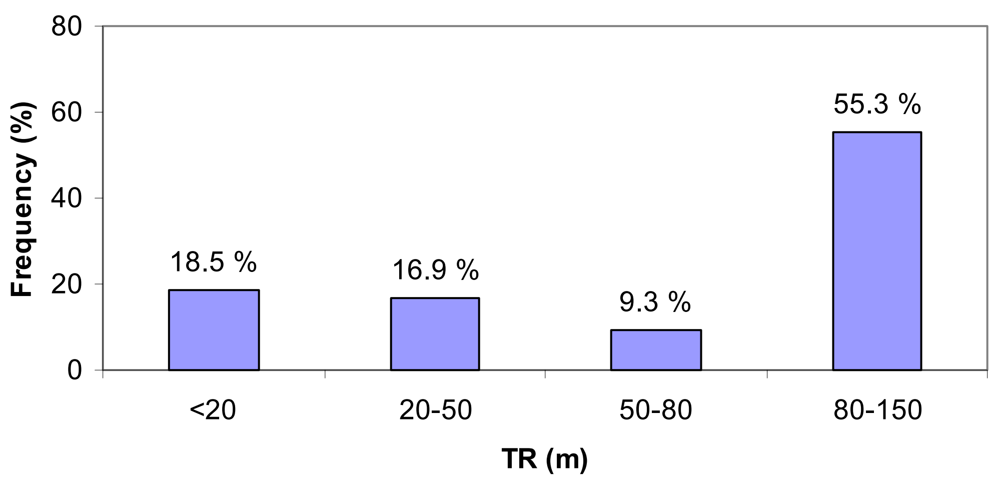


*Figure 4-15 Integrated frequencies distribution of turning radius for off-road data*

that approximately 55% of the off-road movements have the turning radii greater than 80 meters, which can be locally considered as traveling straightly.

The frequencies of turning radii for different missions were analyzed and compared. Slightly different from the integrated TR frequencies for all off-road moving data, Figure 4-16 shows relative higher frequencies on turning radii greater than 50 and less than 80 meters for all three missions. No significant difference of turning radii distribution among the three missions can be observed. Vehicles conducting locally straight travel motions were considered as an important condition for identifying potential roads. Those areas where the concentrated traffic with high turning radii occurred were considered having high possibility for the existence of potential roads and need to be investigated.

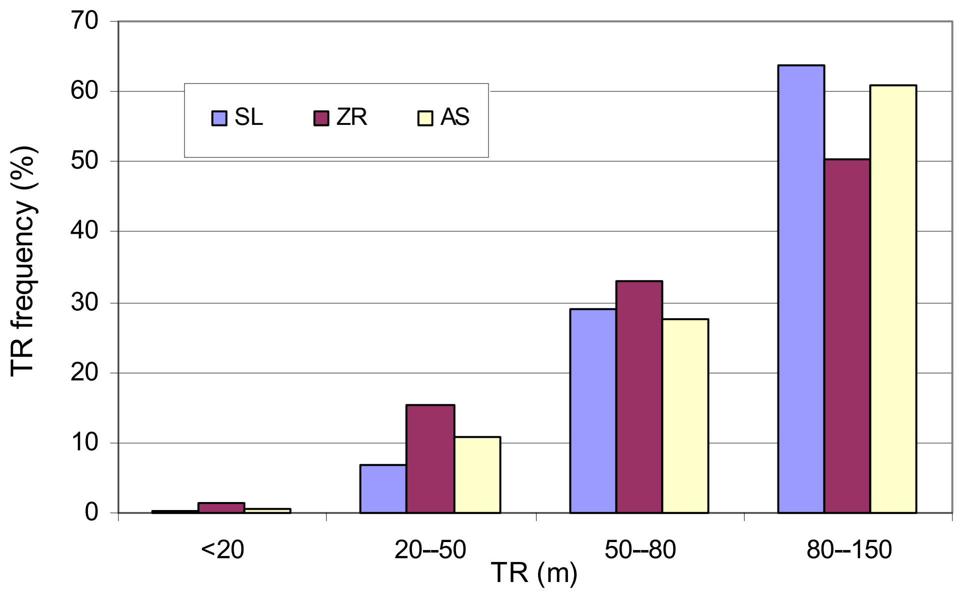


*Figure 4-16 Comparison of TR frequency distribution for different missions*

### 4.2.4 Travel directions

The vehicle travel directions can also be used for characterizing vehicle movements. An output of the GPS receivers, Course over Ground (COG), provides the vehicle heading direction. Analysis of the COG from the GPS vehicle tracking data enables to determine vehicles approached a certain area in one direction or multiple directions. GPS vehicle tracking data were analyzed for the standard deviation of COG within the search area (the area with a 10-meter radius) for both on-road and off-road moving data. The frequencies of standard deviations for both on-road and off-road moving data and their comparison are shown in Figure 4-17, Figure 4-18, and Figure 4-19 respectively. The locations with the standard deviations of COG smaller than 20 indicates that vehicles approached the specific location from the same direction. This may include both single pass and multiple passes. Locations with the standard deviations of COG close to 90 degree indicate that the vehicles passed the same area in opposite directions (approximately equal number of opposite direction passes).

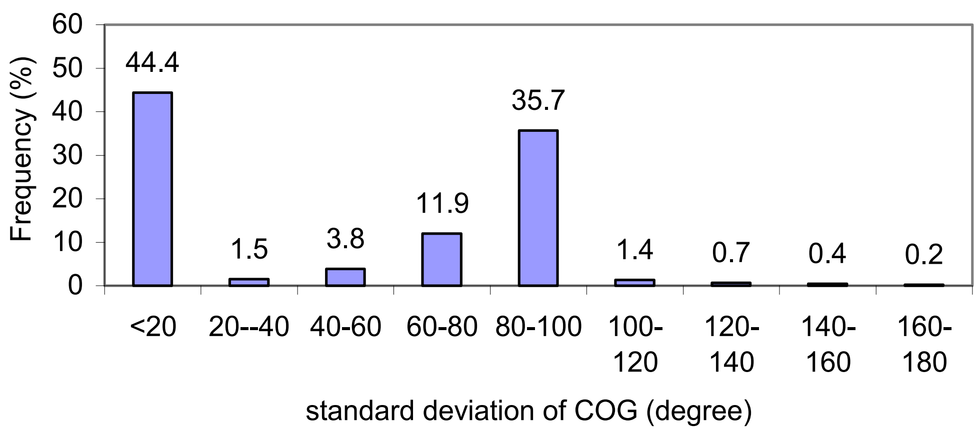


*Figure 4-17 Frequency distribution of standard deviations of COG for on-road data*

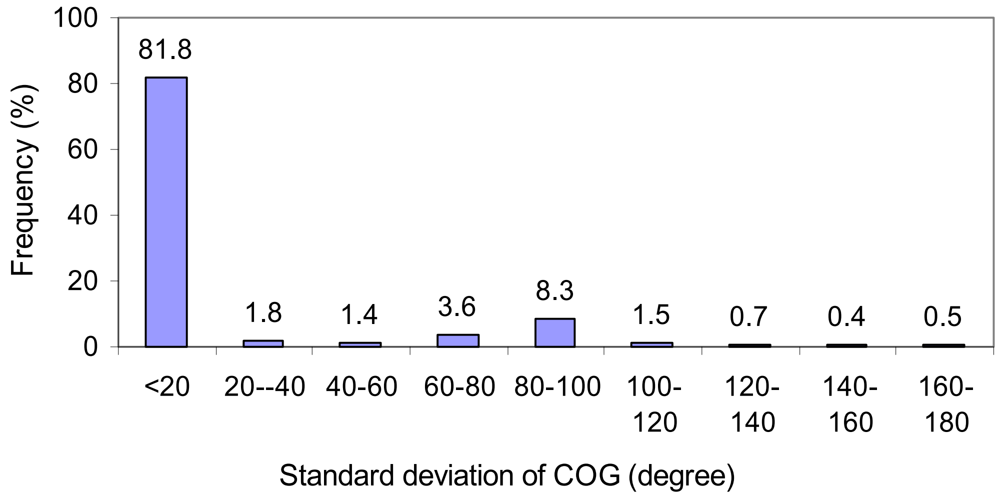


*Figure 4-18 Frequency of standard deviation of COG for off-road data*

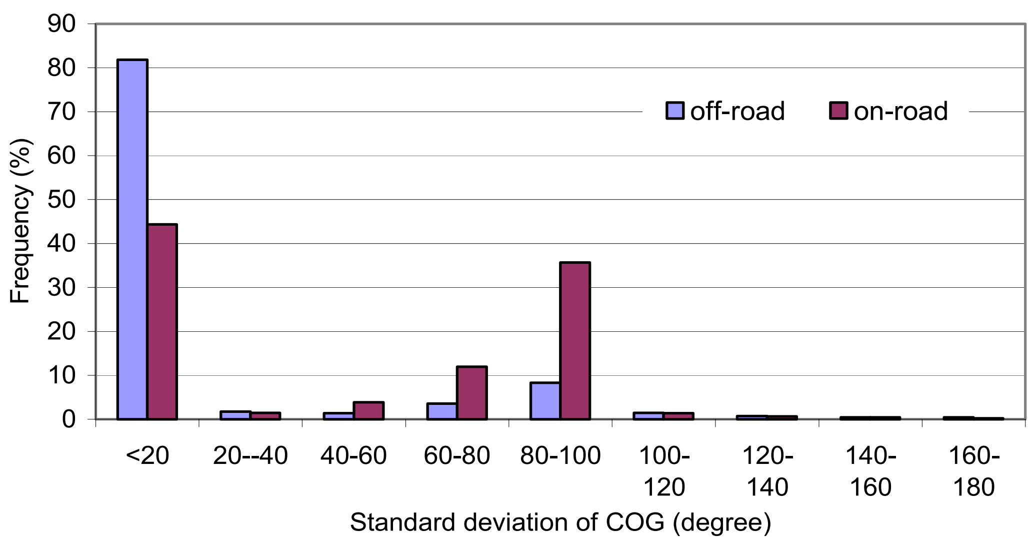


*Figure 4-19 Comparison of the STD_COG frequency distribution for on-road and off-road moving data*

The frequency distribution of the standard deviations of COG for off-road moving data (Figure 4-18) indicates a significant amount of locations where vehicles passed through in one direction. Approximately 8% of the off-road movement may be considered as that the vehicles passed the certain area in two opposite directions; those areas also may be studied further for identifying potential roads. The comparison of standard deviations of COG for on-road and off-road moving data shown in Figure 4-19 indicates that differences exist in the situations with the standard deviations of COG less than 20, between 60 and 100. These differences suggest further studies on these particular locations. Figure 4-20 shows the locations in screen line area with the standard deviations of COG close to 90 degrees. More figures showing the locations with standards deviation of COG close to 90 degree for area security and zone reconnaissance areas can be found in Appendix I.

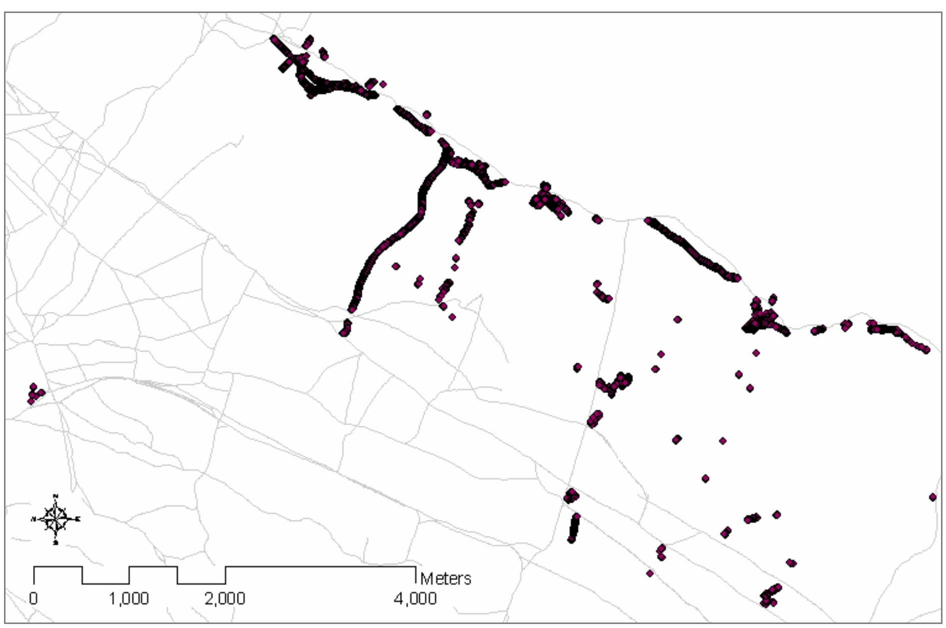


*Figure 4-20 Locations in screen line area with the COG standard deviations close to 90*

## *4.3 Special Off-road Movement Patterns*

When exploring different vehicle movement patterns, interesting off-road patterns in screen line area drew attention. In that particular area, concentrated and repeated vehicle traffic from different troops occurred during different days; GPS traces appeared to be in linear shapes; but no road can be found on current installation road map. An unmapped road or a road newly formed by vehicles' concentrated traffic during the training exercise was considered existing in this area based on the special movement patterns.

### 4.3.1 Special movement patterns for potential roads

The special movement patterns in the screen line area are shown in Figure 4-21. Circled areas in Figure 4-21 with label "1", "2", and "3" were extracted and analyzed for the factors describing the special movement patterns. Details for the emphasized areas are shown in Figure 4-22, Figure 4-23, and Figure 4-24. Figure 4-22 shows that different vehicles from different troops moved around (traveled in more than three different directions) in the same area during different days; the GPS trace may not be considered as a potential road. Figure 4-23 shows the location labeled as "2" in Figure 4-21. The left partial GPS traces came from six different vehicles that belong to three different troops; those vehicles passed this area during four different days and in opposite directions. The right portion GPS traces came from two vehicles that passed during one day in the same direction; the two vehicles belong to the same troop. The left portion of the GPS traces was considered more likely to be a segment of a potential road.

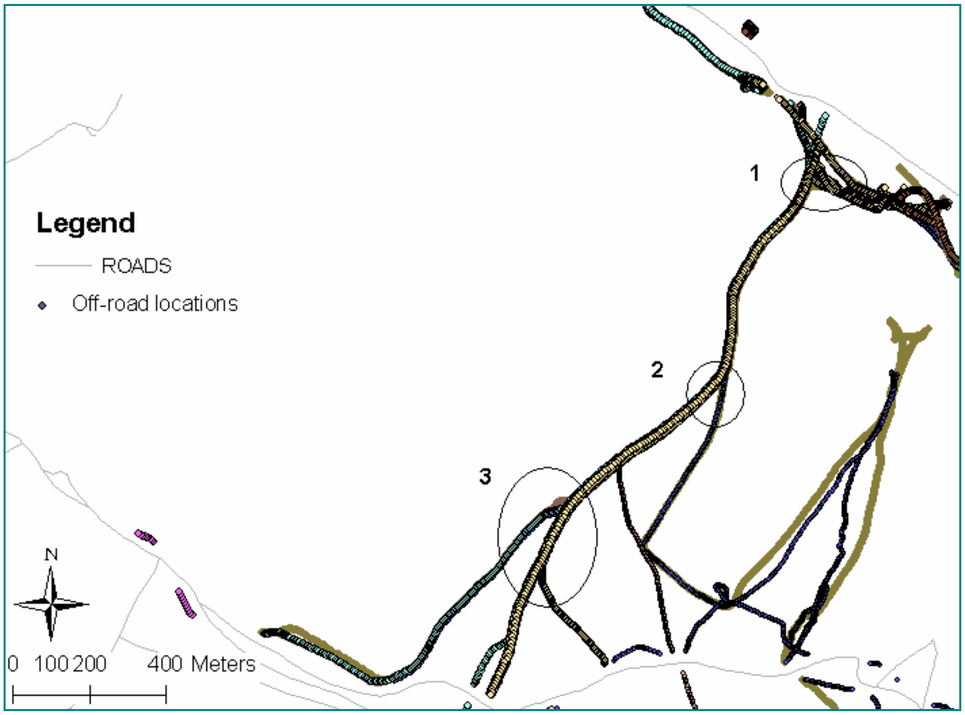


*Figure 4-21 Special off-road movement patterns in the screen line area*

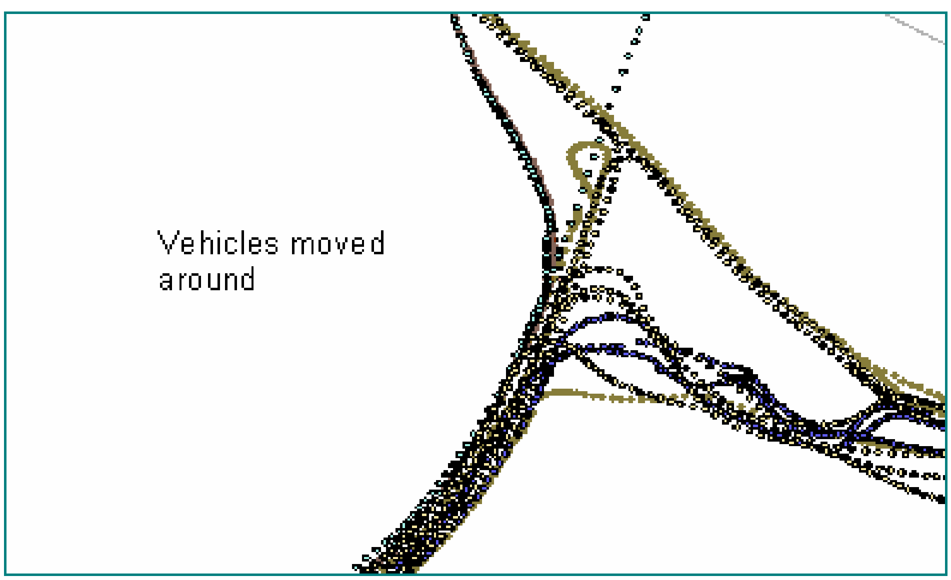


*Figure 4-22 Vehicles moved around; location "1" in Figure 4-21*

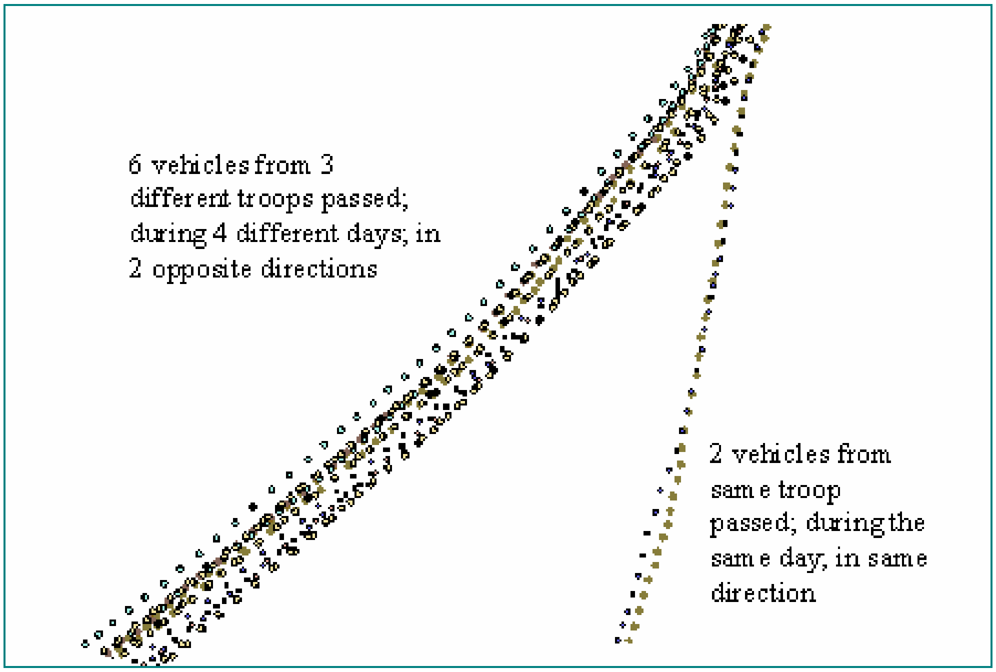


*Figure 4-23 Several vehicles passed same area; location "2" in Figure 4-21*

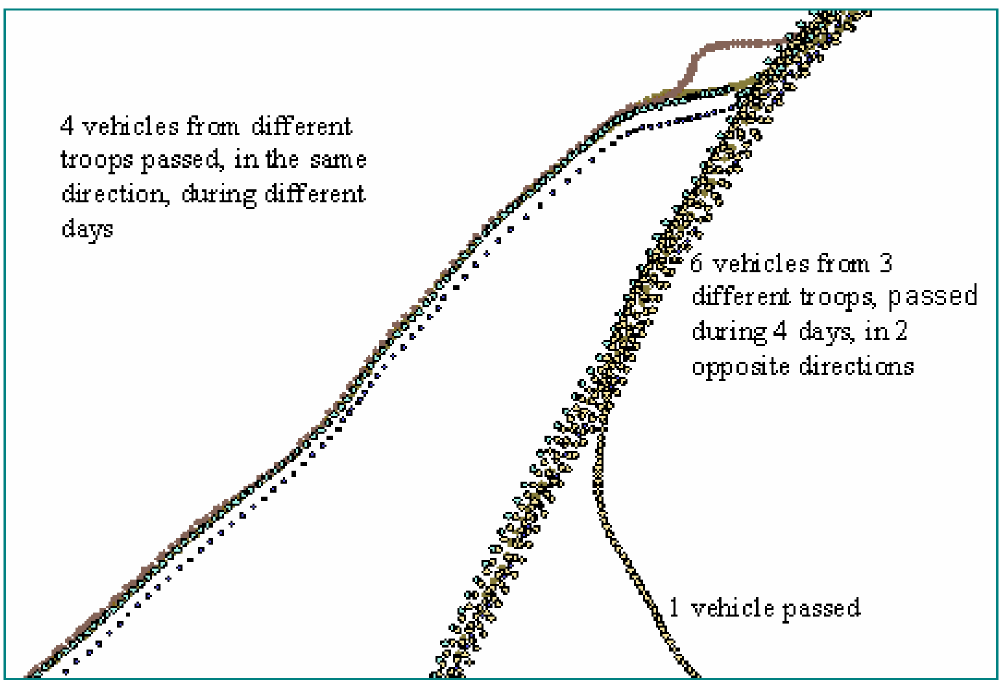


*Figure 4-24 Different movements; location "3" in Figure 4-21*

Figure 4-24 shows the different movements in the location labeled as "3" in Figure 4-21. The middle portion GPS traces were a continuous part of the major traces in Figure 4-23: six vehicles from three different troops passed during different days in opposite directions; it was also considered as portion of a potential road. The left segment include the traces from four different vehicles, different troops, different training days, but same direction. A single vehicle path also was also observed in the right bottom side of Figure 4-24; it was not considered as portion of a road.

A site visit on the location where aforesaid special vehicle movement patterns occurred was conducted in June 2003, approximately 2 years after the training exercise. During this two-year period, no additional training exercise occurred in the training center. A military class 4 road was observed in the area where concentrated traffic occurred. The road conditions observed are shown in Figure 4-25. As can be seen from Figure 4-25, a potential road was observed from waypoint 10 to 15; and a vehicle path is barely visible from waypoint 7 to 8 where four vehicles from different troops passed in one direction during different days. Site visit also found no road on the area where only one vehicle passed (the GPS traces in the right bottom side of Figure 4-24) or the area where two vehicles from same troop passed in one direction during one day (the traces in the right side of Figure 4-23 ). Different land recovery strategies may be required for the multi-tracked areas based on their disturbance severities, especially for the potential road areas. The confirmation of the potential road in the screen line area necessitates the identification of potential roads within the entire training center to support training land management.


*Figure 4-25 Site visit result for the potential road in the screen line area*

### 4.3.2 Quantitate the factors for identifying potential road

Based on the investigation and comparison of vehicles' movement patterns in the screen line potential road area, several factors were considered important for identifying potential road areas from GPS vehicle tracking data. The factors include several conditions: 1) how many different vehicles that passed the study area; 2) if the vehicles that passed the area belong to one troop or different troops; 3) if vehicles passed the area within one day or during different days; and 4) if vehicles passed the area in opposite directions. It is expected that the area where more vehicles from different troops passed during different days in opposite directions has greater possibilities to be a portion of a potential road. The vehicle movement pattern similar to those observed in the screen line potential road area was termed potential road movement pattern. The identification of

potential roads from GPS vehicle tracking data then can be approached by identifying the locations where the potential road movement patterns occurred.

GPS off-road tracking data were analyzed for an overview of the vehicle movement patterns based on the conditions utilized to characterize potential road movement patterns. GPS off-road tracking data for all vehicles were imported into ArcGIS, for each point, to count within a 10-meter radius surrounding area: 1) how many different vehicles passed; 2) how many troops' vehicles passed; 3) during how many different days the vehicles' passes occurred. Result of the movements conducted by different vehicles is shown in Figure 4-26. Approximately half of the off-road travel accessed the areas that already had been accessed by other vehicles, which indicates repeat traffic from different vehicles exists in certain areas. Figure 4-27 shows the frequency distribution of movements from different troops. About one third of the movements from different troops occurred in some locations. Figure 4-28 shows the frequency distribution of the movements occurred during different days. Approximately 40% of the movements that conducted during different days occurred in same locations. Based on the analysis results, it was believed that possible potential roads exist, besides the observed one in the screen line area. A feasible method is needed to identify potential roads based on the analysis of GPS vehicle tracking data.

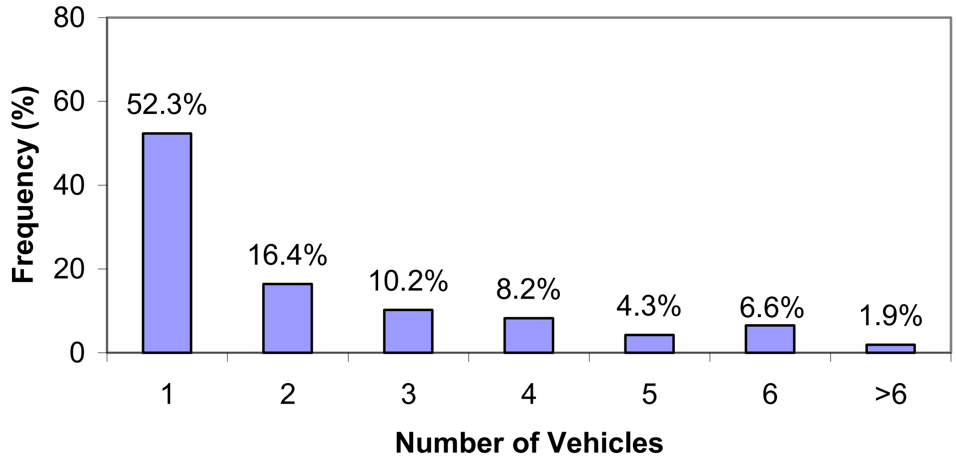


*Figure 4-26  Frequency distribution of movement patterns by different vehicles*

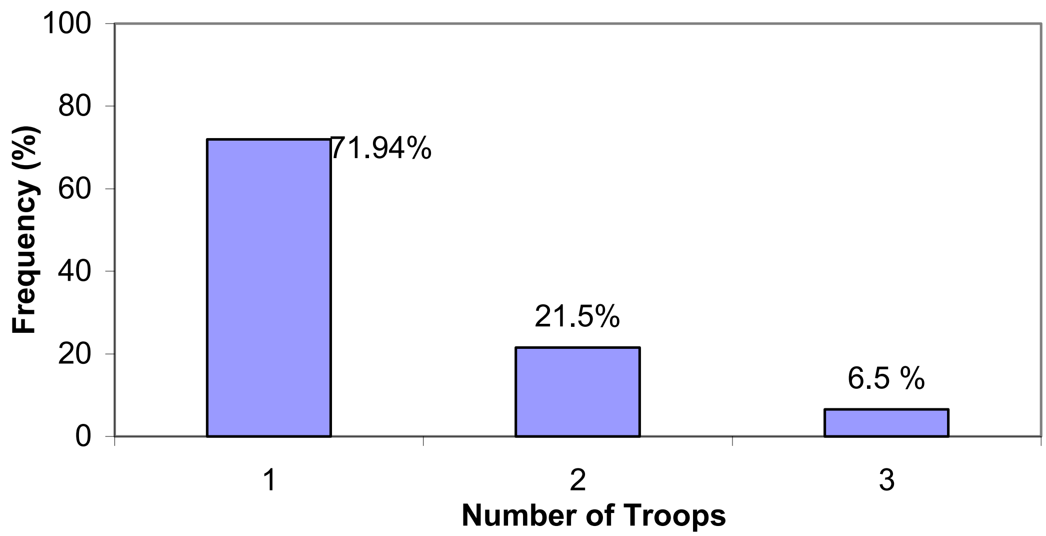


*Figure 4-27 Frequency distribution of movement patterns by different troops*

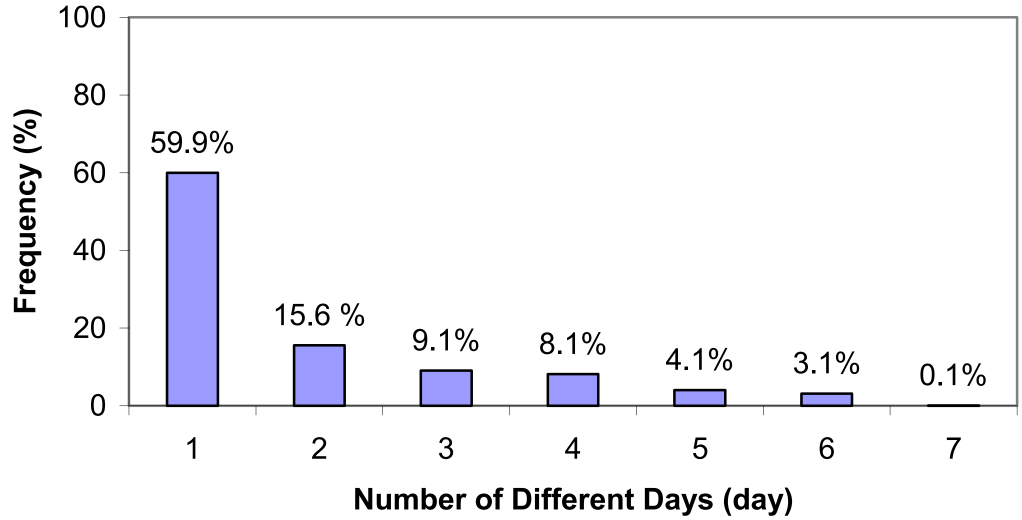


*Figure 4-28 Frequency distribution of movement patterns by different days*

# CHAPTER 5 - MULTICRITERIA POTENTIAL ROAD IDENTIFICATION

Chapter 4 extracted factors to characterize and relate vehicle movement patterns to potential roads. These factors include: 1) the number of different vehicles passed a certain location; 2) if the vehicles that passed the area belong to same troop of different troop; 3) if the vehicles passed the location within one day or during different days; and 4) if the vehicles passed the location in the same direction or in two opposite directions. Based on these conditions, this chapter developed a multicriteria method to identify if a study unit is a portion of a potential road or not based on the vehicle movement patterns occurred within the study unit during the training exercise.

## *5.1 Study Areas and Study Units*

As mentioned in Chapter 4, the identification of potential roads can be approached by identifying the locations where special movement patterns occurred. The special movement pattern, termed potential road movement pattern, was defined as the movement that fulfilled these conditions: different vehicles from different troops passed a certain area during different days in opposite directions. The procedures for identifying potential roads include the following major steps: 1) within a small study unit, based on the conditions the study unit fulfilled, quantifying the similarity of vehicle movement

pattern and potential road movement pattern; 2) identifying the study units containing potential road movement patterns as potential road grids; and 3) clustering the contiguous potential road grids to form potential roads. The procedures for identifying potential roads were developed inside ArcGIS. ArcGIS has the advantage in developing criteria based on neighborhood analysis operations and accomplishing spatial multi-criteria. ArcGIS also helps in evaluating criteria and visualizing the results.

The study focuses on three major study areas where the three different missions occurred. Locations of the three major study areas are shown in Figure 5-1. The GPS traces in the left side of Figure 5-1 came from vehicle No.15, which had a mechanical problem during the training exercise and was shipped through interstate highway (I-82) to the cantonment. Because the interstate highway is not identified on the YTC road map; this part of GPS data was selected as off-road data based on 30-meter road buffer analysis; the data set was excluded in this study, but can be used as test data.

A polygon shape file was created based on the extent of the YTC map to break the entire Yakima Training Center into small study units. The YTC map was projected into UTM coordinate systems: WGS1984 UTM Zone 10N; all data used in this study were projected into the same coordinate systems. The polygon file separated the YTC training area into many 25 by 25 square meter polygons; each polygon was considered as a study unit. The 25 by 25 square meter polygon size was chosen based on the accuracy of the GPS receivers used in the vehicle tracking activity in 2001 and the accuracy of the YTC road map (Huagen, 2002; Ayers, et al., 2004). Figure 5-2 demonstrates an example for the small units containing GPS off-road moving data.

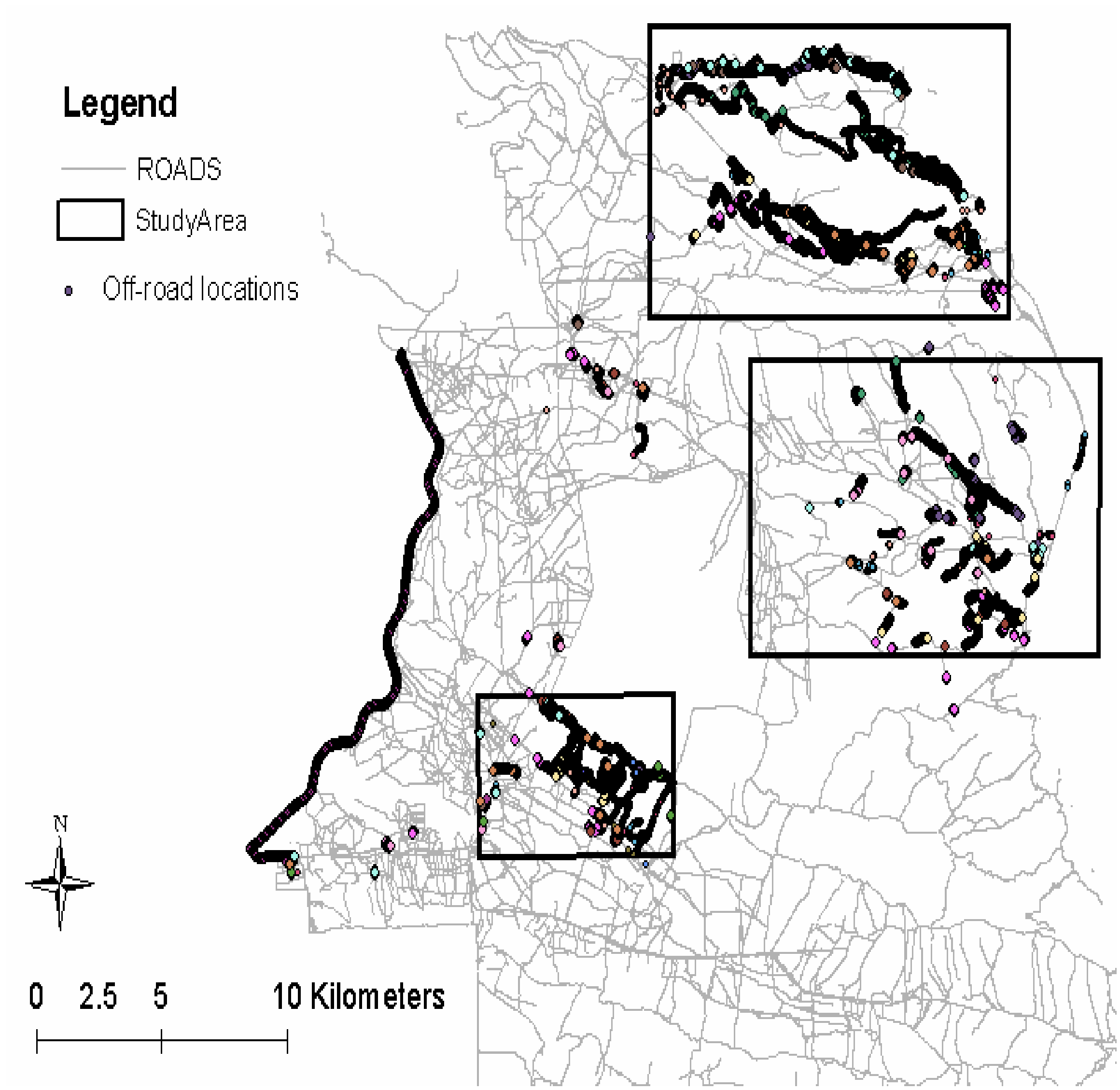


*Figure 5-1 Study areas for potential road identification*

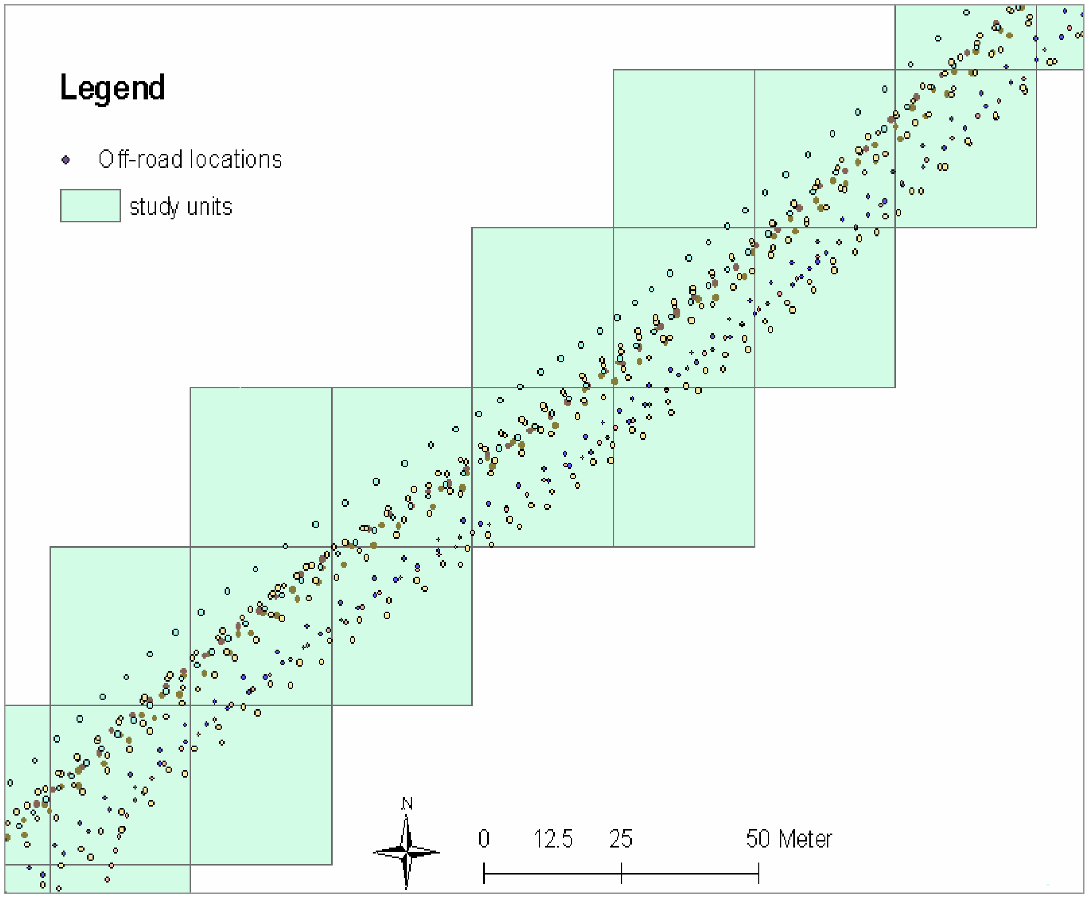


*Figure 5-2 25 by 25 square meter study units*

## *5.2 Five Criteria Method*

As mentioned early, a location can be classified as a portion of a potential road if it meets the following conditions: 1) different vehicles passed through the area; 2) vehicles that passed the same area on different days; 3) vehicles from different troops used the same area; and 4) vehicles passed the same area in opposite directions. According to these conditions, criteria were developed to classify the study units. Besides the four factors, a criterion was used as precondition for selecting the study units that contain at least two GPS points. This procedure is identified as five criteria method, which includes the following five criteria for selecting the potential road grids from all study units: 1) at least two points falls inside the study unit; 2) different vehicles passed the unit; 3) vehicles that passed the unit in different days; 4) vehicles that passed the unit belong to different troops; and 5) vehicles passed the unit in opposite directions. Table 5-1 shows the details of these factors, their denotations, and relevant criteria.

*Table 5-1 Five criteria for potential road identification*

| Factors | Denotation | Criteria | Description |
|---|---|---|---|
| GPS points | cnt_pnt | cnt_pnt >2 | The number of GPS points within the study unit |
| Number of Vehicles | V_num | V_num >1 | The number of vehicles that passed the study area |
| Passage Intervals | Dif_day | Dif_day = 1 | Vehicles past the same study unit in different day |
| Vehicles' Attributes | Dif_Troop | Dif_Troop = 1 | Vehicles that passed the study area belong to different troop |
| Travel Directions | SD_SOG | SD_SOG>20 | Using standard deviation of Course Over Ground (COG) to determine if the vehicles move in same or different directions |

The selection of these criteria was motivated by the fact that they are easy to understand, and are representative of the characteristics of an area. As different criteria are usually characterized by different importance levels, the subsequent step of criteria analysis is the prioritization of the criteria. It is expected that locations meeting more criteria have a higher possibility to be a potential road.

In order to obtain the summarized GPS information for each study polygon, the GPS vehicles' off-road tracking data for each tracked vehicle was combined into a point shape file. A new field with a data range from 1 to 20 was added to the file to distinguish different vehicles from each other. The GPS vehicle tracking data were summarized for each study units in ArcGIS. As a result, the summarized information for each study unit include: the number of GPS points fall inside, the number of different vehicles that the GPS data came from; the number of troops that the vehicles belong to; the time interval of the different activities occurred within the study unit; the standard deviation of COG for all the GPS points fall inside the study unit indicating if vehicles approached the same area in one or multiple directions. Then each study unit can obtain a value indicating the criteria level met by the specific study unit.

Table 5-2 shows a portion of the resulted table: the "ObjectID" identifies each individual study unit; a "0" value under a criterion represents that the study unit did not meet the specific criterion; and the "1" value means the criterion was met by the study unit; the value under "criteria levels" represents the total number of the criteria met by the specific study unit. Based on the summarized attributes (Table 5-2), each study unit was classified into potential road grids with different certainty levels represented by how

*Table 5-2 A portion of the summarized attributes for the study units*

| Object ID | Other attributes | Pnt_2 | V_num | dif_day | dif_trp | dif_dir | Criteria levels |
|---|---|---|---|---|---|---|---|
| … | | … | | | | | … |
| 14 | | 1 | 1 | 1 | 1 | 1 | 5 |
| 26 | | 1 | 1 | 1 | 0 | 1 | 4 |
| 27 | | 1 | 1 | 1 | 1 | 1 | 5 |
| 28 | | 1 | 1 | 1 | 1 | 1 | 5 |
| 30 | | 1 | 1 | 1 | 0 | 1 | 4 |
| 31 | | 1 | 1 | 1 | 0 | 0 | 3 |
| 32 | | 1 | 1 | 1 | 0 | 1 | 4 |
| 33 | | 1 | 1 | 1 | 0 | 1 | 4 |
| 37 | | 1 | 1 | 1 | 0 | 1 | 4 |
| 38 | | 1 | 0 | 1 | 0 | 1 | 3 |
| 39 | ….. | 1 | 1 | 1 | 0 | 1 | 4 |
| 40 | | 1 | 1 | 1 | 0 | 1 | 4 |
| 41 | | 1 | 0 | 1 | 0 | 1 | 3 |
| 42 | | 1 | 1 | 1 | 0 | 1 | 4 |
| 43 | | 1 | 1 | 1 | 0 | 1 | 4 |
| 44 | | 1 | 0 | 1 | 0 | 1 | 3 |
| 45 | | 1 | 1 | 1 | 0 | 1 | 4 |
| 46 | | 1 | 0 | 1 | 0 | 1 | 3 |
| 48 | | 1 | 0 | 1 | 0 | 1 | 3 |
| 49 | | 1 | 1 | 1 | 0 | 1 | 4 |
| … | | … | | | | | … |

many criteria the individual study unit met.

Figure 5-3 shows the original map for all the study units in the screen line area. A serial of figures (Figure 5-4, Figure 5-5, Figure 5-6, Figure 5-7, Figure 5-8, and Figure 5-9) show the selected study units that meet different criteria levels in the screen line area. Figures showing the selected units in area security and zone reconnaissance mission areas can be found in Appendix II.

### *5.3 Clustering Potential Road Grids*

The procedures completed in the section 5.2 classified study units into potential road grids with different certainty levels represented by the number of criteria met by the study units. The selected study units were also termed potential road grids. Those grids met same criteria levels and spatially close to each other need to be clustered to form potential road segments.

Clustering the potential road grids that met same criteria level and are spatial contiguous can be approached by using different methods. This section utilized the data from the screen line area (showing in Figure 5-3) to demonstrate an approach implemented inside ArcGIS 9.0. This approach include three major steps: 1) convert the polygon shape file to raster file based on the criteria level value; 2) convert raster file back to polygon shape file to group the grids with same criteria levels and spatial contiguous; and 3) select the clusters with relatively large areas to be investigated for potential roads. The detailed procedures were demonstrated as follows by using the sample data from the screen line area. The polygon shape file containing the criteria level for each study unit (shown as Figure 5-3) was converted to a raster file based on the

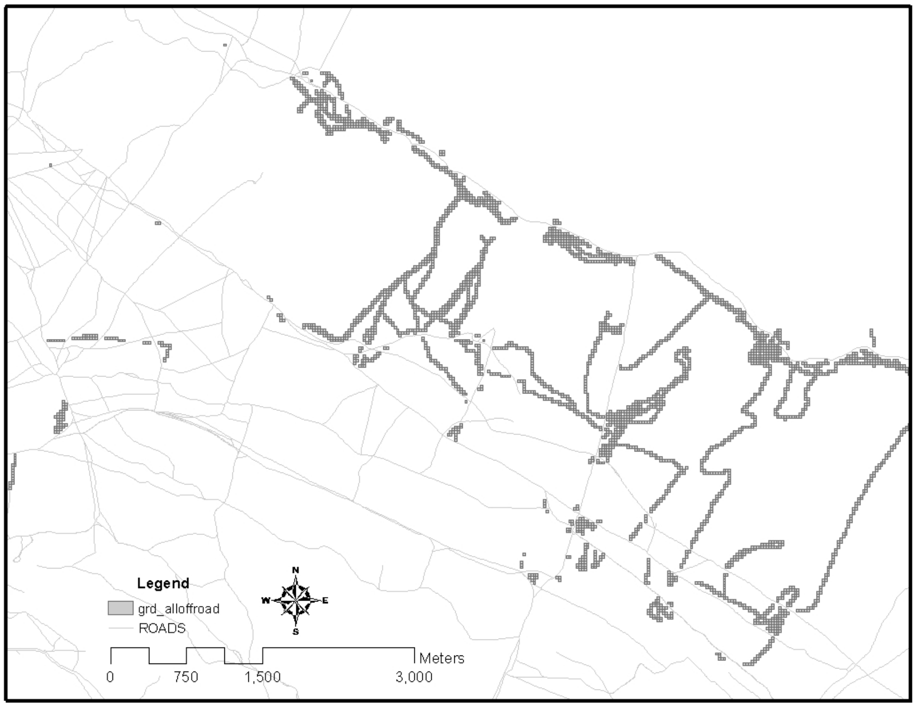


*Figure 5-3 Original map for all study units in the screen line area*

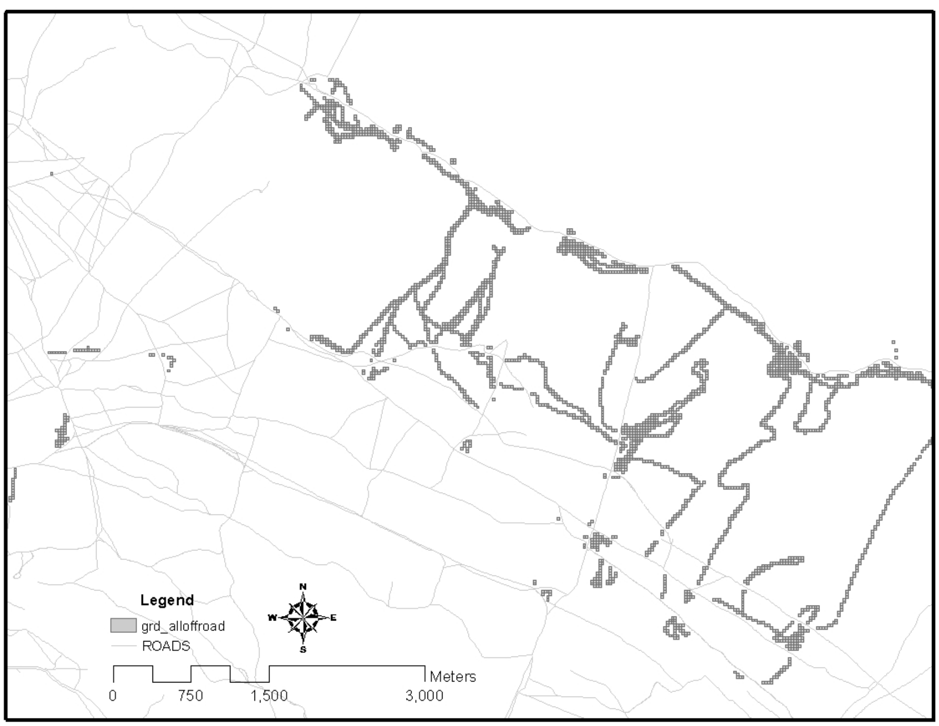


*Figure 5-4 Selected study units in screen line area with more than 2 points inside*

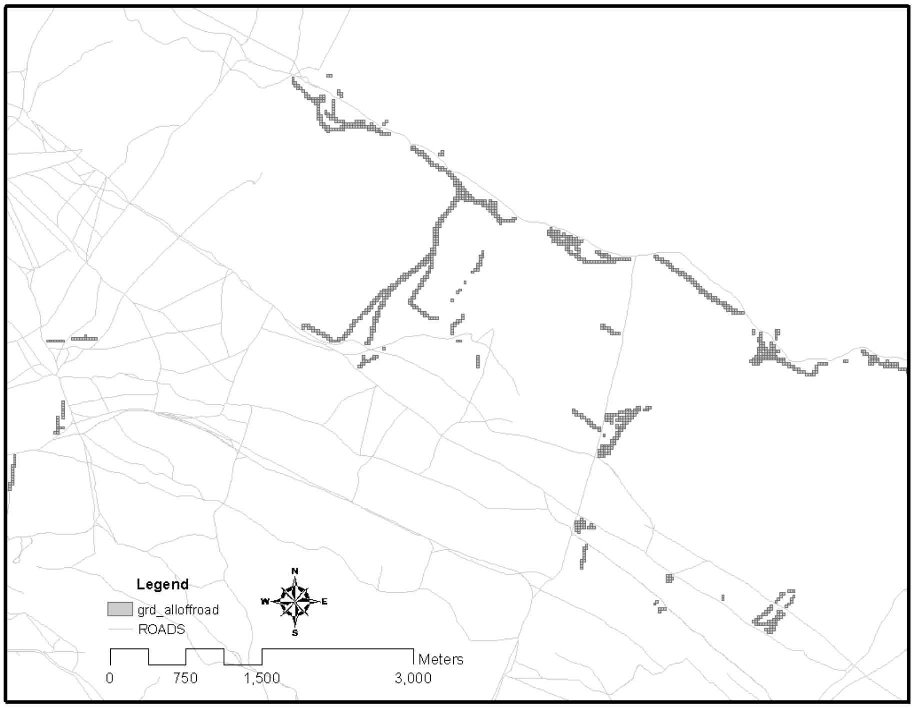


*Figure 5-5 Selected study units in screen line area where at least two vehicles passed*

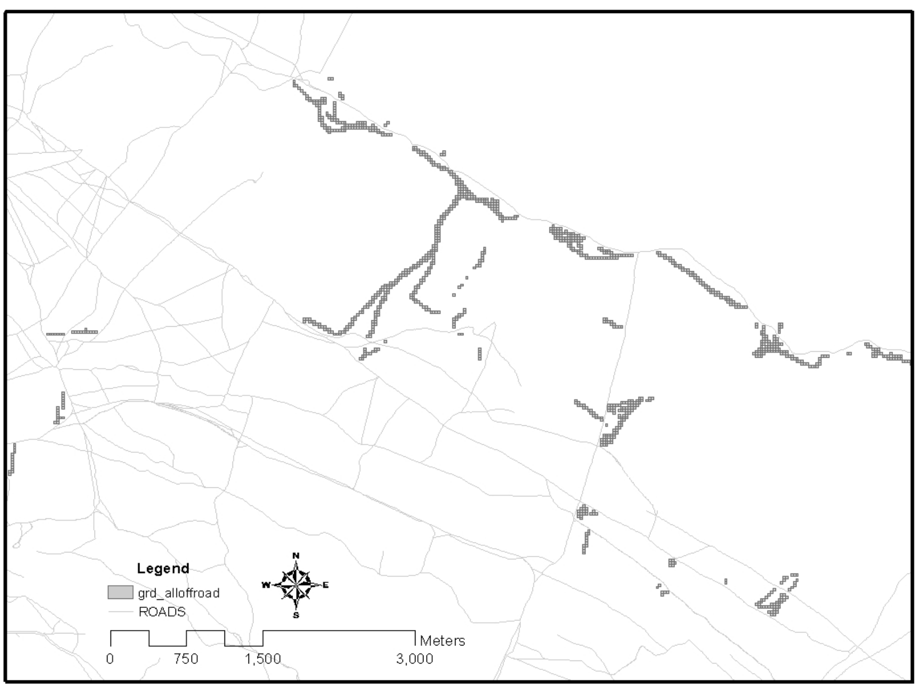


*Figure 5-6 Selected study units meet at least two criteria in the screen line area*

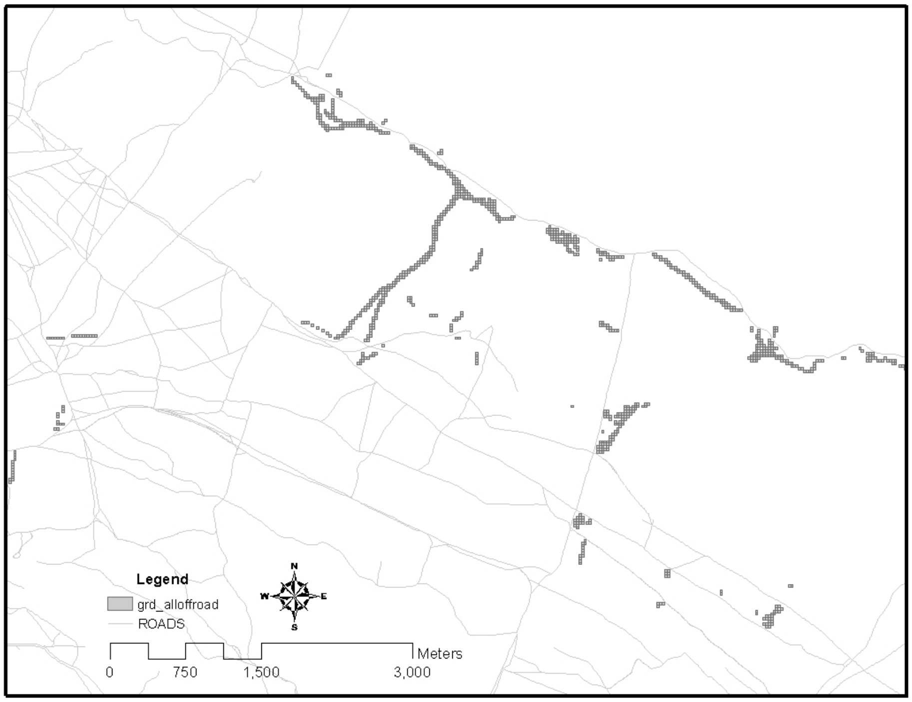


*Figure 5-7 Selected study units meet at least three criteria in the screen line area*

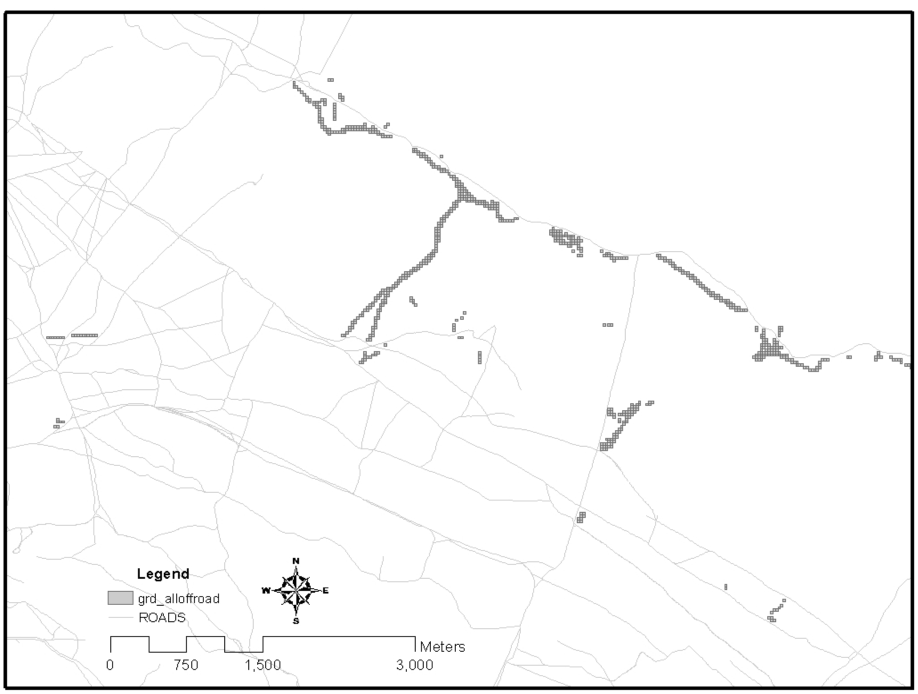


*Figure 5-8 Selected study units meet at least four criteria in the screen line area*

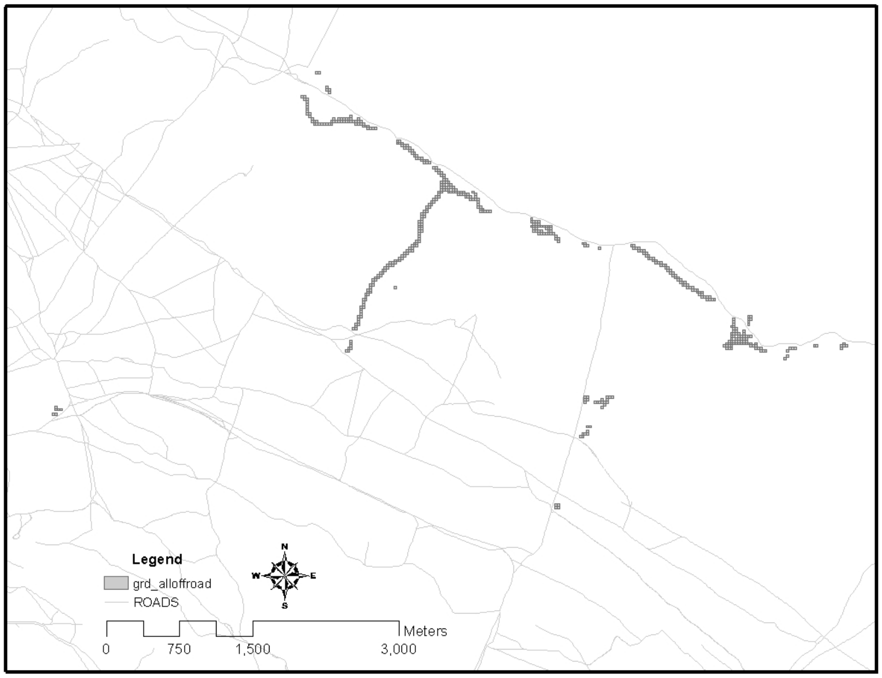


*Figure 5-9 Selected study units meet five criteria in the screen line area*

attribute "criteria levels". The output raster file has the same cell size as the study unit. The resulted raster file is shown in Figure 5-10: each cell contains the criteria level inherited from the specific study unit.

The raster file resulted was converted back to a polygon feature file based on the cell value. After this operation, the potential grids that meet the same criteria level and spatially contiguous were grouped to form a polygon. The resulted shape file is shown in Figure 5-11; details for the selected areas (labeled as "1" and "2" in Figure 5-11) are shown in Figure 5-12.

As can be seen from Figure 5-12, there exist small discrete grids around the two selected large polygons. Only the clusters with relatively large area need to be selected for further investigation for potential roads. Instead of visually selecting the relatively

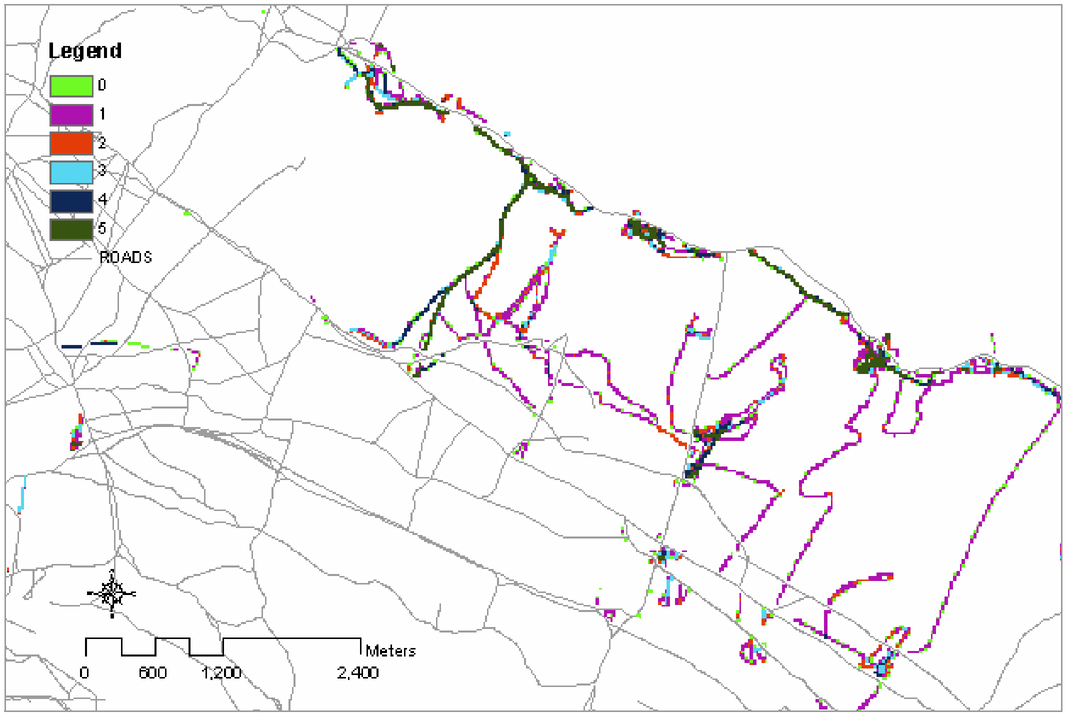


*Figure 5-10 Raster file identifying the criteria levels in the screen line area*

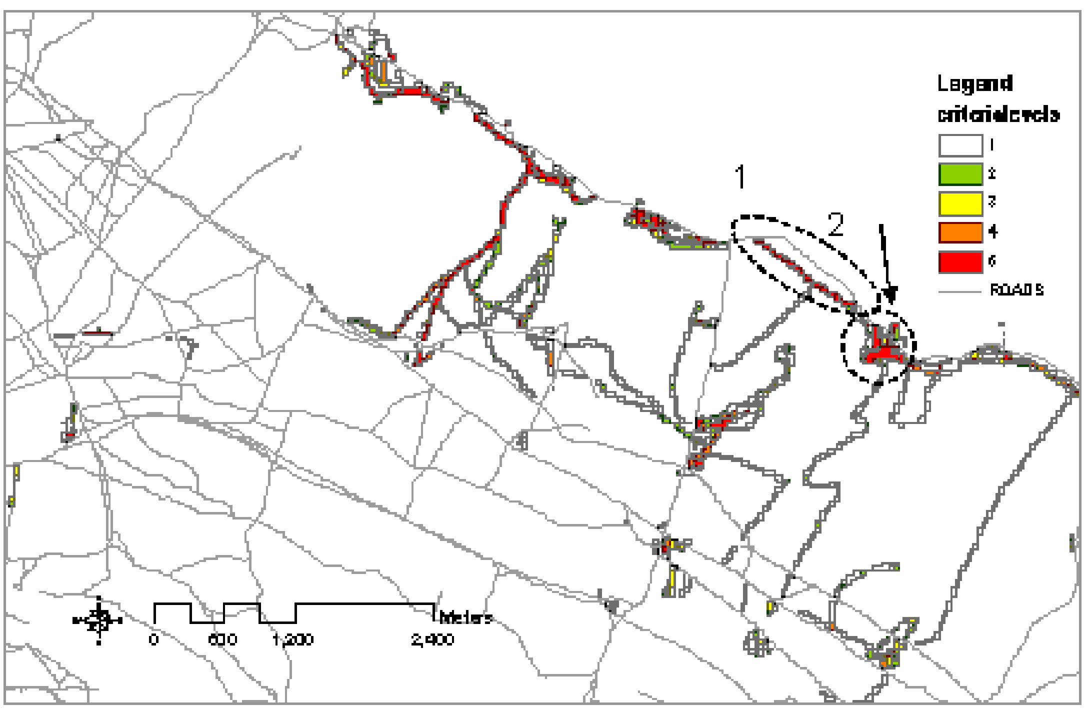


*Figure 5-11 Grouped potential road grids in the screen line area*

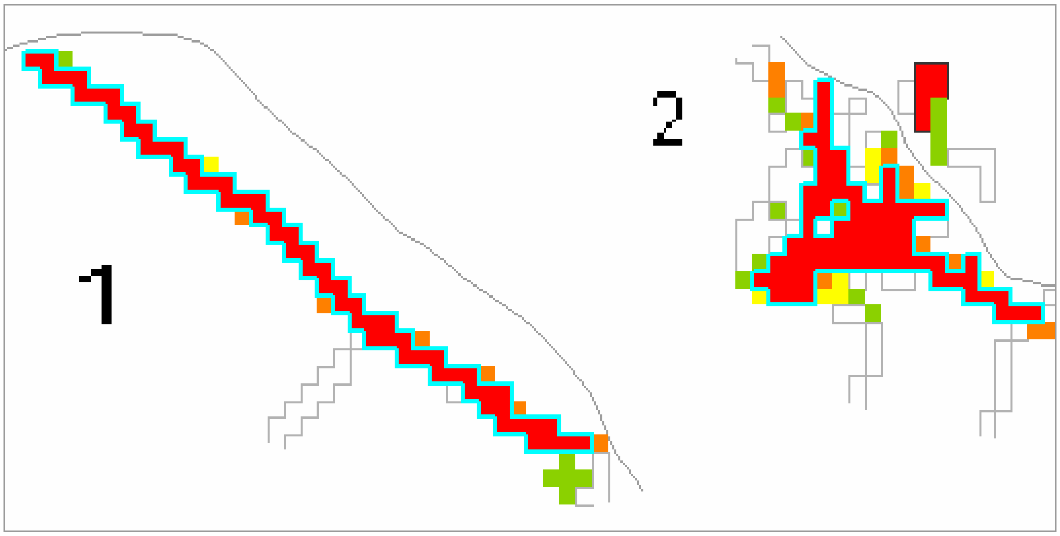


*Figure 5-12 Two clusters selected from Figure 5-11*

large clusters one by one, the selection can also be achieved by calculating the area for each polygon and identifying the polygons with large areas. Considering that discontinuous polygons exist in some locations, which may affect the selection, a function "Eliminate" in ArcGIS 9.0 can be used to merge small polygons with neighboring polygons with the largest shared border, or with the largest area. Figure 5-13 shows an example in the screen line area: improvement of the continuity can be observed after the "Eliminate" operation. This eliminate function may be applied multiple times depending on if the result is satisfied or not.

Figure 5-14 shows the polygons (potential road clusters), resulted from the clustering procedures. Those polygons with higher criteria levels are expected to have higher possibilities to be potential roads. The polygons with different criteria levels need to be investigated further to be identified as potential roads. Comparing the shapes of the potential road clusters shown in Figure 5-14, high potential road possibilities may also be

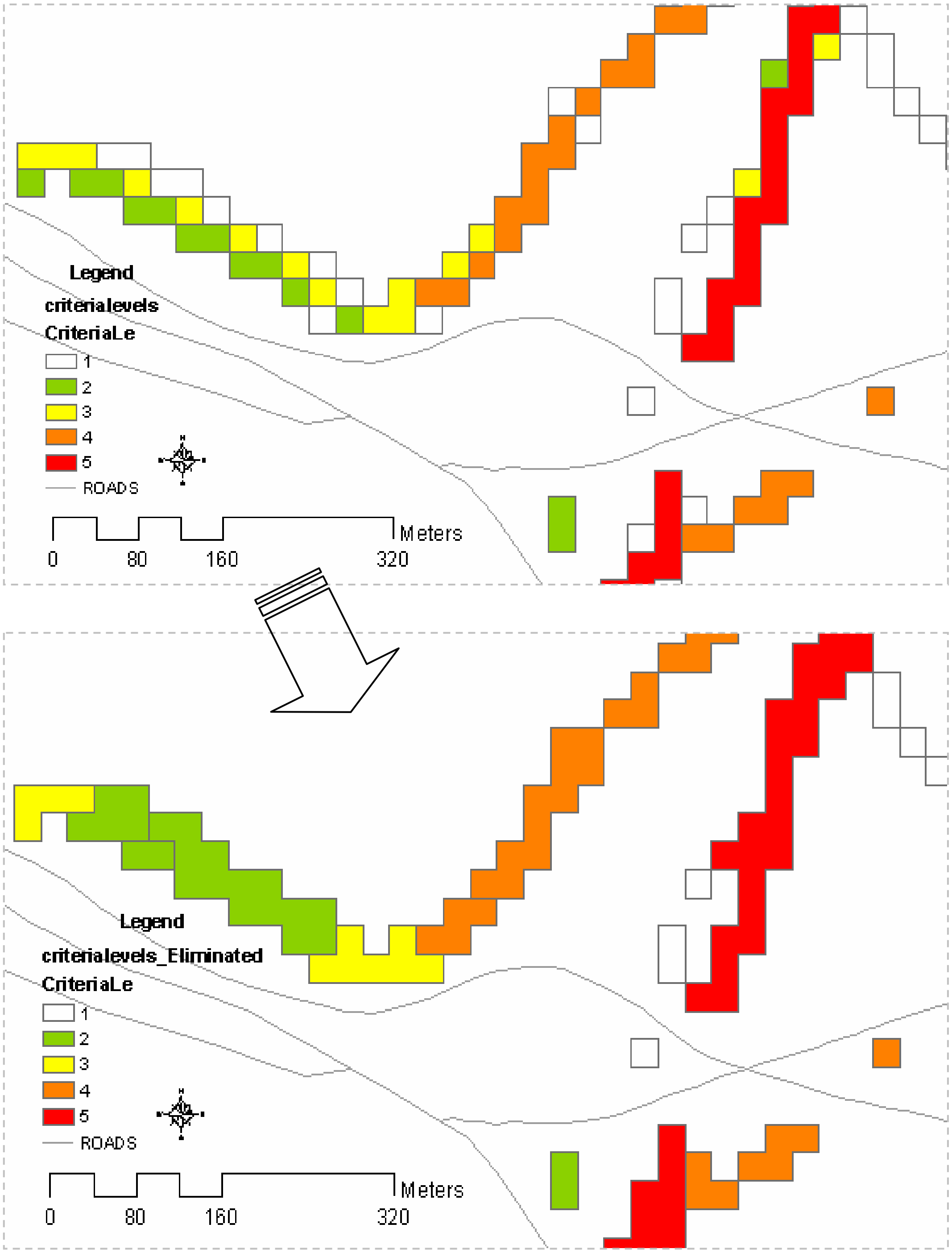


*Figure 5-13 Using "Eliminate" function to improve the continuity*

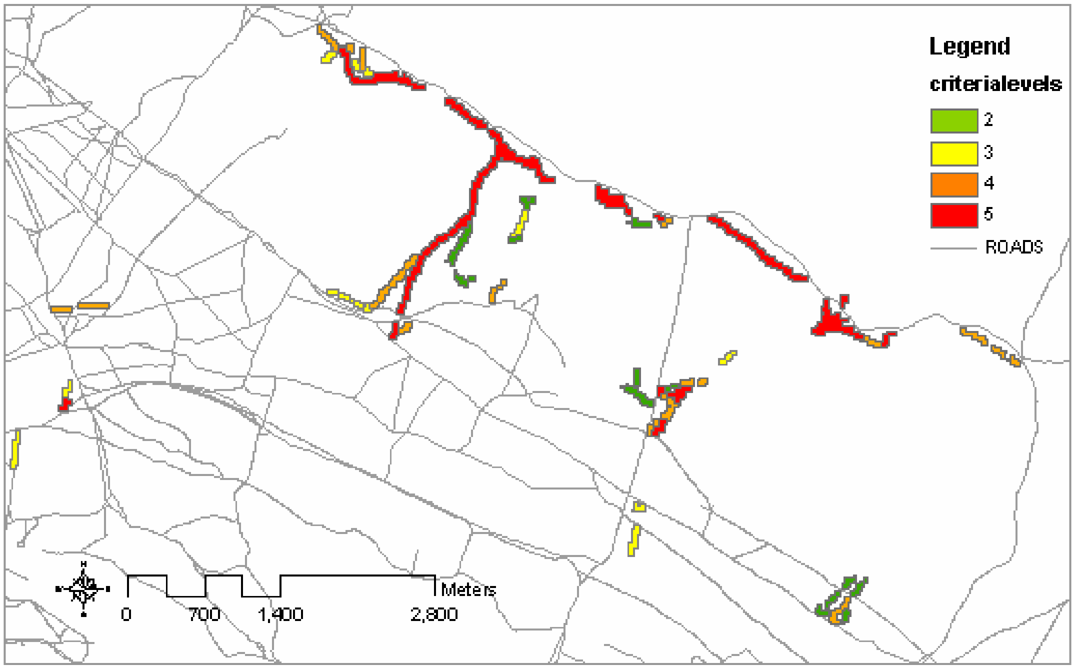


*Figure 5-14 Selected clusters in screen line area*

assigned to those with linear shape, which is expected to be a natural character of a road. Strategy is needed to identify the clusters with linear shapes. An analysis on the elongation of the potential road clusters was conducted to select the clusters with linear shapes.

Elongation was defined as the length-width ratio of the grouped potential road grids; it was used to exclude those groups without linear shapes. The elongation can be estimated based on the area and the perimeter of the polygon, which can be calculated within ArcGIS 9.0.

Assuming a polygon has even length and width (i.e. the polygon shape is relatively regular), denoting the length as $l$, and width as $w$, the area as $A$, the perimeter as $P$, the elongation (the polygon length-width ratio, denoted as $EL$) of the polygon can be roughly calculated as:

$$EL = \frac{l}{w} = \frac{P + \sqrt{P^2 - 16A}}{P - \sqrt{P^2 - 16A}} \tag{1}$$

Equation (1) was derived based on the following simple relations:

$$\begin{cases} l + w = \dfrac{P}{2} \\ \\ l * w = A \end{cases} \tag{2}$$

Based on Equation (1), the elongations calculated for the potential road clusters in the screen line area are shown in Figure 5-15 and Table 5-3. The clusters with relatively larger elongation values were selected as: cluster 6, 7, 9, 10, and 11. As can be seen from Figure 5-15, the cluster 6 should not be identified based on its shape. In this case the assumption that the length and width of the polygon are even is violated, then the elongation estimation can be misleading. Visual observation for identifying potential roads with linear shape may be better if the number of clusters is limited.

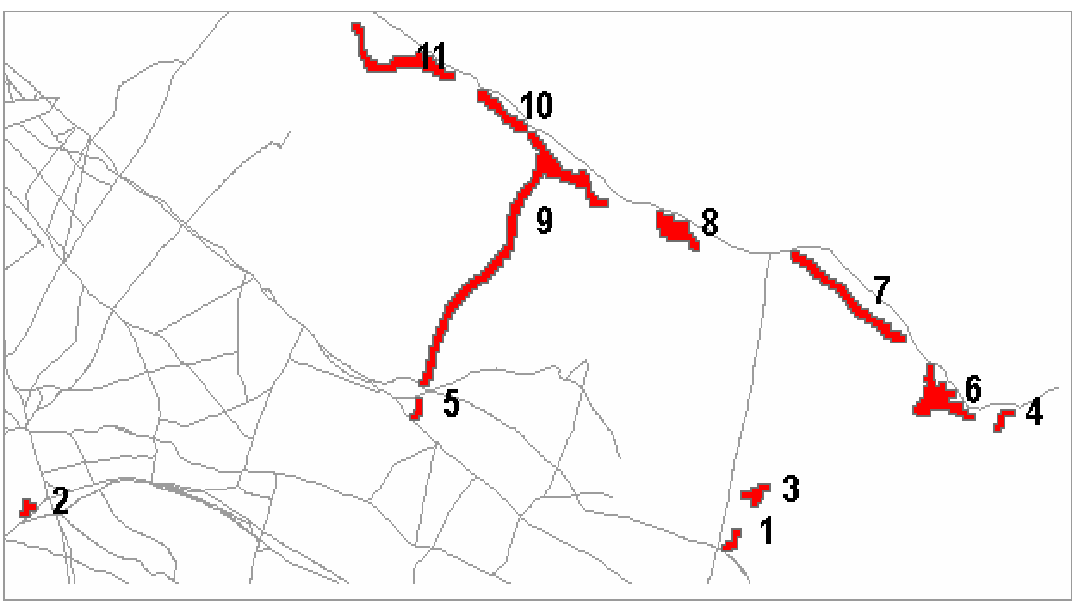


*Figure 5-15 Labeled potential road clusters met five criteria in screen line area*

*Table 5-3 Elongation analysis for the potential road clusters in the screen line area*

| Cluster_ID | Area ($m^2$) | Perimeter (m) | Elongation |
|---|---|---|---|
| 1 | 12500 | 600 | 5.00 |
| 2 | 10000 | 500 | 4.00 |
| 3 | 18125 | 750 | 5.58 |
| 4 | 11250 | 600 | 5.83 |
| 5 | 10000 | 500 | 4.00 |
| 6* | 67500 | 2000 | 12.74 |
| 7* | 74375 | 3000 | 28.22 |
| 8 | 42500 | 1200 | 6.31 |
| 9* | 193750 | 7000 | 61.21 |
| 10* | 31875 | 1300 | 11.17 |
| 11* | 68125 | 2600 | 22.76 |

* Clusters with relatively higher elongation values

## *5.4 Identify Potential Road Segments*

A total of nine groups of potential road grids were selected as potential roads; details for each identified group of potential road grids are shown in Table 5-4. Figures 5-16, 5-17, and 5-18 show the identified grids: four sets in the screen line area (Figure 5-16), two sets in the zone reconnaissance area (Figure 5-17), and three sets in the area where the area security mission was conducted (Figure 5-18). In order to get a potential road, instead of potential road grids / areas, a line was generated for each set of selected potential road grids by connecting the contiguous averaged GPS positions. The averaged GPS position was calculated by averaging all the GPS points that fall inside the selected potential road grids. Figure 5-19 shows the identified potential roads in the screen line area; potential roads in other mission areas can be found in Appendix II.

*Table 5-4 Details for the identified potential roads met five criteria*

| Mission | Potential road | # of vehicles passed | Average TR (m) | Average velocity (m/s) | SD_COG (deg) | Elongation |
|---|---|---|---|---|---|---|
| Screen line | SL_PR_1 | 4 | 136 | 5.6 | 86 | 61.2 |
| | SL_PR_2 | 4 | 92 | 3.2 | 98 | 22.8 |
| | SL_PR_3 | 4 | 105 | 3.7 | 96 | 11.2 |
| | SL_PR_4 | 5 | 138 | 8.3 | 92 | 28.2 |
| Area security | AS_PR_1 | 3 | 123 | 5.1 | 87 | 14.8 |
| | AS_PR_2 | 6 | 108 | 5.2 | 92 | 6.7 |
| | AS_PR_3 | 6 | 121 | 6.5 | 115 | 7.7 |
| Zone reconnaissance | ZR_PR_1 | 4 | 130 | 7.2 | 96 | 15.6 |
| | ZR_PR_2 | 3 | 89 | 2.1 | 90 | 9.3 |

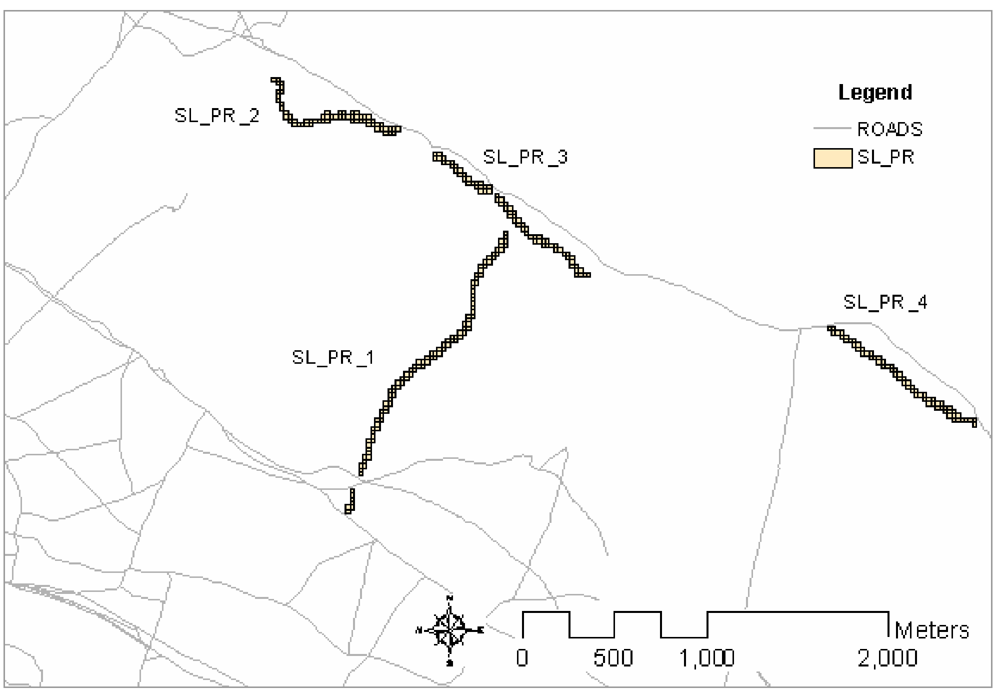


*Figure 5-16 Identified potential road areas in the screen line area*

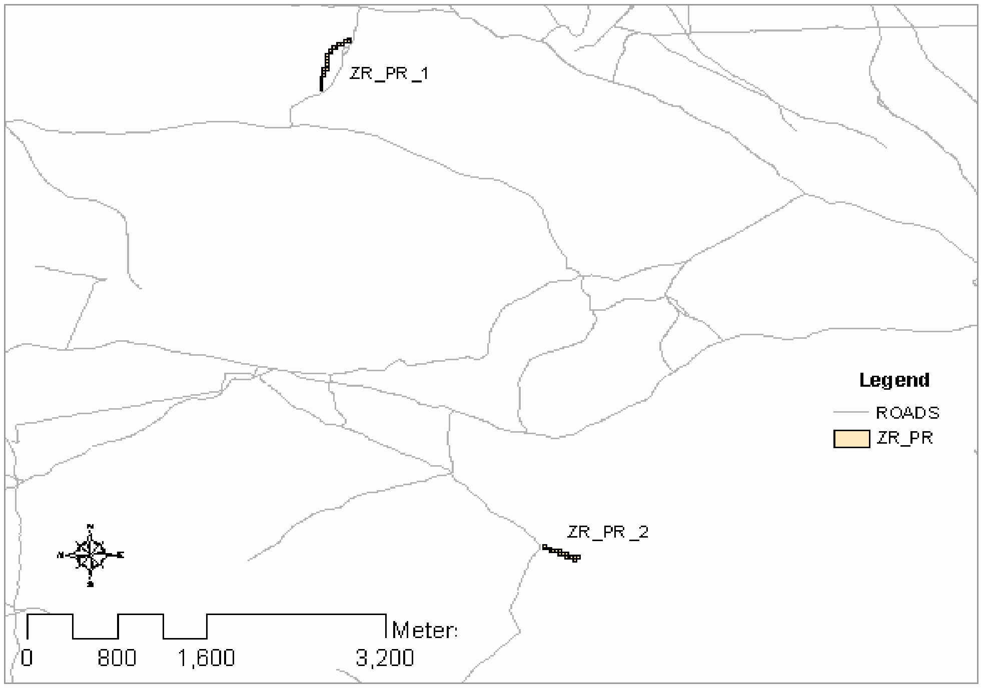


*Figure 5-17 Identified potential road areas in the zone reconnaissance*


*Figure 5-18 Identified potential road areas in the area security*

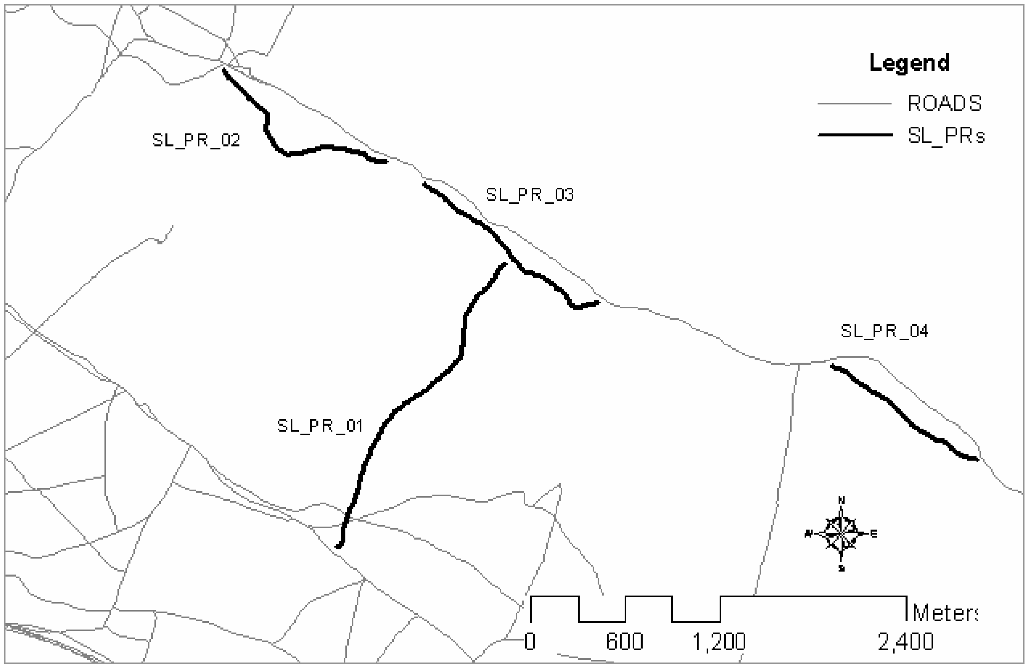


*Figure 5-19 Identified potential roads in the screen line area*

# CHAPTER 6 - MODEL EVALUATION

A multicriteria method was developed in Chapter 5 to identify potential roads based on vehicle movement patterns and predicted nine segments over the training center met all criteria as potential roads. This chapter serving as model evaluation evaluated the method by comparing site observed results to the predictions resulted from the multicriteria method and analyzed the sensitivity of the prediction related to the size of the study units. A brief explanation on uncertainty analysis and sensitivity analysis is also provided in this chapter.

## *6.1 Model Evaluation*

As stated by Qureshi *et al.* (1999), a model evaluation involved three components: 1) verification -- ensuring that the model properly implements its specifications (i.e. the model is correctly built from a formal point of view); 2) validation -- ensuring that the structure of the model is correctly built from a conceptual and operational point of view (if it is appropriate for its intended purpose), according to a specific methodology; and 3) sensitivity analysis -- examining the stability of the model (or its predictive ability), checking the extent of variation in the output when parameters are systematically varied over a given range of interest, either individually or combined. The components 1) and 2) can be included in the procedure of uncertainty analysis.

### 6.1.1 Uncertainty analysis

The concept of uncertainty is used to represent lack of confidence that a particular mathematical model is a "correct" formulation of the assessment problem (Hammonds et al., 1994). Model uncertainty exists if there is possibility that an incorrect result could be obtained even if exact values are available for all of the model parameters. Input data used in the execution of any model is usually subject to diverse sources of uncertainty (measurement errors in data acquisition, format conversions, lack of information, etc.). A variety of uncertainties in model parameters, structures, assumptions and specifications affect the model output. Uncertainty analysis allows assessing the uncertainty associated with the model output resulting from the input data errors and uncertainties in the model itself.

A straight-forward approach for assessing model uncertainty is through model validation, comparing the model predictions to actual measured data. This approach is applicable if the measured outputs (field data) are available.

Another general approach to quantitative analysis of uncertainty is to use either analytical or numerical techniques to propagate the uncertainty in the components of equations into an assessment of uncertainty in the overall result. Analytical approach based on error propagation is to find the covariance matrix for output given the covariance matrix for the inputs (Keren et al., 2002); it works for those models having explicit formulas to describe relationship between model inputs and outputs. The numerical methods for uncertainty analysis are needed when the relationships between the model inputs and outputs are complicated and may not be characterized by explicit

formulas, for example, a model developed by using artificial neural networks techniques. As a commonly used approach for numerical uncertainty analysis, Monte Carlo simulation method demonstrated its success in some applications (Crosetto et al., 2000; Crosetto and Tarantola, 2001). More details for applying the Monte Carlo method in uncertainty analysis can be found in Efron and Gong (1983), Madras (2002), Metropolis and Ulam (1949), and Rasmussen (2003).

The selection of uncertainty analysis methods depends on the model itself. Many studies have been conducted addressing the uncertainty analysis for the GIS-based spatial models (Crosetto et al*.,* 2000; Foody, 2003; Hwang et al., 1998). In this potential road identification method, different criteria were developed based on the analysis of GPS vehicle tracking data and evaluated by using a sequence of GIS operations. Uncertainties exist in the input data, the methods for analyzing the GPS data, the procedures for developing and evaluating the criteria, the predicted potential road segments, and the location of the potential roads. Due to the specialties of this potential road identification method, Monte Carlo simulation method for the uncertainty analysis may not be practical and was not applied in this study.

Identification and quantification of the uncertainties associated with the model inputs and the modeling method are so difficult that analytical method can not be applied in this case. It is difficult to quantify the uncertainties associated with the input data used to identify the potential roads. The inputs of this potential road identification model include two major data resources: the GIS data from Yakima Training Center and the GPS vehicle tracking data. The quality of GIS data, as mentioned by Guptill and

Morrison (1995), is determined by lineage, positional and attributes accuracy, completeness, consistency, semantic accuracy, and temporal accuracy; too many variables involved to be quantified. The accuracy of GPS vehicle tracking data, as described in Section 4.1, is difficult to be quantified too. The propagation of uncertainties associated with different steps of the modeling process is hard to quantify either. The GIS operations involved in developing and evaluating the multicriteria method include the point operation (the attribute value of an object or at a field location is computed from other attributes relating to the same object or location), neighborhood operations (the attribute is derived from attributes of a window or area surrounding the object or location), and global operations (far-reaching spatial interactions). These operations carried and propagated the uncertainties from inputs to the outputs in different levels that are difficult to quantify.

The method by comparing the field measurements to the prediction seems a better way to estimate the accuracy of the potential road identification method. The multicriteria method was evaluated by comparing the predicted potential roads to the actual observed results on the specific locations.

### 6.1.2 Sensitivity analysis

As part of the model evaluation, sensitivity analysis studies how the variations in the model output can be apportioned quantitatively or qualitatively, to different sources of variation (i.e. how the given model depends upon the information fed into it). Delgado and Sendra (2004) provided a review on sensitivity analysis on spatial decision making. Delgado and Sendra (2004) examined twenty-eight studies related to land planning

processes, environmental management, and location of noxious facilities to investigate how sensitivity analysis has been conducted to the models based on GIS and multicriteria evaluation techniques. They found that the analysis most frequently used is based on the variation of the weights of the factors applied in the process to test whether it significantly modifies the results obtained. More studies on the sensitivity analysis on spatial model can be found in Abdel-Kader *et al.* (1998), Crosetto *et al.* (2000), Crosetto and Tarantola (2001), and Fleming *et al.* (2004).

The multicriteria method for identifying potential roads contains five criteria and evaluates the number of criteria met by an individual study unit to determine the study unit is a portion of potential road or not. These criteria, instead of being assigned different weights, act as constraints for selecting the study units to construct potential roads. The sensitivity analysis can be achieved by investigating the possibility of a potential road existence for a certain criteria level met by the visited areas. As the study unit was set to be a 25 by 25 square meter grid, the investigation of the influence of the prediction to the size of the study units is also needed to complete the sensitivity analysis. Different maps containing different sizes study units were created to identify the potential roads by using the same multi-criteria method; the results in the screen line area were compared for sensitivity of the potential road prediction to the size of the study unit.

Oftentimes, uncertainty analysis, sensitivity analysis and error propagation are also considered the same process (Lowry, 1995; Hwang et al., 1998) for model evaluation. By conducting a site visit at selected potential road segments met different criteria levels, the following sections attempt to evaluate the method by answering these questions: 1)

how accurate is the potential predictions; 2) how the observed results related to the criteria levels; 3) how the predicted road locations different from the recorded track and road locations; and 4) how the grid sizes affect the prediction.

## *6.2 Site Visit*

A site visit was conducted on the locations selected based on the results from Chapter 5. As indicated in Chapter 5, a total of nine segments meeting all five criteria over the Yakima Training Center (YTC) were identified as potential roads. In order to investigate the possibility of road existence for the locations meeting less than five criteria, 25 more segments were added for the site visiting. The 34 selected segments include 11 segments meeting five criteria (additional to the nine segments, two small segments in zone reconnaissance (ZR_021 and ZR_05) were also selected for the visit), nine segments meet four criteria, and seven segments that meet both three and two criteria.

### 6.2.1 Site visit locations

The selected locations meeting a variety of different criteria levels are shown in Figures 6-1, 6-2, and 6-3. The selected road segments include 15 segments from screen line area (Figure 6-1), six segments from zone reconnaissance (Figure 6-2), and 11 segments from area security (Figure 6-3). Those areas met more criteria are expected to have higher possibility for road existence. In order to exclude the subjective influence, the selected segments were labeled based on spatial location, instead of criteria levels. The selected road segments were exported from ArcGIS and saved to the format

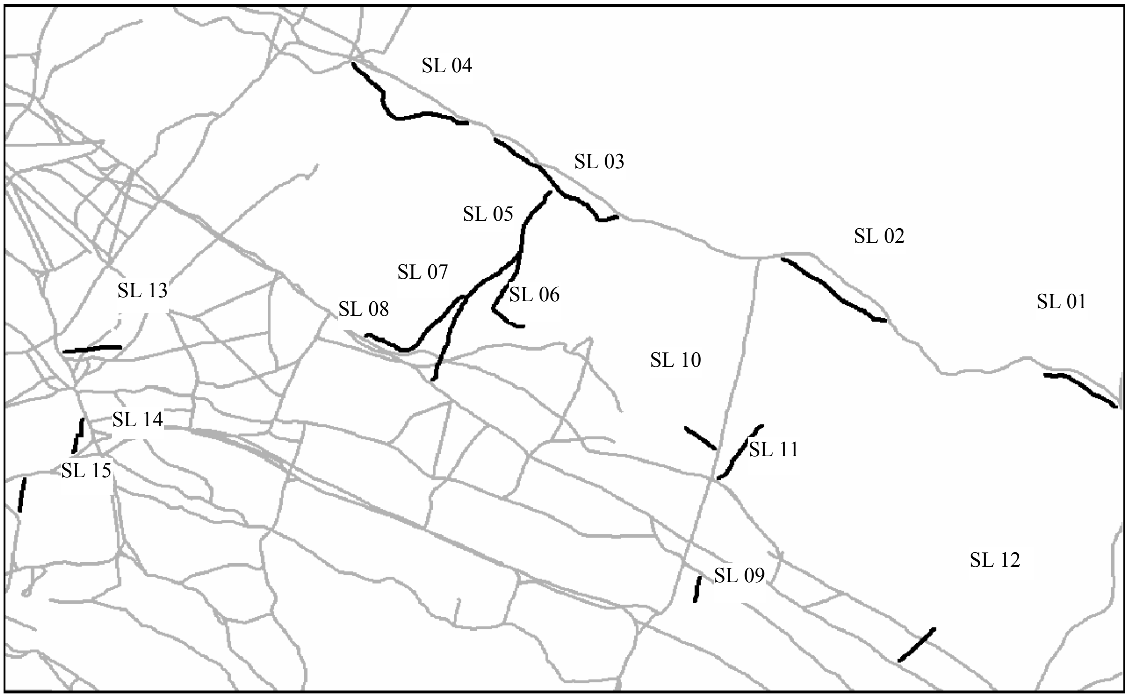


*Figure 6-1 Selected potential road segments at the screen line area*

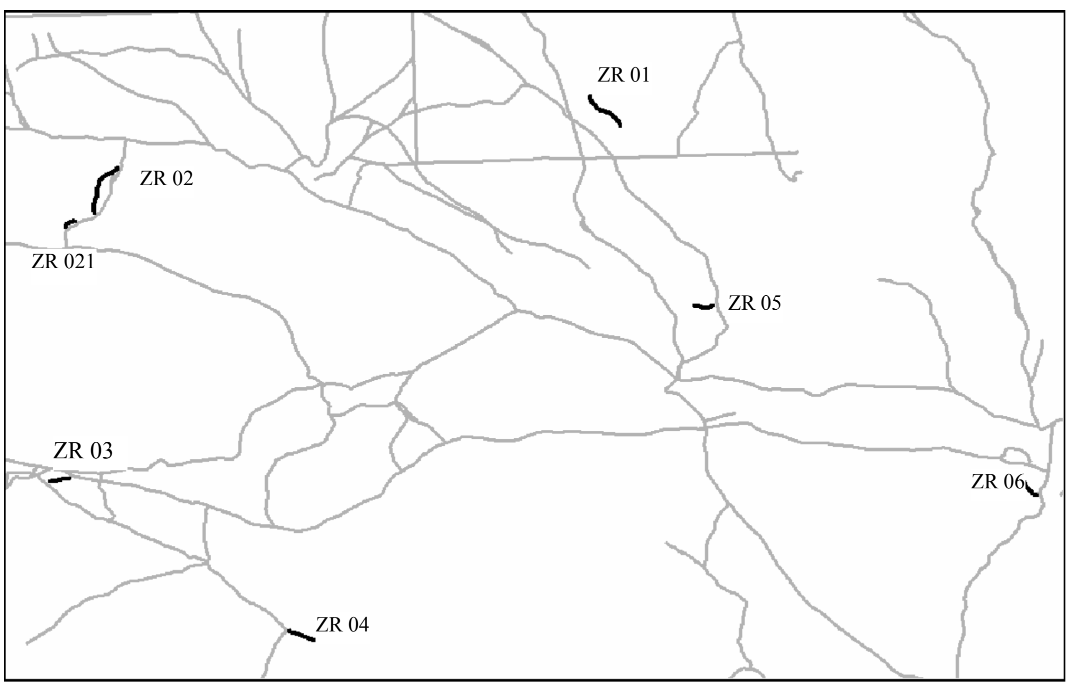


*Figure 6-2 Selected potential road segments in the zone reconnaissance*

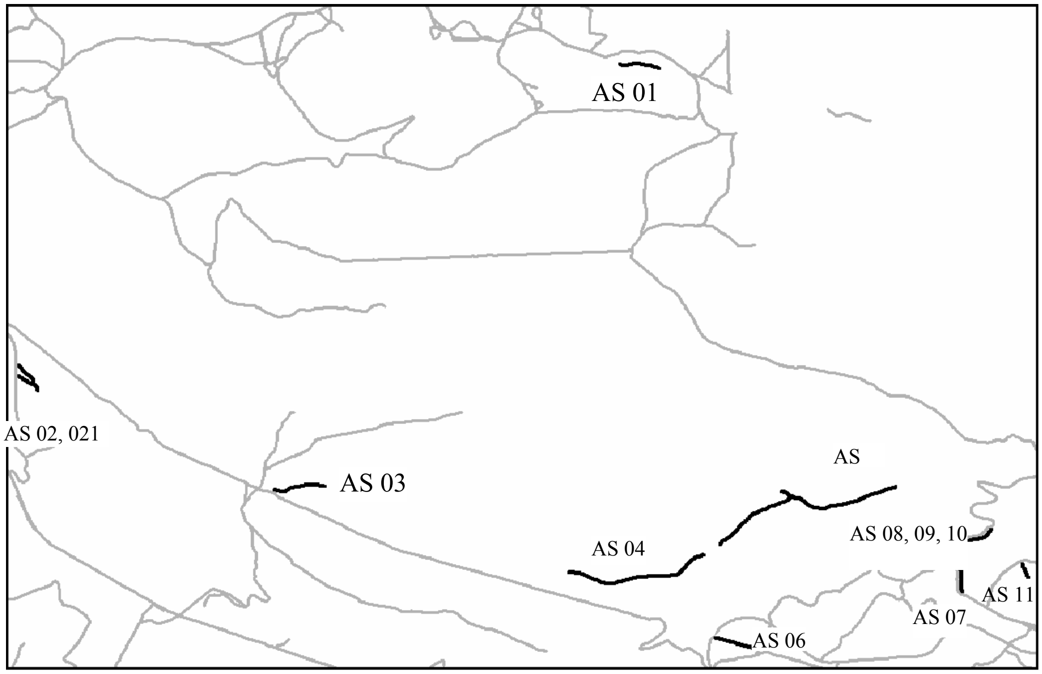


*Figure 6-3 Selected potential road segments in the area security*

compatible with ArcPad in Compaq IPAQ Pocket PC for GPS navigating.

### 6.2.2 Equipment

The site visit was conducted in May 2004, approximately three years after the training exercise. A Trimble Ag 132 GPS receiver (shown in Figure 6-4) with OmniSTAR differential correction was used for locating the selected road segments and recording the track. Notes were taken for the observed results at each visited road segment. Pictures and video were taken to provide additional information to describe the condition of each visited segment. The GPS receiver and its accessories constructed a GPS-based tracking system that allows navigating to the potential roads' locations and record the track of the site visit.

The total travel distance during the two days visiting is approximately 140 miles. The accessed areas during the site visit are shown in Figure 6-5.

*Figure 6-4 GPS receiver used for site visit*

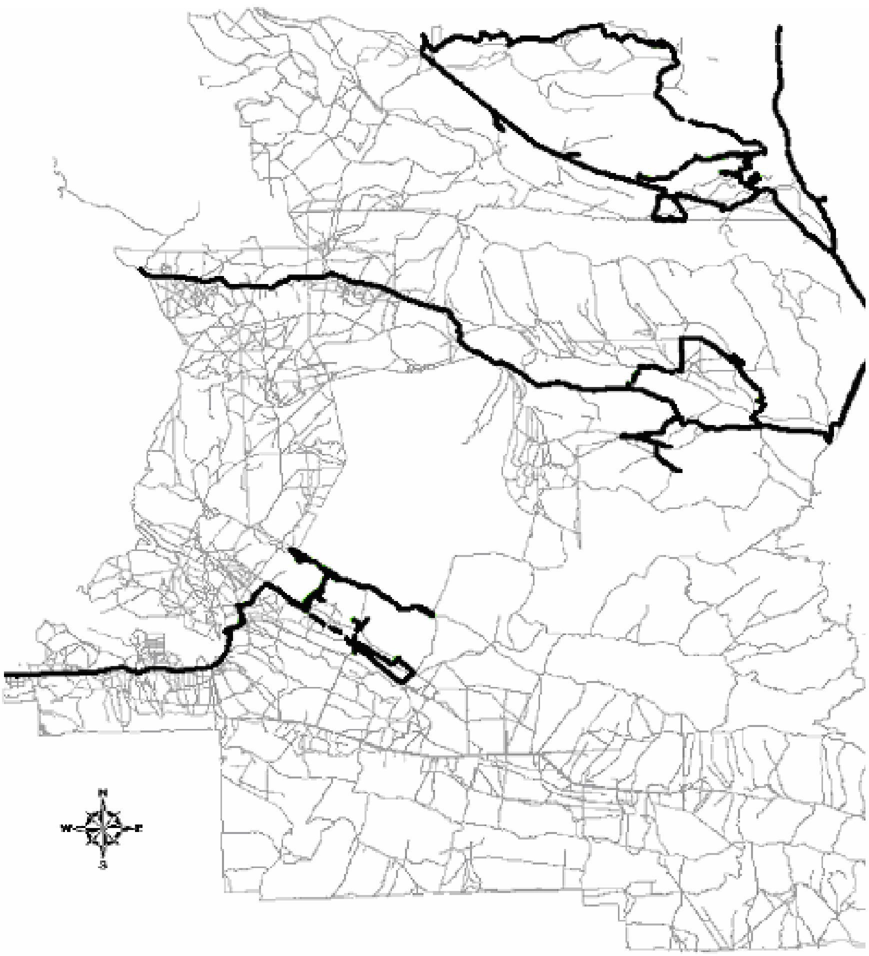

*Figure 6-5 Site visit tack in the YTC in may 2004*

### 6.2.3 Results

The site visit found 17 roads from the 34 visited locations: seven roads in area security, six in screen line, and four in zone reconnaissance mission area. Based on the military class road description, observed results can be classified into Military Class 2, 3, 4, and 5 roads; most of the class 2 and 3 roads were also called rerouted road: a road newly constructed near to an old road to substitute the old road. In this exercise, the vehicles were traveling on the new road that was not yet identified on the GIS road map.

Table 6-1 shows the details of the observed results for the 34 selected segments covered by the site visit. As can be seen from the table, different observations can be found in a same potential road segment. The potential road "ZR 04" was found as the combination of military class 4 and class 5, and "SL 03" was found partially rerouted and military class 5. Remnant vehicle tracks can be observed partially for the visited segments: "AS 01", "AS 021", "SL 10", and "ZR 01", which can be partially identified as military class 5 roads, according to the definition of the military road classes (Table 1-1),. However, the overall observed result for each of these four segments was still considered as no road, since the observed track is a small portion of the segment and it is expected to return to the status like the rest of the segment where vehicle tracks are invisible.

The locations for accessing the 17 observed potential roads and their length are shown in Table 6-2. The observed potential roads at different mission areas are shown respectively in Figure 6-6, Figure 6-7, and Figure 6-8.

*Table 6-1 Site visit results*

| Train Area | Mission | Name | Criteria level | Site Visit Result | Results (Military Road class) |
|---|---|---|---|---|---|
| 2 | Area Security | AS 01 | 4 | No road; MC 5 uphill | 0 |
| | | AS 02 | 3 | No road | 0 |
| | | AS 021 | 3 | MC 5; No road | 0 |
| | | AS 03 | 4 | MC 4 | 4 |
| | | AS 04 | 2 | No road | 0 |
| | | AS 05 | 4 | MC 4 | 4 |
| | | AS 06 | 5 | MC 4 | 4 |
| | | AS 07 | 5 | MC 2; Rerouted | 2 |
| | | AS 08 | 4 | MC 4; MC4.5 | 4 |
| | | AS 09 | 5 | MC 2; Rerouted | 2 |
| | | AS 10 | 4 | MC 2; Rerouted | 2 |
| | | AS 11 | 2 | No road | 0 |
| 12 | Screen Line | SL 01 | 4 | No road | 0 |
| | | SL 02 | 5 | Rerouted | 3 |
| | | SL 03 | 5 | Rerouted; MC 5; No road | 3 |
| | | SL 04 | 5 | MC4 | 4 |
| | | SL 05 | 5 | MC 4 | 4 |
| | | SL 06 | 2 | No road | 0 |
| | | SL 07 | 4 | No road | 0 |
| | | SL 08 | 3 | No road | 0 |
| | | SL 09 | 3 | No road | 0 |
| | | SL 10 | 2 | MC 5; no road | 0 |
| | | SL 11 | 4 | No road | 0 |
| | | SL 12 | 2 | No road | 0 |
| | | SL 13 | 4 | MC 3 | 3 |
| | | SL 14 | 3 | No road | 0 |
| | | SL 15 | 2 | MC 3 | 3 |
| 4 & 5 | Zone Reconnaissance | ZR 01 | 3 | MC 5; No road | 0 |
| | | ZR 02 | 5 | MC 3; Rerouted | 3 |
| | | ZR 021 | 5 | MC 3; Rerouted | 3 |
| | | ZR 03 | 2 | No road | 0 |
| | | ZR 04 | 5 | MC 4; MC 5 | 4 |
| | | ZR 05 | 5 | No road | 0 |
| | | ZR 06 | 3 | MC 4 | 4 |

*Table 6-2 Locations for the identified potential roads in the YTC*

| Train Area | Potential Road Name | Length (m) | Entry Point Coordinates | | Exit Point Coordinates | |
|---|---|---|---|---|---|---|
| | | | E | N | E | N |
| 2 | AS 03* | 628 | 719331 | 5196646 | 719847 | 5196736 |
| | AS 05* | 2670 | 726378 | 5196677 | 725220 | 5196533 |
| | AS 06* | 488 | 724935 | 5194741 | 724439 | 5194881 |
| | AS 07 | 294 | 727340 | 5195442 | 727302 | 5195739 |
| | AS 08* | 700 | 727035 | 5195813 | 726356 | 5195939 |
| | AS 09 | 212 | 727148 | 5195848 | 727292 | 5196034 |
| | AS 10 | 318 | 727405 | 5196073 | 727693 | 5196219 |
| 12 | SL 02 | 1046 | 710433 | 5176385 | 711378 | 5175803 |
| | SL 03 | 1315 | 708444 | 5177209 | 708071 | 5177465 |
| | SL 04* | 1270 | 707907 | 5177573 | 706870 | 5178146 |
| | SL 05* | 2063 | 707569 | 5175286 | 708546 | 5176973 |
| | SL 13* | 472 | 704977 | 5175573 | 704467 | 5175522 |
| | SL 15* | 293 | 704121 | 5174098 | 704165 | 5174417 |
| 4 & 5 | ZR 02 | 547 | 722404 | 5186060 | 722633 | 5186569 |
| | ZR 021 | 120 | 722136 | 5185908 | 722235 | 5185988 |
| | ZR 04* | 308 | 724209 | 5181965 | 724421 | 5181869 |
| | ZR 06* | 264 | 731320 | 5183255 | 731150 | 5183463 |

Note: The potential roads with * are newly formed roads.

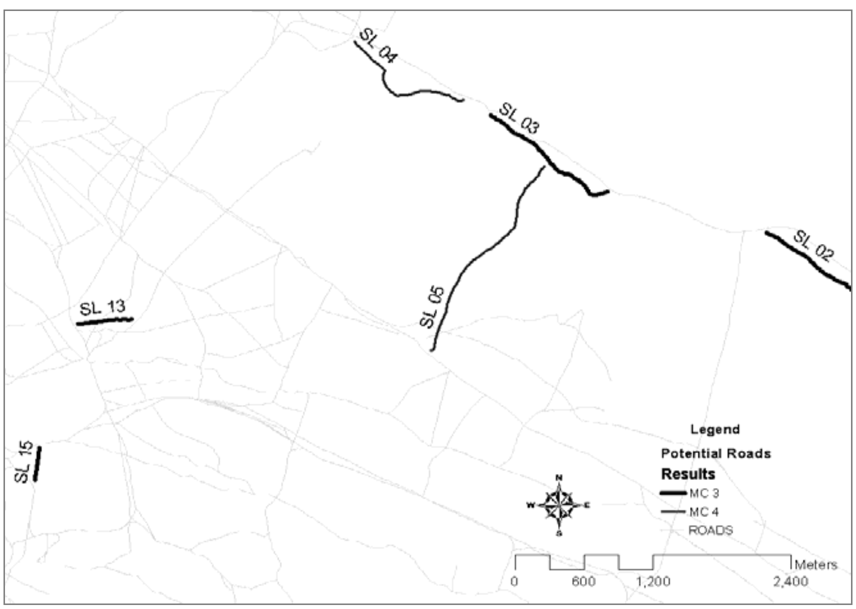


*Figure 6-6 Potential roads observed in the screen line area*

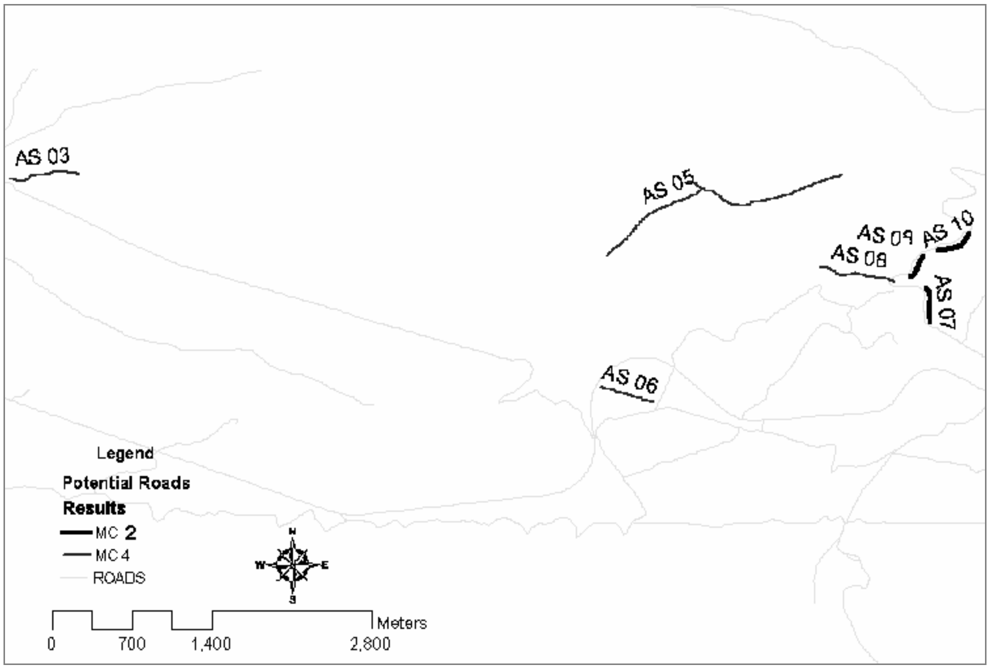


*Figure 6-7 Potential roads observed in the area security*

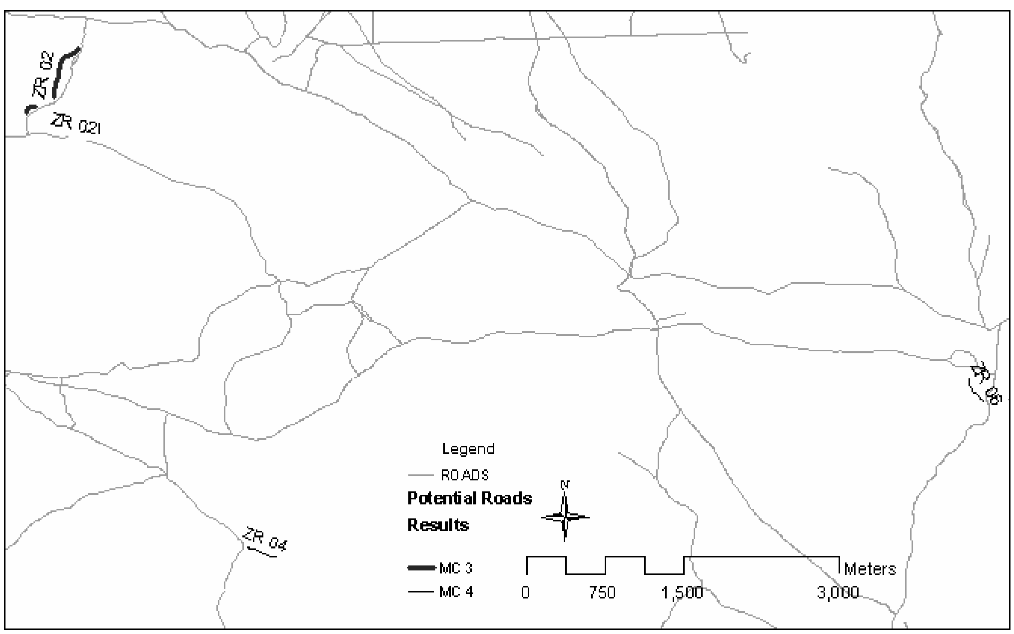


*Figure 6-8 Potential roads observed in the zone reconnaissance area*

A correlation coefficient analysis on the GPS data and site observed results for the visited areas has been conducted. The results are shown in Table 6-3. A hypothesis of no correlation test on the factors and potential road observed results has also been conducted (a 95% confidence interval has been applied in the testing). The resulted p-value matrix is shown in Table 6-4.

As can be seen from Table 6-3, the five factors (Points, SD_COG, V_num, Dif_day and Troops) utilized in the multicriteria method are correlated to the existence of the potential road (PR) at different levels. A location used by vehicles in different days was found highly correlated to the existence of a potential road (0.52). Besides the five factors, the velocity parameters, average velocity (Ave_V) and standard deviation of the velocities (SD_V), are found related to the existence of a potential road at a certain location. The correlation coefficient between SD_V and PR is 0.5.

Additional factors that have been included in this analysis include the Average COG (Ave-COG), average turning radius (Ave_TR), and standard deviation of the turning raduis (SD_TR). These additional factors were found not highly correlated to the existence of the potential road (-0.12, 0.2 and -0.18 for Ave_COG, Ave_TR, and SD_TR respectively). However, based on the p-values shown in Table 6-4, there is no evidence showing these factors are not correlated to the existence of a potential road.

This analysis validated the multicriteria method by showing acceptable correlation coefficients between the predictors and the prediction. It also suggested a potential approach for improving the method: considering the velocity factors (Ave_V and SD_V).

*Table 6-3 Correlation coefficients between the PR observed results and the factors*

| | Points | Ave_COG | SD_COG | Ave_TR | SD_TR | Ave_V | SD_V | Troops | V_num | Dif_day | PR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Points** | 1 | | | | | | | | | | |
| **Ave_COG** | 0.04 | 1 | | | | | | | | | |
| **SD_COG** | 0.43 | 0.02 | 1 | | | | | | | | |
| **Ave_TR** | -0.19 | -0.11 | 0.01 | 1 | | | | | | | |
| **SD_TR** | 0.28 | 0.08 | 0.07 | -0.77 | 1 | | | | | | |
| **Ave_V** | -0.07 | -0.11 | 0.15 | 0.61 | -0.67 | 1 | | | | | |
| **SD_V** | 0.37 | -0.06 | 0.48 | 0.21 | -0.05 | 0.43 | 1 | | | | |
| **Troops** | 0.29 | -0.17 | 0.33 | 0.25 | -0.2 | 0.5 | 0.55 | 1 | | | |
| **V_num** | 0.5 | -0.16 | 0.43 | 0.23 | -0.13 | 0.43 | 0.65 | 0.77 | 1 | | |
| **Dif_day** | 0.31 | -0.12 | 0.55 | 0.19 | -0.11 | 0.36 | 0.52 | 0.61 | 0.56 | 1 | |
| **PR** | 0.31 | -0.12 | 0.49 | 0.2 | -0.18 | 0.37 | 0.5 | 0.42 | 0.4 | 0.52 | 1 |

*Table 6-4 Pvalues between the PR observed results and the factors*

| | Points | Ave_COG | SD_COG | Ave_TR | SD_TR | Ave_V | SD_V | Troops | V_num | Dif_day | PR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Points** | 1 | | | | | | | | | | |
| **Ave_COG** | 0.203 | 1 | | | | | | | | | |
| **SD_COG** | 0 | 0.435 | 1 | | | | | | | | |
| **Ave_TR** | 0 | 0 | 0.77 | 1 | | | | | | | |
| **SD_TR** | 0 | 0.006 | 0.016 | 0 | 1 | | | | | | |
| **Ave_V** | 0.028 | 0 | 0 | 0 | 0 | 1 | | | | | |
| **SD_V** | 0 | 0.063 | 0 | 0 | 0.093 | 0 | 1 | | | | |
| **Troops** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | | | |
| **V_num** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | | |
| **Dif_day** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | |
| **PR** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

### 6.2.4 Different observed road conditions

This section presents some pictures taken during the visit to provide visual descriptions for the conditions of different military class roads. The site visit found three military class 2 roads in area security mission area: "AS 07","AS 09", and "AS 10"; the observed road condition is shown in Figure 6-9. "AS 07", "AS 09", and "AS 10" are the different sections of a rerouted road.

A total of six military class 3 roads were found during the visit including four segments from screen line area: "SL 02", "SL 03", "SL 13", and "SL 15"; and two segments from zone reconnaissance: "ZR 02" and "ZR 021". "ZR 02" and "ZR 021" are also the two different sections of one rerouted road. A typical road condition for military class 3 road is shown in Figure 6-10. The observed result for "SL 03" is shown in Figure 6-11, which also shows the typical conditions for rerouted road: a new road was well constructed to substitute the old one. The observed road condition for "SL 15" is also shown in Figure 6-12: a new road that was included in the established road construction and maintenance programs but has not been mapped.

Eight observed potential roads were classified as military class 4 roads: four roads from area security: "AS 03", "AS 05", "AS 06" and "AS 08"; two roads from zone reconnaissance: "ZR 04" and "ZR 06" ; and the rest two from screen line: "SL 04" and "SL 05". Figure 6-13 shows an example for the condition of military class 4 road. In some locations, the vegetation change resulted from the vehicular off-road traffic can be observed (Figure 6-14). More observations for the visited potential roads can be found in Appendix III. Based on the different conditions, land managers can make different

*Figure 6-9 Observed road condition for military class 2 road: from AS_10*

*Figure 6-10 Observed road condition for military class 3 road: from SL_13*


*Figure 6-11 Observed condition on a rerouted military class 3 road: from SL_03*

*Figure 6-12 Observed condition on a newly constructed road: from SL_15*

*Figure 6-13 Observed road condition for military class 4 road: from AS_03*

*Figure 6-14 Observed vegetation change inside track: from AS_05*

strategies to either help them return to their natural status or to have them included in the road maintenance programs.

### *6.3 Criteria Level vs. Road Existence*

A sensitivity evaluation on the criteria was conducted by comparing the criteria levels met by a visited road segment to its site visit result. Figure 6-15 and Table 6-5 show the comparison of the selected road segments that met different criteria levels and their site visit results. An analysis result on the possibilities for road existence corresponding to different criteria levels is shown in Figure 6-16. As can be seen from Figure 6-16, locations that met higher criteria levels have higher possibilities to be roads. The comparison also shows that those locations meeting criteria level four have a 55% probability to find roads; and within those locations that meet only criteria level two or three, there is a 28.6% probability for the existence of roads.

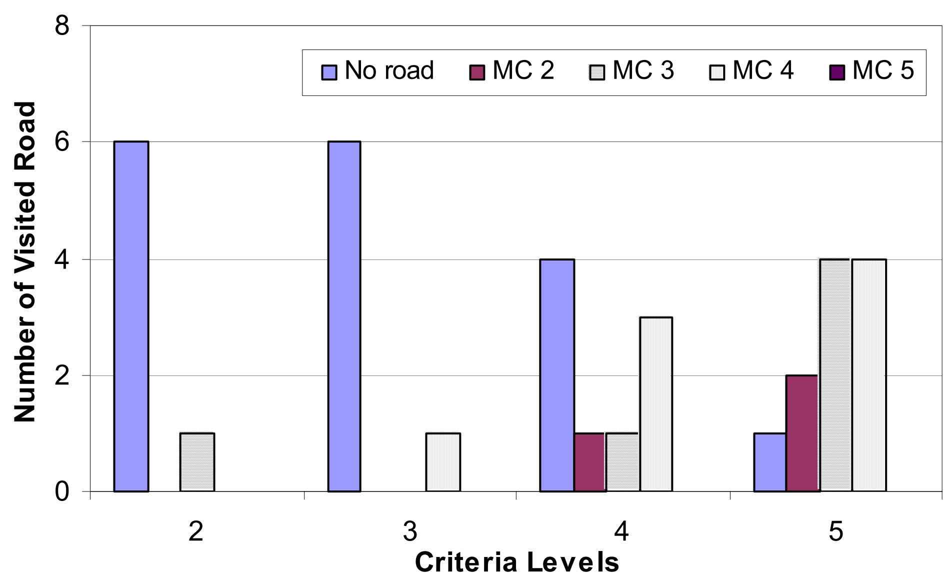


*Figure 6-15 Site visit results vs. criteria levels*

*Table 6-5 Site visit results vs. criteria levels*

| Criteria Level | Number of selected segments | No road | Number of roads observed | | | | | Percentage for road existence (%) |
|---|---|---|---|---|---|---|---|---|
| | | | MC 2 | MC 3 | MC 4 | MC 5 | Sub Total | |
| 2 | 7 | 6 | 0 | 1 | 0 | 0 | 1 | 14.3% |
| 3 | 7 | 6 | 0 | 0 | 1 | 0 | 1 | 14.3% |
| 4 | 9 | 4 | 1 | 1 | 3 | 0 | 5 | 55.6% |
| 5 | 11 | 1 | 2 | 4 | 4 | 0 | 10 | 90.9% |
| Sub Total | 34 | 17 | 3 | 6 | 8 | 0 | 17 | 50.0% |

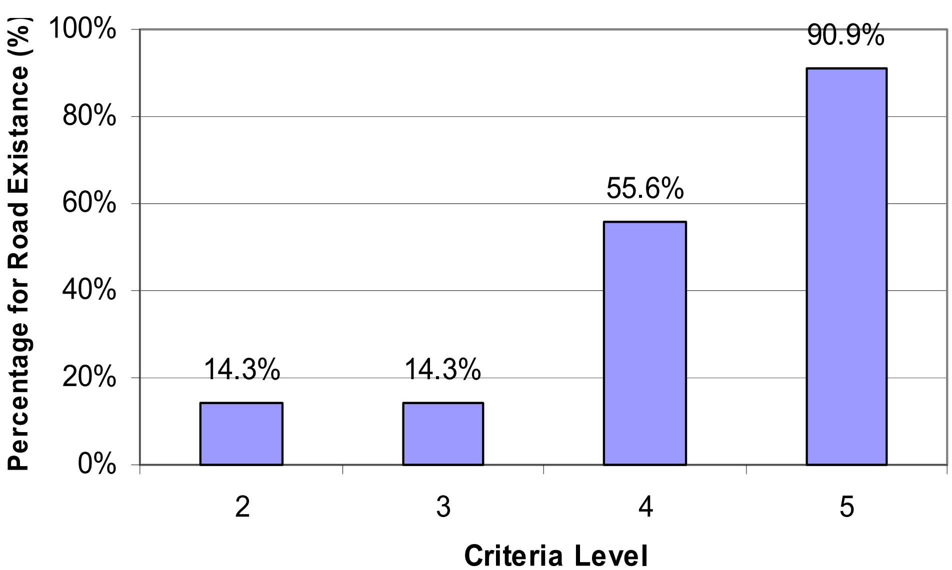


*Figure 6-16 Possibilities of potential road existence for different criteria levels*

Within the 11 segments that met all five criteria, only one segment was found not to be a road: "ZR 05"; six segments were rerouted roads: "AS 07", "AS 09","SL 02","SL 03","ZR 02",and "ZR 021"; and four segments were found to be newly formed roads: "AS 06", "SL 04","SL 05", and "ZR 04". The GPS vehicle tracking data overlay on the selected grids at location "ZR 05" is shown in Figure 6-17, and the field visited condition is shown in Figure 6-18. As can be seen from Figure 6-17, the vehicles' traffic in this area is dispersed: only several passes occurred; each 10 to 20 meters apart; and the total length for the selected grids is relative small: approximately 100 meters. It was expected not to observe a road at that area based on the vehicles' movement patterns. The resilient vegetation cover at this location (big sagebrush) also makes it difficult to form a new trail. From the 23 segments that met less than five criteria, the site visit found one rerouted road, nine newly formed roads and 14 segments not to be roads.

Overall, the site visit found seven rerouted roads and 10 newly formed roads in the training center. Those observed potential roads altered the distribution of on-road and off-road movements during the training exercise; a description of the alteration is presented in Section 6.4. These rerouted roads with improved surfaces, which indicate that they have been included in the existing road maintenance program, can be used to update the existing Yakima Training Center road map. These ten newly formed roads, as shown in Table 6-2, may need to be evaluated by land managers to be rehabilitated or to be included in road maintenance programs. An approximately 5-m offset can be expected to access the identified potential roads if a Trimble GPS Ag132 is used for navigating. Detailed discussion can be found in Section 6.5.

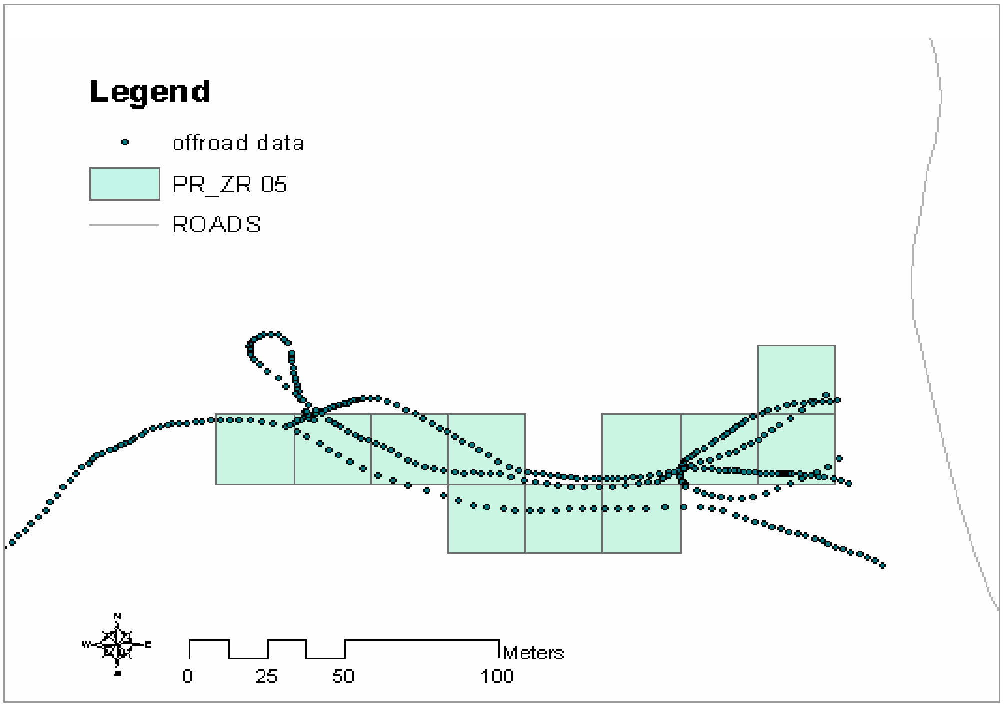


*Figure 6-17 Vehicle movements during the training exercise at ZR_05*

*Figure 6-18 Observed land conditions on ZR_05*

## *6.4 Alteration of On/Off-road Movement Distribution*

Based on the description in Section 6.2, a total of 17 potential roads were found in the YTC. The off-road vehicle moving data can be updated by excluding potential road moving data. The GPS vehicle moving data collected in October 2001 in the YTC was classified into three groups: on-road moving data that selected based on 10-meter road buffer (approximately 70% of the entire moving data); the off-road moving data by selecting the GPS points that fall outside of a 30-meter road buffer area (approximately 20%); and the data excluded between the two groups (10%).

After the potential road segments identified, those GPS data that the vehicles traveled on the identified potential road area need to be excluded from the off-road data. It results in an alteration on the distribution of the on/off road movements: the on-road movement percentage increased from 69.1% to 73.2%; and off-road movement percentage decreased from 20.0% to 15.8% (shown in Figure 6-19). Over 20% of the traffic previously identified as off-road was found occurred on the potential roads.

The alteration of the velocity distribution for the updated off-road data shown in Figure 6-20 indicates that majority of data from the potential road has a high velocity. Due to the large amount of on-road moving data, the velocity distribution of the on-road data do not have big alteration after adding the potential roads' GPS moving data to it.

The comparison of the velocity distributions for both updated on-road data, which include the potential road moving data, and the updated off-road data is shown in Figure 6-21. Compared to Figure 4-10, the distinguished differences of frequencies between on-road and off-road data for both velocity less than 3 m/s and velocity greater than 6 m/s

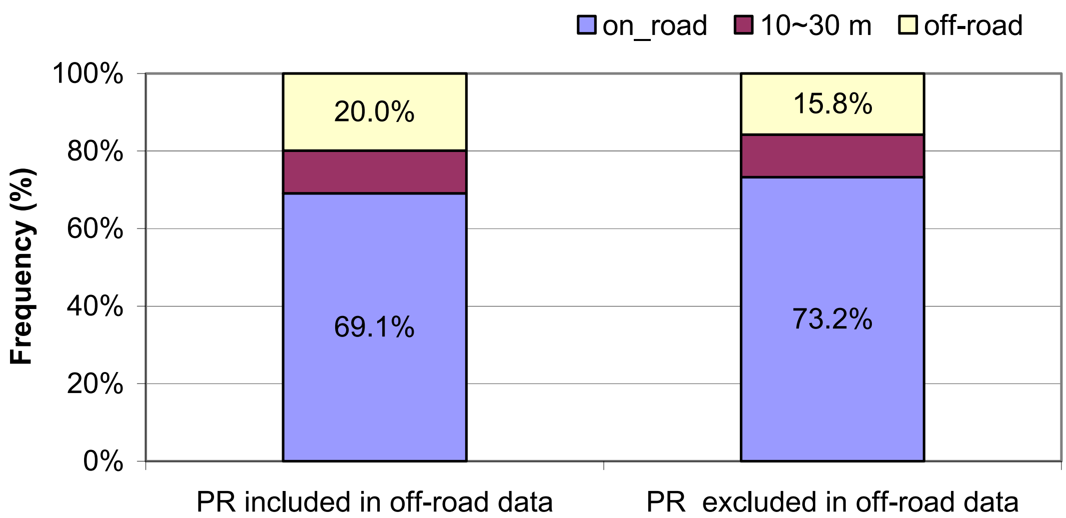


*Figure 6-19 Potential roads changes the off-road movement percentage*

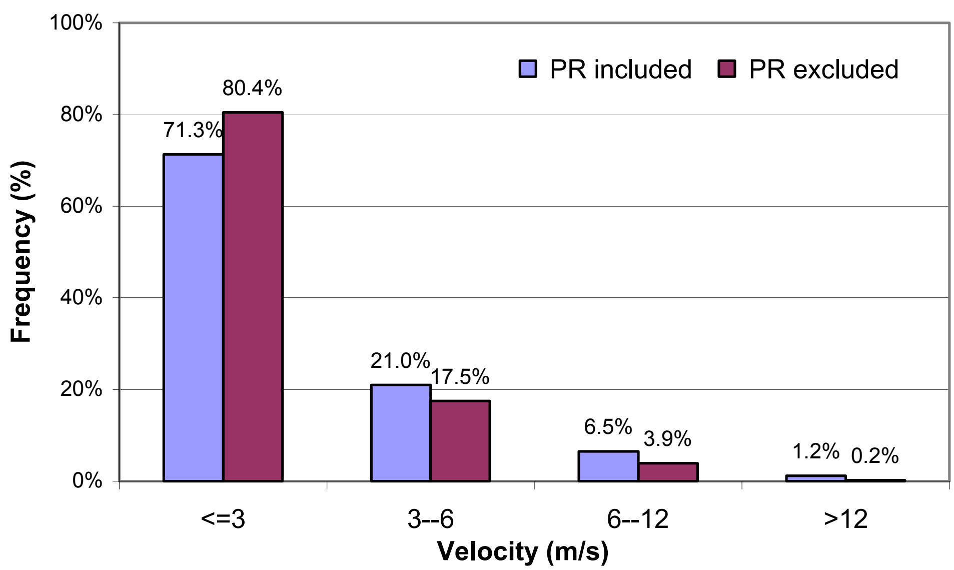


*Figure 6-20 Alteration of velocity distribution for off-road moving data*

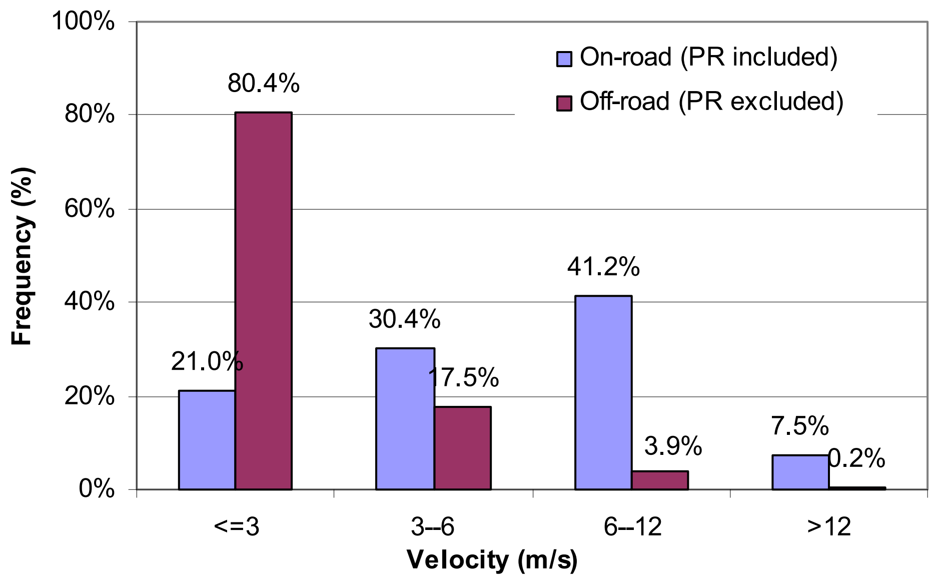


*Figure 6-21 Updated on/off road data velocity distribution*

indicate that the velocity is an important feature to describe on-road and off-road vehicle movement patterns. Within the updated off-road moving data, a selected data set with velocity greater than 10 m/s found an interesting movement pattern in zone reconnaissance (shown in Figure 6-22). The scenario shown in Figure 6-22 has not been interpreted yet; however it shows the capability of using velocity for locating special movement patterns.

## *6.5 Uncertainty for Locating Potential Roads*

As mentioned early, positional accuracy affect GIS data quality. In this study, GIS data from a variety of sources brought various uncertainties in locating the identified potential roads: the YTC road map was created by using different GPS receivers with a 30 meters reported accuracy; the vehicles' tracking data were collected by using Garmin 35-HVS GPS receivers with approximately 8 meters static accuracy (2DRMS) (Ayers

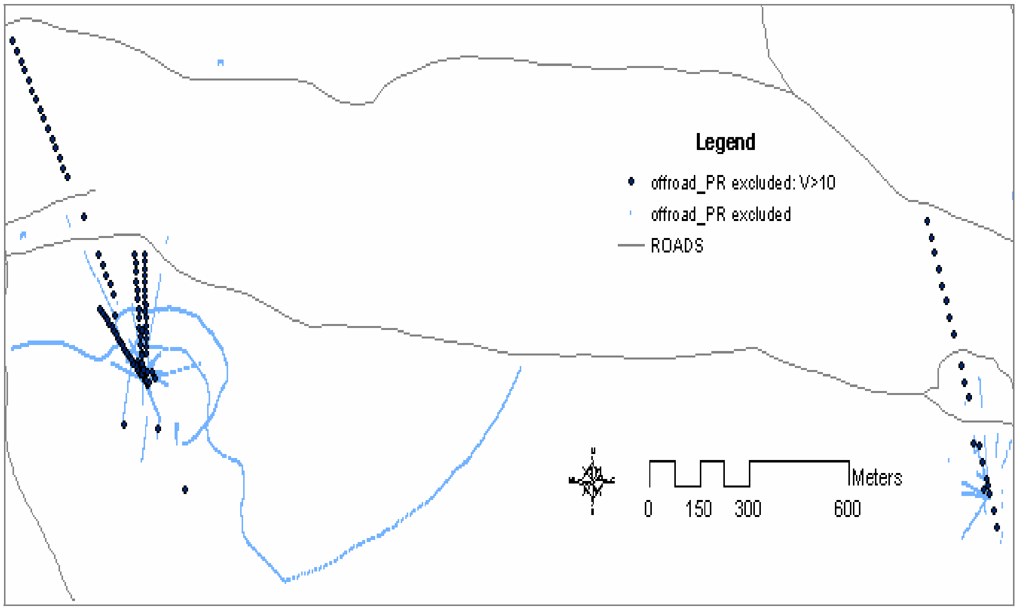


*Figure 6-22 Unknown patterns in zone reconnaissance identified using velocity*

et al., 2004). As discussed in Section 6.1, quantifying the uncertainties associated with potential roads is difficult. This section attempts to approximate the uncertainty of the locations of predicted potential roads by comparing the site visit track recorded during the visit in 2004 to the GPS trace collected during the training exercise in 2001 and to the roads on the current training center GIS road map.

The track recorded during the site visit shows a 4-meter shift over from the identified potential road and a 3-meter shift over from a road on current GIS road map (Figure 6-23). Figure 6-24 shows a similar shift from the site visit track to a predicted potential road at a different location; but the site visit track is right on top of an existing road. By exploring the site visit tracks for the visited potential road areas, an average 5-meter offset was observed. Comparing to the reported 30-meter accuracy for the GIS road map, this 5-meter offset is acceptable.

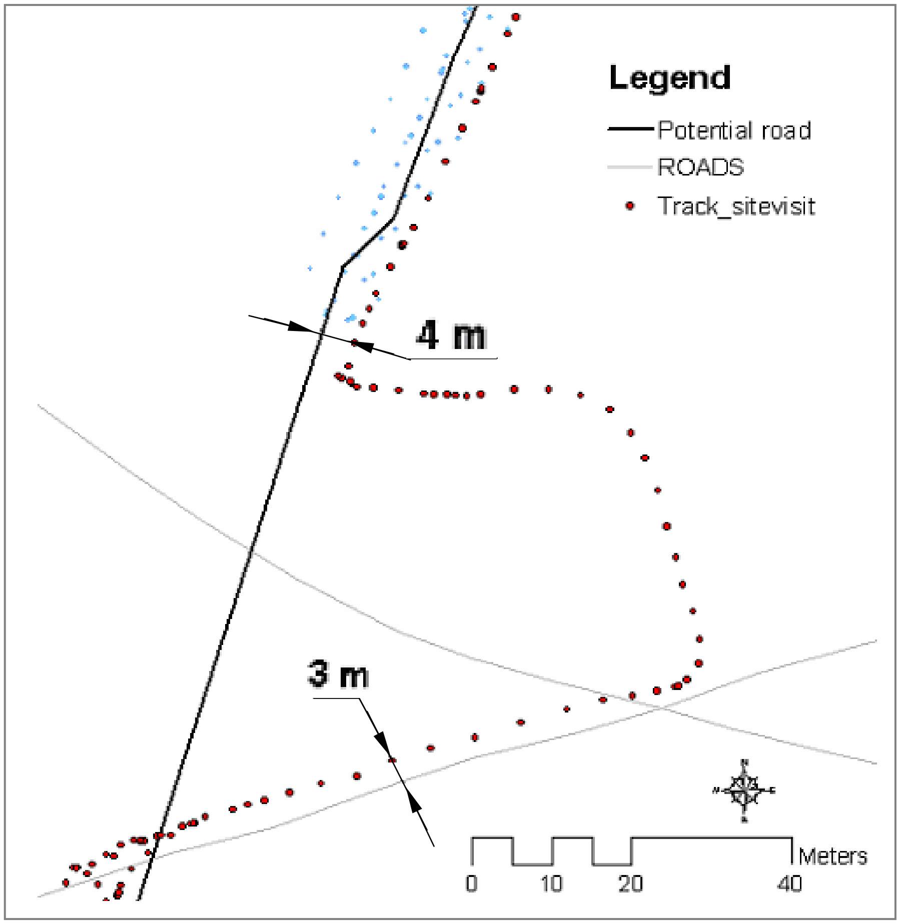

Figure 6-23 Uncertainty in locating the potential road

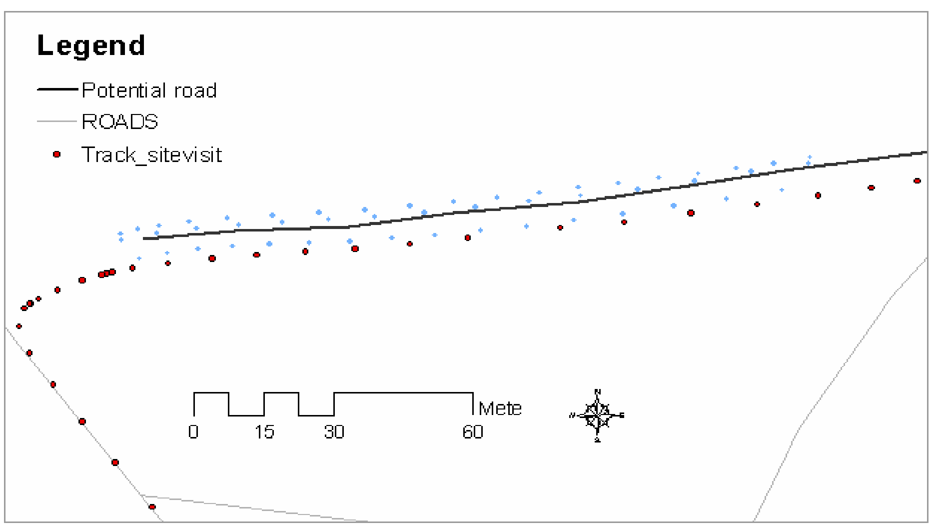

Figure 6-24 Track offset in the right side of a potential road

### *6.6 Sensitivity of the Size of Study Unit*

The vehicle tracking data in the screen line area was selected for analyzing the sensitivity of the identified potential roads on the sizes of study units. Varieties of polygon shape files with different resolutions were created to divide the YTC into small grids. The grid size for the polygon shape file was set as 5 by 5, 10 by 10, 20 by 20, 30 by 30, and 50 by 50 square meters respectively. As shown in Figure 6-25, Figure 6-26, Figure 6-27, Figure 6-28, and Figure 6-29, no substantial difference can be observed from the identified potential road areas that meet all the five criteria in the screen line area, except the results from the map with the 5 by 5 square meter grid size. As shown in Figure 6-30, a group of identified potential road grids extracted using the 5 by 5 square meter study units are discrete. A special topic on improving the continuity of the grids by using kernel smoothing technique can be found in Chapter 8.

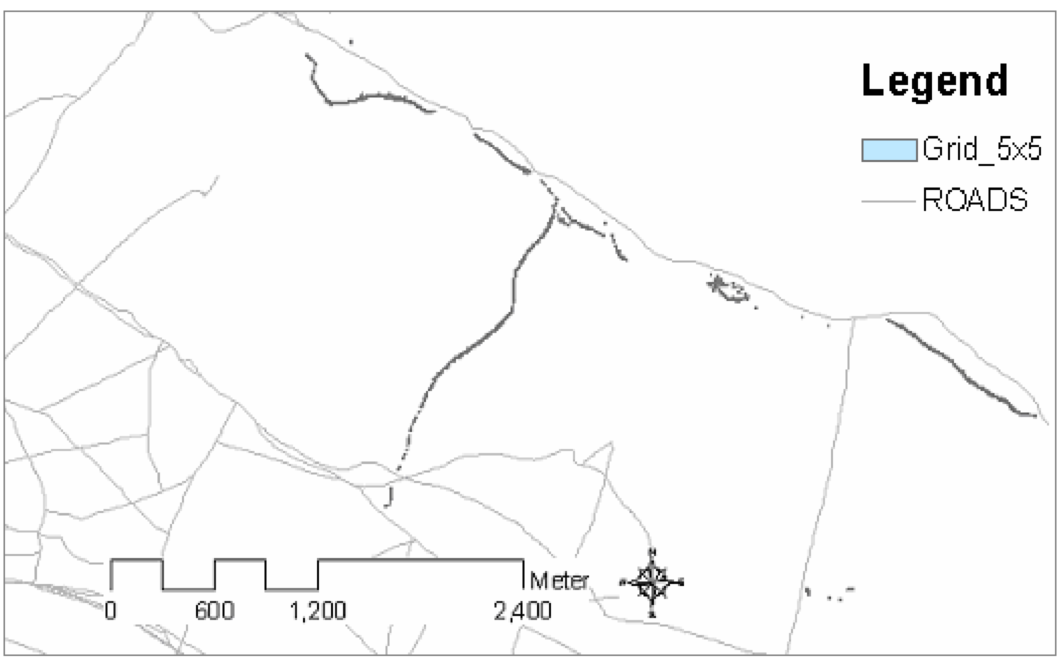


*Figure 6-25 Screen line potential roads by using 5 by 5 square meter grids*

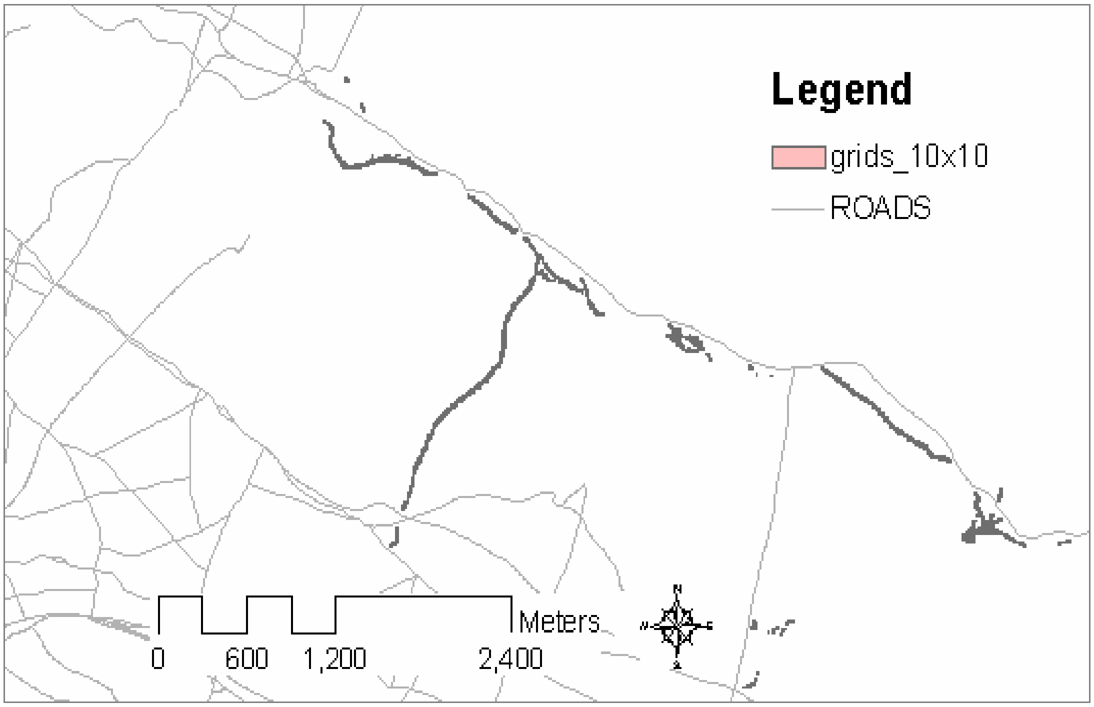


*Figure 6-26 Screen line potential roads by using 10 by 10 square meter grids*

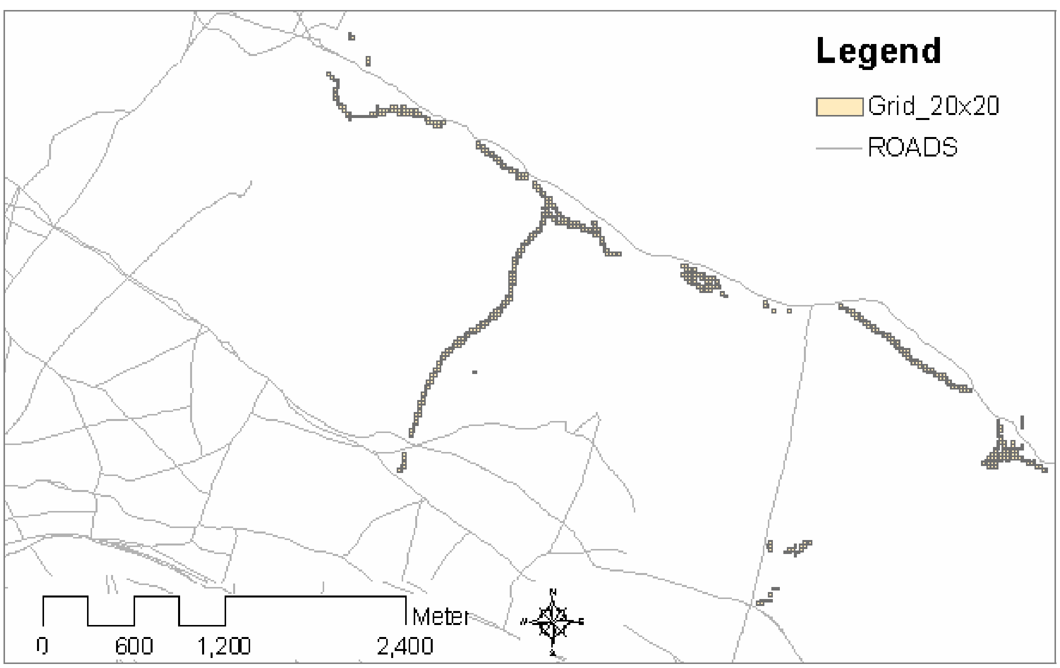


*Figure 6-27 Screen line potential roads by using 20 by 20 square meter grids*

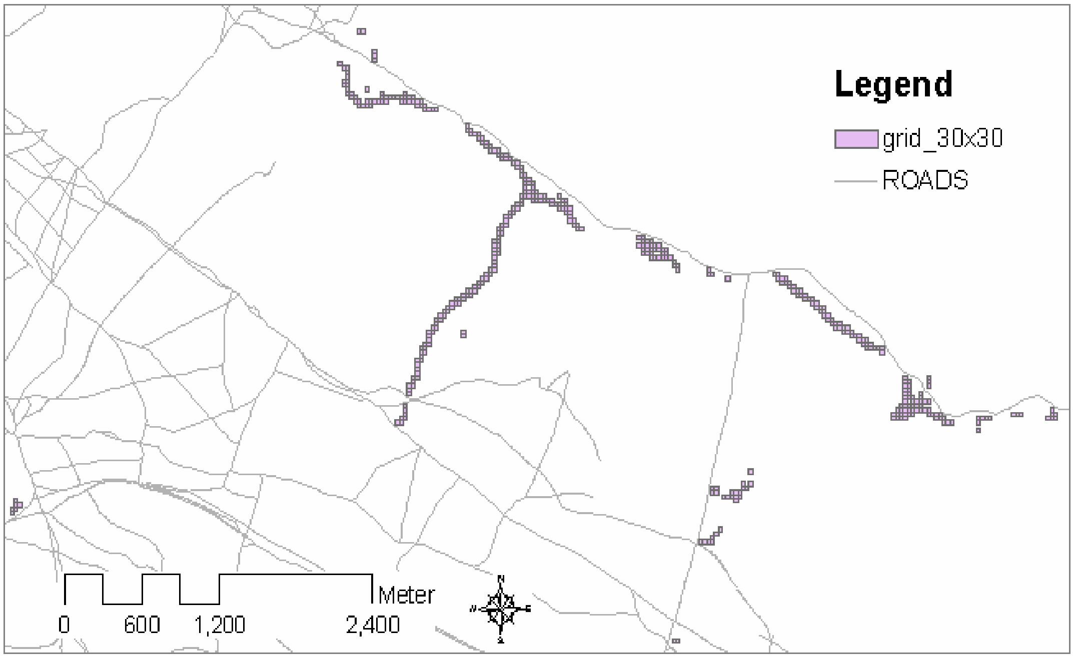


*Figure 6-28 Screen line potential roads by using 30 by 30 square meter grids*

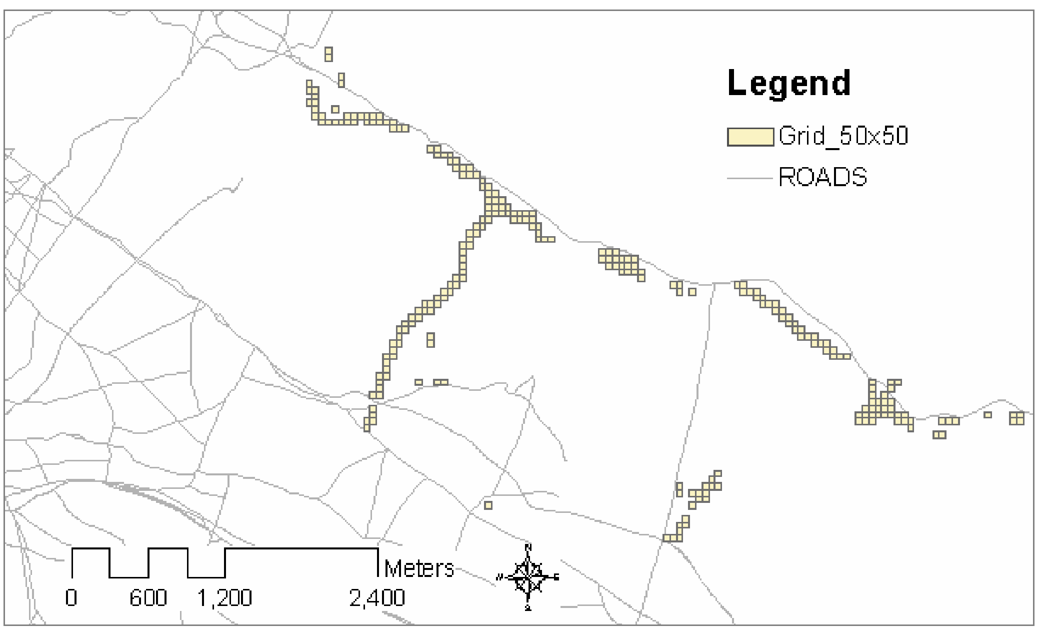


*Figure 6-29 Screen line potential roads by using 50 by 50 square meter grids*

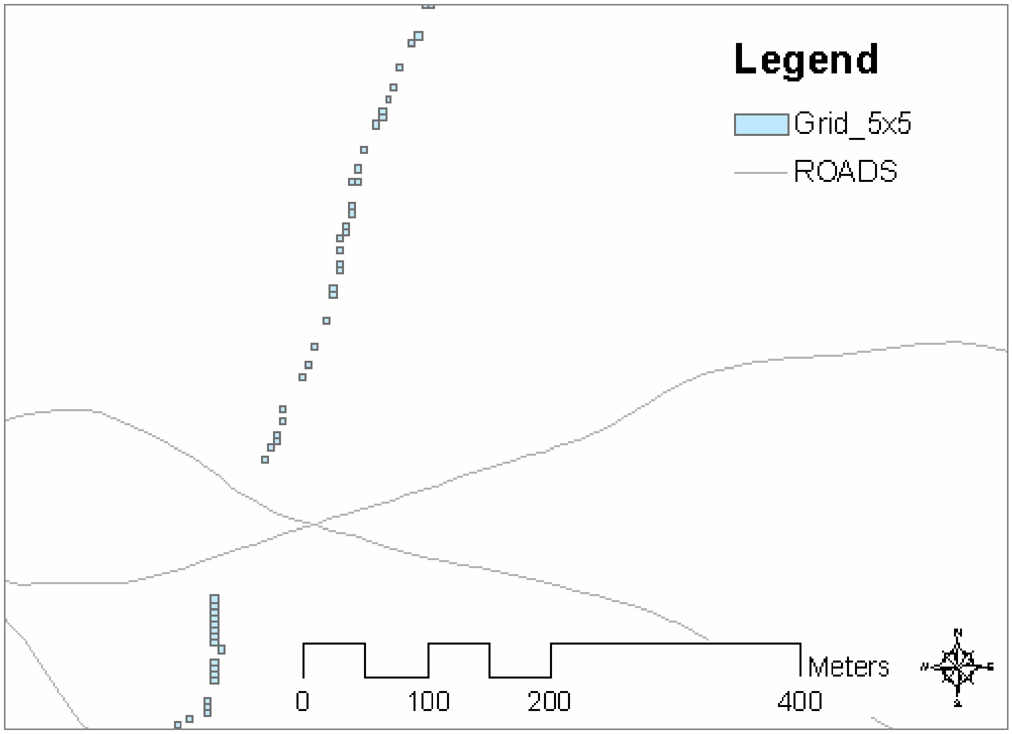


*Figure 6-30 Discrete problem when using 5 by 5 square meter grids*

The comparison of the extracted potential road grids in the same locations is shown in Figure 6-31. The comparison shows that the study unit with size greater than 10 by 10 square meter works for the potential roads identification by using the multi-criteria method. However, the size of the study units affects the processing speed. The usage of the smaller study units slows the processing, especially when the size of GPS vehicle tracking data is huge.

Serving as a model evaluation, this chapter introduced and compared the site observed results for 34 visited road segments meeting different criteria levels. The criteria level met by a location was found directly related to the road existing possibility. Locations meeting all five criteria have an approximately 91% possibility for road existence; those meeting four criteria may have 56%. This multicriteria method proved

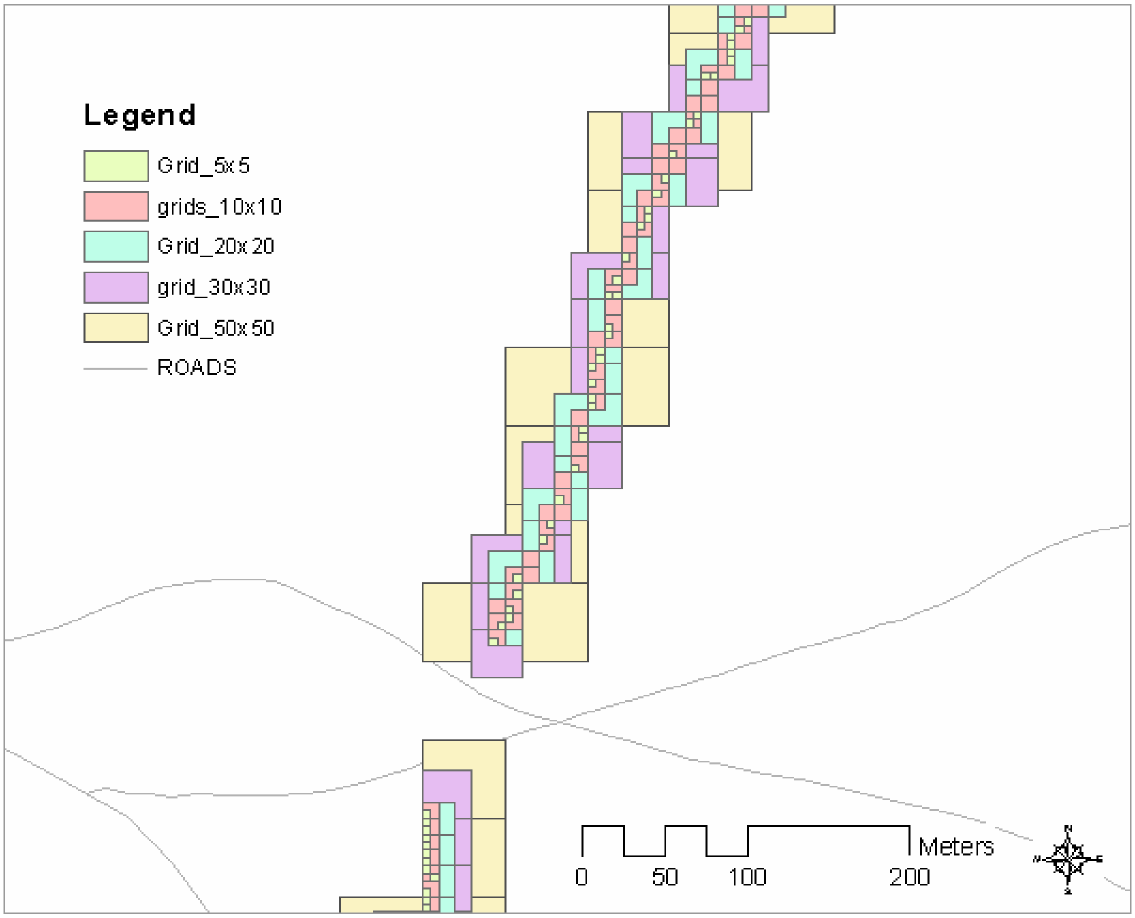


*Figure 6-31 Comparison of the continuities from different grid sizes*

to be an efficient method for finding well established roads by visiting those areas meeting five criteria. However, the possibility for finding roads at locations meeting two or three criteria is the same (14.3%). Adjustment may be made on the criteria or alternate methods can be applied to improve the potential road identification from GPS vehicle tracking data.

# CHAPTER 7 - ALTERNATIVE METHODS

Identifying potential roads based on analysis of vehicles' movement patterns during military training exercises can be approached in different ways. A multicriteria method was introduced in Chapter 5 and was evaluated in Chapter 6 to be a practical approach for identifying the potential roads resulted from military training exercises. In this chapter, the Artificial Neural Network (ANN) technique was introduced and applied to identify the potential road areas based on GPS vehicle tracking data. A neural network was trained using the observed potential road data from screen line area, and was applied to predict the potential road areas for the entire training area. The ANN method was evaluated using the site visit data and was compared to the multicriteria method. This chapter also attempted to develop a simplified method by investigating the applications of three variables individually for identifying potential roads. Each application utilized one of the three variables: the GPS point density, the average velocity, the number of passes; results were also evaluated and compared using the site visit results.

## *7.1 ANN for Potential Road Identification*

As mentioned in Section 3.5.2, artificial technologies for knowledge discovery can be integrated into GIS to assist spatial decision making (Mas et al., 2004; Skabar, 2003). Many studies demonstrated the advantages to apply ANN in GIS for solving

spatial problems (Mas et al., 2004; Skabar, 2003; Pijanowskia et al., 2002; Sung et al., 2001). This section introduces a method combining ANN with GIS to identify potential roads based on the GPS vehicle tracking data in the Yakima Training Center (YTC). The ANN method was tested by using the training data and on-road moving data; the results found approximately 94% accuracy rate for the training data, and 85% for the on-road moving data. The predicted results for off-road moving data by ANN method were compared to the multi-criteria prediction and the site observation. Results show that the ANN method emphasizes on factors different from the multicriteria method in identifying potential roads and has approximately 78% prediction accuracy.

### 7.1.1 ANN

Artificial neural networks are mathematical models that emulate the function of the human brain. ANN can be described as a data processing system consisting of a large number of simple, highly interconnected processing elements (artificial neurons) in an architecture inspired by the structure of the cerebral cortex (Tsoukalas and Uherg, 1996). Two of the major functions of neural networks are learning and recall (Riid, 2002). Learning is the mechanism that initiates a cycle and keeps it refreshed (experiences are transformed into memories, memories affect behavior, and behavior provides new experiences). Also, learning is the process of adapting the connection weights in an ANN to produce the desired output vector in response to the input vector. Recall is the process of accepting an input stimulus and producing an output response in accordance with network weight structure. Since a desired response must be compared to the true output

to create an error function, recall is also an integral part of the learning process (Riid, 2002).

The key element of the ANN paradigm is the structure of the information-processing system, which is composed of a large number of highly interconnected processing elements. These elements are analogous to neurons and are tied together with weighted connections. Based on the different connections and activation functions, ANN has different paradigms: back propagation, learning vector quantization, adaptive resonance theory, self-organizing map, Adline, Hopfield, boltzmann machine, and so on. During the last decade, research efforts made significant progress in both theoretical development and practical applications. Neural networks have been demonstrated as a competitive alternative to traditional classifiers for many practical classification problems (Zhang, 2000). The ANN can be applied to learn the relationships of the factors characterizing the vehicle potential road movement patterns and to identify the locations where the special movement patterns occurred.

### 7.1.2 NN applied for identifying potential roads

As mentioned in Chapter 5, the vehicle movement patterns can be characterized by different factors. As vehicles travel across the terrain, factors that indicate these vehicles are traveling on a newly formed, or existing but unidentified road include number of points, number of vehicles, number of troops, travel directions, turning radius distribution, passage interval, and vehicle velocities. Among these factors, travel directions were represented by the average and the standard deviation of Course over Ground (COG); and turning radius distribution was described by the average and the

standard deviation of turning radius. The multicriteria method described in Chapter 5 was derived from subjective description of potential roads: locations where more than one vehicle from different troops passed during different day in opposite directions. Instead of using the subjective interpretation of potential roads, this section investigated the application of ANN for identifying potential roads: learning from the observed potential roads in screen line area the relationship between the factors and results; and predicting the potential roads for the entire training center.

Ten variables were extracted from GPS vehicle tracking data for each study grid as the inputs of the ANN including: 1) the number of points (Points), 2) number of vehicles (V_num), 2) number of troops (Troops), 4) passage interval (Diff_day), 5) average velocity (Ave_V), 6) the standard deviation of velocities (SD_V), 7) average COG (Ave_COG), 8) the standard deviation of COG (SD_COG), 9) average of turning radius (Ave_TR), and 10) the standard deviation of turning radius (SD_TR). The output of the NN was set to a potential road attribute: 0 for the grids where no road observed or predicted; and 1 for potential road.

The training data were selected from the observed potential road in the screen line area; Figure 7-1 shows the potential road grids, the no road grids, and other study grids in the screen line area; the data from potential road grids and no road grids were used for training. The training data contains 168 samples (a 168 by 11 matrix): 70 of them are potential road samples; and the other 98 pairs are non-potential samples. Each sample has 10 inputs and 1 output. Considering that these 10 inputs have different units and various data range, the inputs of training data were scaled using mean center unit

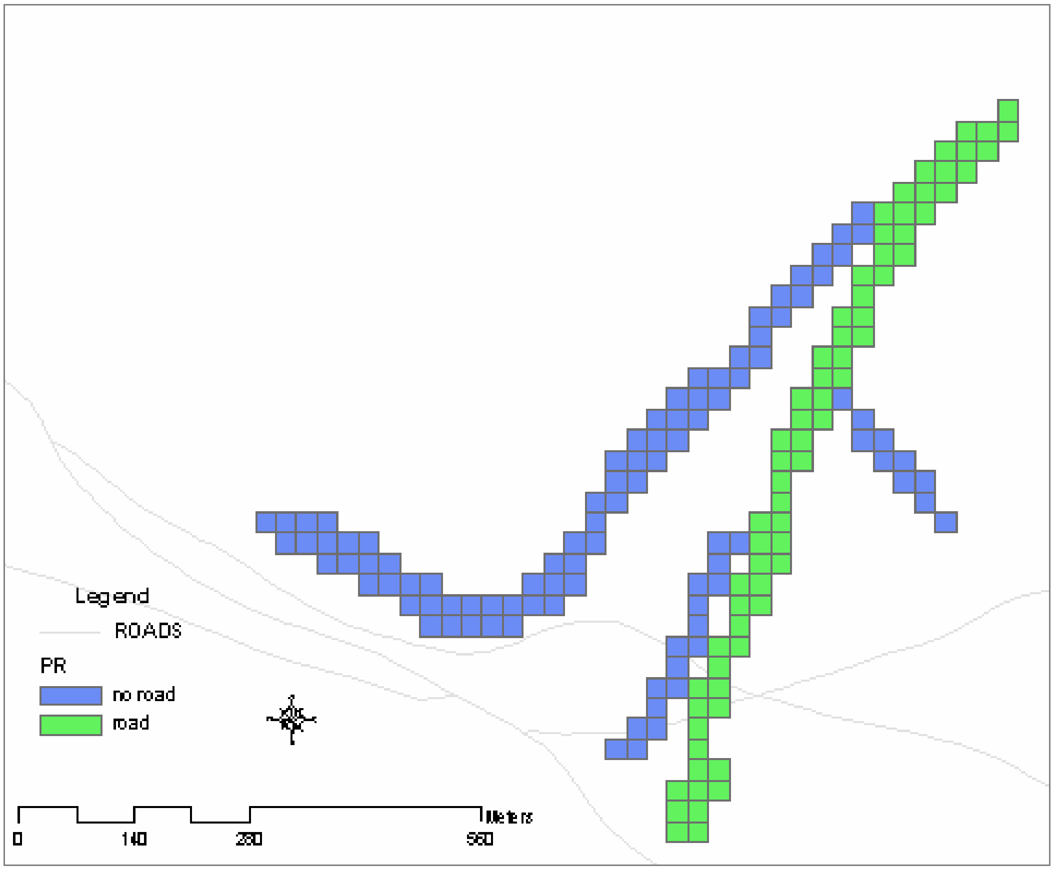


*Figure 7-1 Training data from the screen line area*

variance (MCUV) to avoid premature saturation during neural network training. The weight matrix and scaling parameters (mean and standard deviation of each input variables) were recorded to scale the inputs of predicting data (summarized GPS vehicle tracking data for all YTC study grids) after training is concluded.

A 10-neuron input layer and a 1-neuron output layer were used to define the basic structure of the neural network used in this study. The key parts in this neural network modeling include choosing training algorithm, selecting activation function, and designing the hidden layer. A Levenberg-Marquardt backpropagation (BP) algorithm was chosen for training the neural network. The Levenberg-Marquardt backpropagation algorithm is designed to approach the second-order training speed without having to compute the Hessian matrix. This algorithm appears to be the fastest method for training moderate-sized feedforward neural networks (MATLAB, 2002). The MATLAB function "trainlm" has been used for learning the relationship between the inputs and output. Because of the binary output, the log-sigmoid transfer function was selected as the activation function for the hidden layer and the output layer. The performance of the training process indicated that three hidden neurons are adequate for this particular problem. The input layer of the actual neural network has 10 neurons for 10 input variables, and all neurons are fully connected. Figure 7-2 shows the simplified neural network structure (the actual neural network was fully connected).

A common problem during the training process is overfitting, model fits training samples very well but has poor generalization capability when used for generalization. An approach for improving network generalization is to use a network that is just large

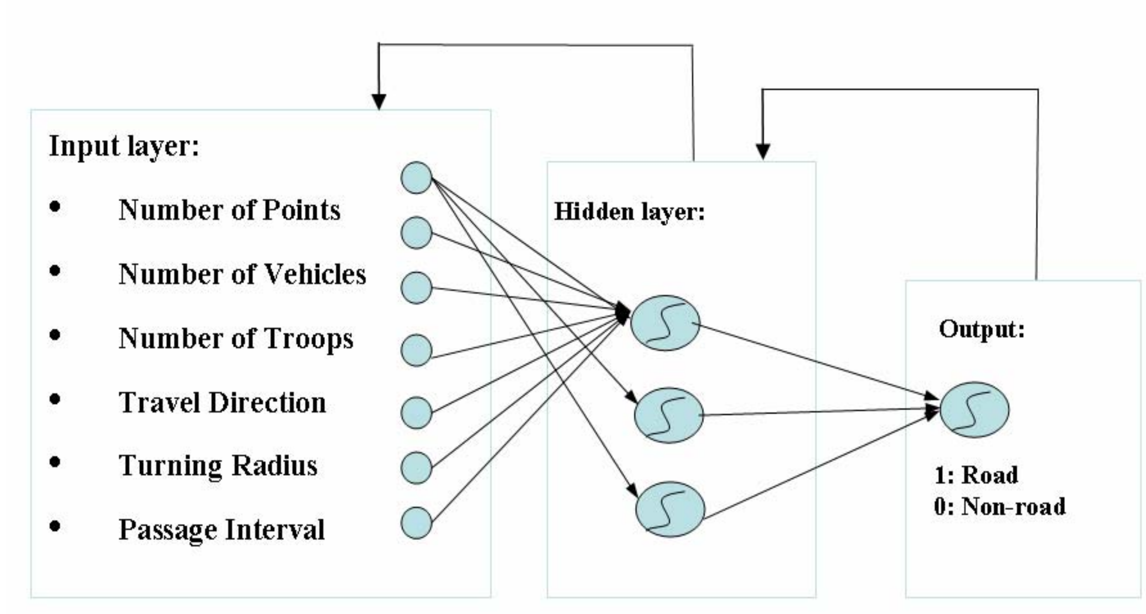


*Figure 7-2 Structure of the neural network*

enough to provide an adequate fit. But it is difficult to know beforehand how large a network should be for a specific application. In this case, the training data set is limited; an early stopping strategy (to set a loose training error goal) was used to avoid the overfitting problem.

After the training was complete, the neural network was tested by using training data selected from the screen line area. The neural network obtained a near 94% training accuracy. Figure 7-3 shows the neural network test results for the observed potential road segments in the screen line area.

The neural network was applied to the on-road grids to evaluate the method, and was applied to all off-road grids to predict the potential road areas. The on-road grids were generated using the on-road moving data, which were selected based on a 10-meter road buffer. Similar to the procedures for generating the off-road study units: a polygon

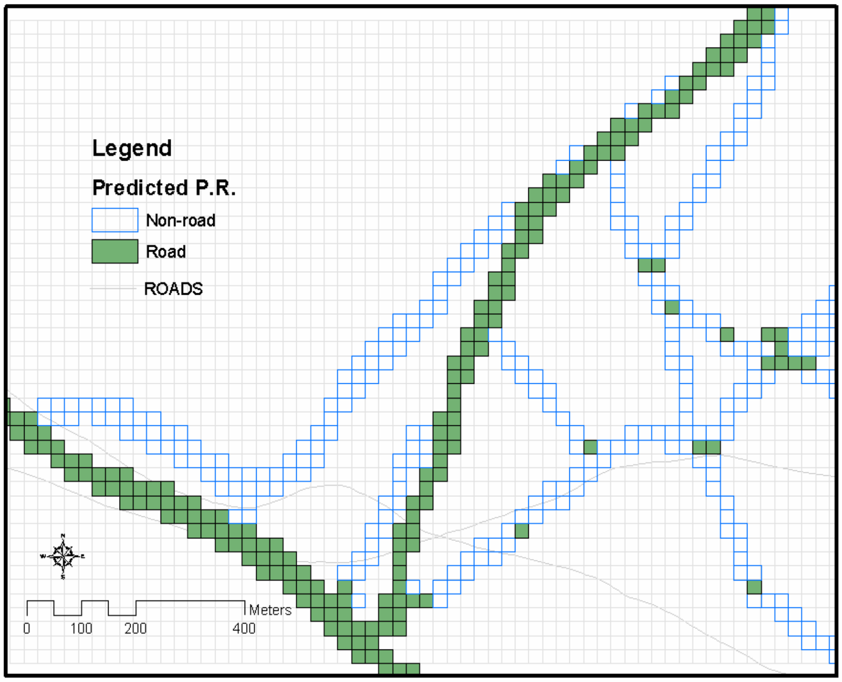


*Figure 7-3 Neural network testing performance in observed potential road area*

shape file dividing the YTC into 25 by 25 square meter small grids were created; those grids containing on-road moving data were selected and saved as on-road grids (a total of 20,136 grids). GPS vehicles' on-road tracking data were summarized for on-road grids to be used as inputs of the neural network to identify the potential road areas. All the on-road grids were expected to be identified by the neural network as potential road grids. The accuracy of this ANN method can be approximated as the percentage of the grids identified as potential road grids

## 7.1.3 NN prediction for on-road data

The neural network predicted 17,111 grids as potential road grids (Figure 7-4 shows the NN predicted on-road locations); approximately 85% of the vehicles' on-road grids were correctly classified as potential road grids. Among the grids classified by NN


*Figure 7-4 NN predicted on-road locations for the 10-m on road moving data*

as potential road grids, approximately 80% the grids are the areas where vehicles passed only once during the eight-day training exercise. It was believed that a single pass on a certain location provided insufficient information for classifying the movement patterns within the grid. The test result of the on-road data indicates that this neural network based potential road identification model is able to provide approximately 85% prediction accuracy.

### 7.1.4 NN prediction for off-road data

This NN method was applied to a total of 12,862 off-road study units, the locations where off-road movement occurred during the training exercise. The NN method predicted approximately 36% of the off-road traffic areas as potential road grids. Figure 7-5 shows the locations predicted as roads by the NN method.

The outstanding segment on the left side of the figure, as mentioned early, is the interstate highway I-82. By correctly identifying this segment as a potential road, the neural network demonstrates its capability in potential road identification. If the interstate highway travel is excluded, the percentage of off-road traffic locations that have been identified as the potential road grids dropped to 31%.

The potential road grids predicted by the NN method in the screen line area are shown in Figure 7-6; and the clustered results are shown in Figure 7-7. Figure 7-7 also shows the comparison of the observed road segments to the NN predictions. As can be seen from Figure 7-7, NN correctly identified all the road segments in this area, but misidentified non-road areas as roads. Similar results can also be found in the areas where area security and zone reconnaissance missions were conducted (Appendix IV).

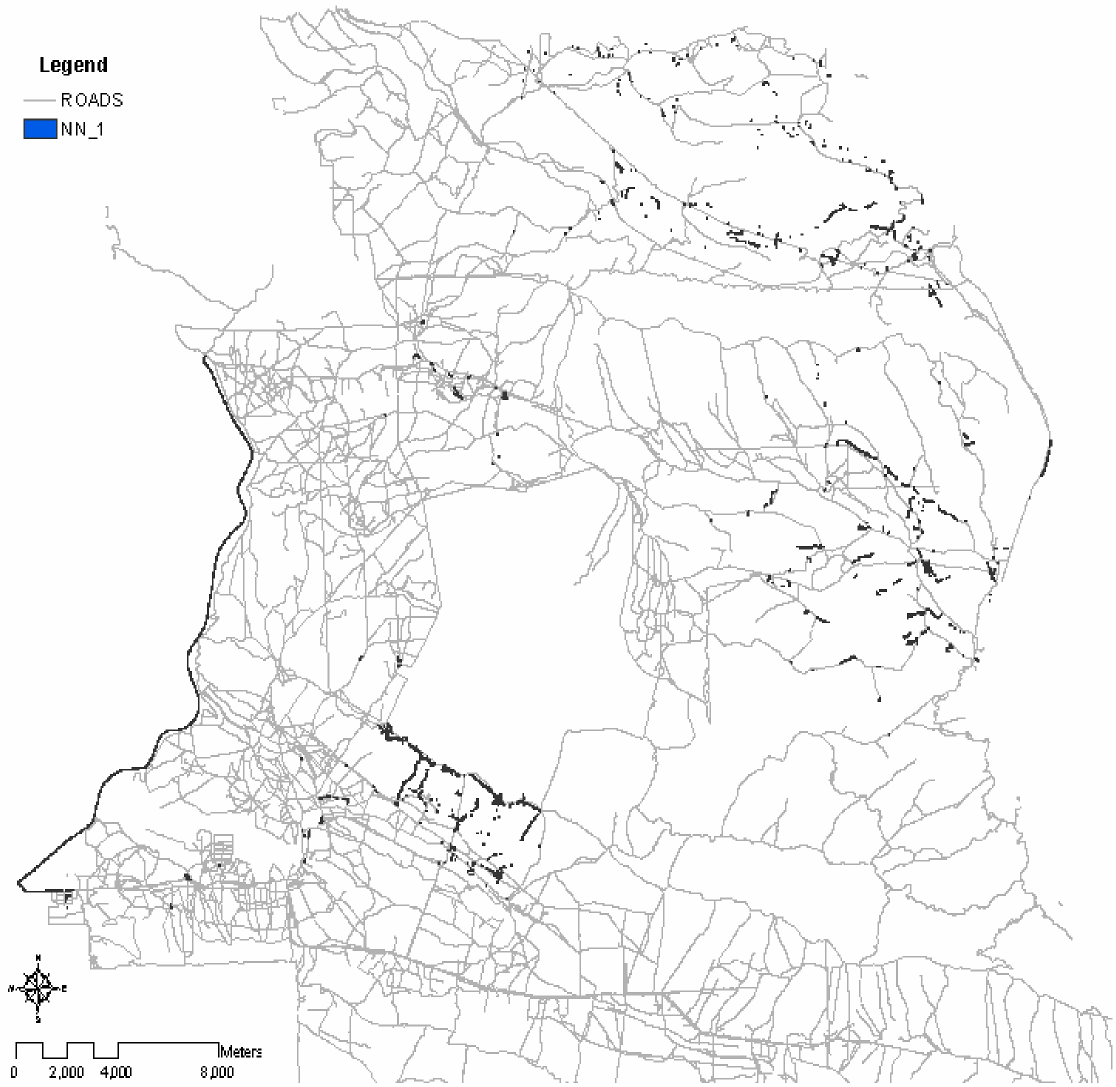


*Figure 7-5 Neural network predicted potential road areas for YTC*


*Figure 7-6   Potential road grids predicted by NN in the screen line area*

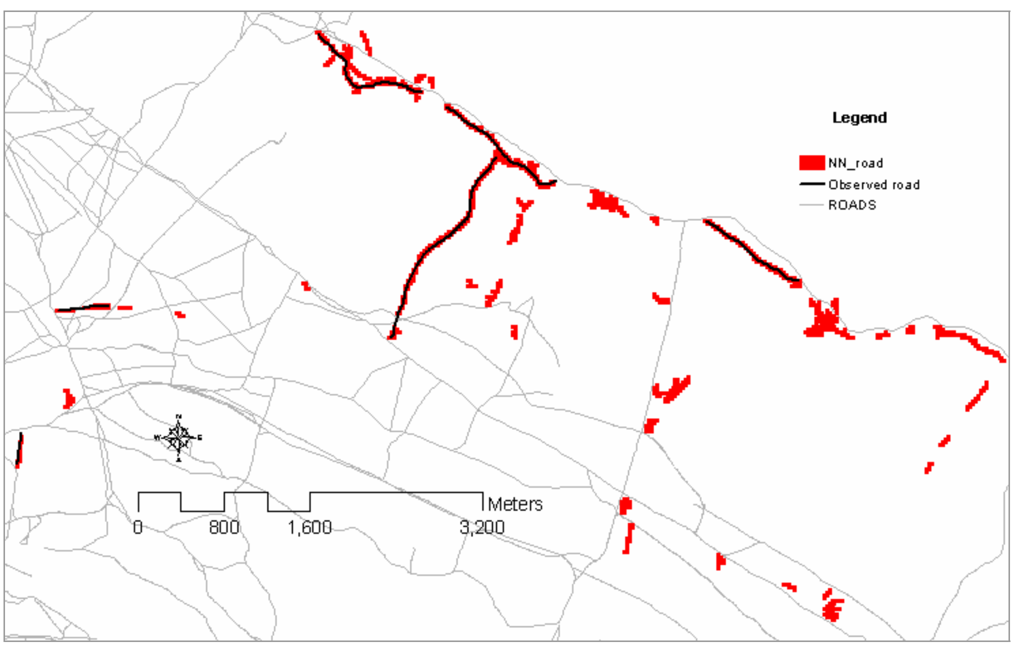


*Figure 7-7 Observed roads vs. NN predictions on the screen line area*

For the 34 segments selected for site visit (a total of 1,102 grids), the NN was able to identify 16 segments out of 17 road segments: the potential road segment "AS_03" (a military class 4 road shown in Figure 6-7) in area security was not identified by the NN method. Based on the analysis on the visited segments, the NN method can be expected to have approximately 94 % accuracy for identifying the potential road segment over the entire training center; but it may be considered less efficient since it misidentified the non-road locations as roads. If the accuracy was evaluated based on individual grid, comparing the NN prediction to the site visit result for each grid for the visited 1,102 grids, the analysis resulted in approximately 77% accuracy. Table 7-1 shows the accuracy calculated based on individual grid: approximately 77% accuracy for both road and no-road prediction.

Comparing the potential road grids in screen line area predicted by the NN method (Figure 7-6) with the results from the multicriteria method (Figure 5-9), differences can be observed that beside the two more road segments identified by the NN method, more discrete grids were resulted from this NN method. Section 7.1.5 discussed more detailed comparison of the NN method and the multicriteria method.

*Table 7-1 Accuracy of NN prediction on the visited locations*

| **NN prediction** | **Site visit results** | | | |
|---|---|---|---|---|
| | No road | | Road | |
| | Number of grid | % | Number of grid | % |
| **No road** | 282 | 76.8% | 85 | 23.2% |
| **Road** | 161 | 21.9% | 574 | 78.1% |

### 7.1.5 NN method vs. multicriteria method

The NN method for identifying potential road grids based on summarized GPS vehicle tracking data within each grid shares some similarities with the multicriteria method. Table 7-2 shows the comparison of the multicriteria method and the NN method from the data source and analysis procedures perspective. Because the outputs of the two methods have different data ranges, and the site visited locations were selected based on the multicriteria method, it is hard to compare the accuracy of the two methods quantitatively. Besides the differences shown in Table 7-2, the outputs from these two methods for both off-road grids and visited grids were compared. Their differences indicate that the two methods emphasized different factors in detecting the potential road grids.

The NN predictions for all off-road grids were compared to the criteria levels met by the grids to investigate the relation between these two methods. Table 7-3 shows the correlation coefficient of different criteria to the NN prediction based on both visited grids and all off-road grids. Clearly, the NN potential road prediction is highly correlated to the criterion: different direction, and relatively correlated to the different day criterion and the criteria levels. The lower correlation coefficients indicated that criteria as serving as constrains, the "number of point inside a grid is greater than 2" and "more than one vehicle passed the grid" were fulfilled by most of the study grids, especially for those visited grids.

The comparison of the NN prediction for the visited locations to the criteria level

*Table 7-2 Methods comparison for multicriteria method and NN method*

<table>
<tr><th></th><th>Multi-criteria Method</th><th>NN method</th></tr>
<tr><td>Similarities</td><td colspan="2">1. Study units: same number of grids: 12,862 grids; same size for each grid: 25 by 25 square meter;<br>2. Data source: GPS off-road vehicle tracking data ;<br>3. Both methods considered the factors: number of points, number of vehicles, number of troops, different days, and different directions.</td></tr>
<tr><td>Differences</td><td>1. Criteria were built based on subjective opinion (human brain learned from experiences);<br>2. Summarized GPS off-road vehicle tracking data were processed as 5 criteria;<br>3. Output for a grid is potential road with a given certainty level (known as criteria level);<br>4. The input and output relation is explicit;<br>5. Easy to apply.</td><td>1. Regulations were learned from field data (Mathematic model simulating the function of human brain);<br>2. Used the summarized data as model inputs directly; included additional parameter velocity as inputs;<br>3. Output for a grid is either 1 or 0: 1 for potential road; 0 for not road;<br>4. The input output relation was implicit, it was recorded as the structure and the weights associated with the network.<br>5. Operator may need special skills to perform the analysis.</td></tr>
</table>

*Table 7-3 Correlation coefficients of different criteria to NN prediction*

| Correlation Coefficient | Criteria levels | Criteria Pnt_2 | V_num | dif_trp | dif_day | dif_dir |
|---|---|---|---|---|---|---|
| Base on visited locations | 0.68 | -0.02 | -0.02 | 0.28 | 0.49 | 0.89 |
| Based on all off-road grids | 0.38 | -0.18 | 0.3 | 0.25 | 0.36 | 0.66 |

met by each grid was conducted to evaluate the efficiency of the NN method. The results are presented in Table 7-4 and Figure 7-8. As can be seen from the figure, the NN method predicted less than 12% of the grids that met less than two criteria as potential road grids, which indicates the NN method agrees with the multi-criteria method that the locations met only two criteria have a lower possibility for a road existence. Figure 7-8 also shows higher percentages of the grids from different criteria levels (criteria level two, three, four, and five) were identified as potential road grids by the NN method. At criteria level four, instead of an expected percentage between criteria level three, and five, a relatively lower percentage was observed. This percentage deviation at criteria level four indicates that the NN method involved factors that were not included in the criteria method (e.g. the velocity), or the NN method emphasized at factors different from the multicriteria method.

A similar comparison for all off-road grids is presented in Figure 7-9. Approximately 91% of the grids identified by the NN method as no road grids (where no potential road exists) met only one criterion. This high percentage again indicates that the NN method and the multi-criteria method share a similar importance in the criteria level one in detecting the non-road grids. The similar lower percentages from the

*Table 7-4 Criteria levels vs. NN predictions*

| Criteria Level | Number of grids met the criteria level | Number of grids identified as road grids by NN | Percentage of the grids identified as road by NN (%) |
|---|---|---|---|
| 1 | 8405 | 949 | 11.3% |
| 2 | 1533 | 1084 | 70.7% |
| 3 | 608 | 554 | 91.1% |
| 4 | 559 | 363 | 64.9% |
| 5 | 703 | 691 | 98.3% |

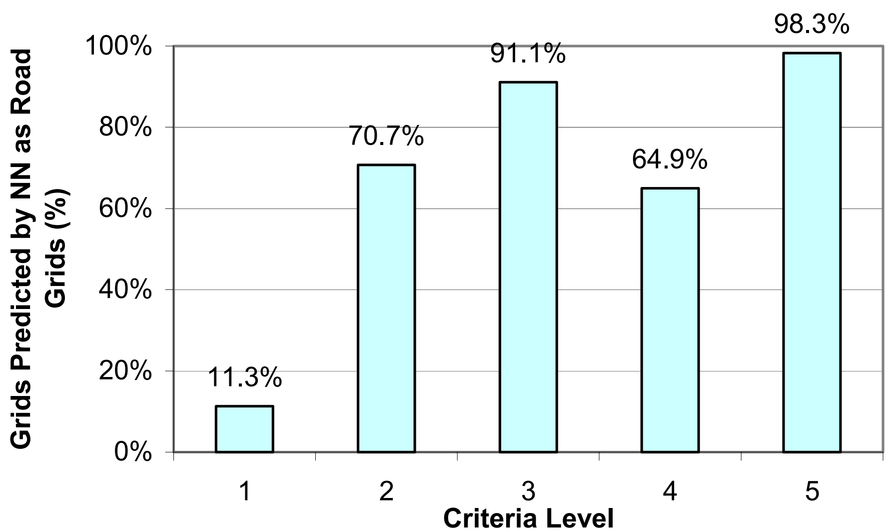


*Figure 7-8 Percentage of predicted road grids by NN at different criteria levels*

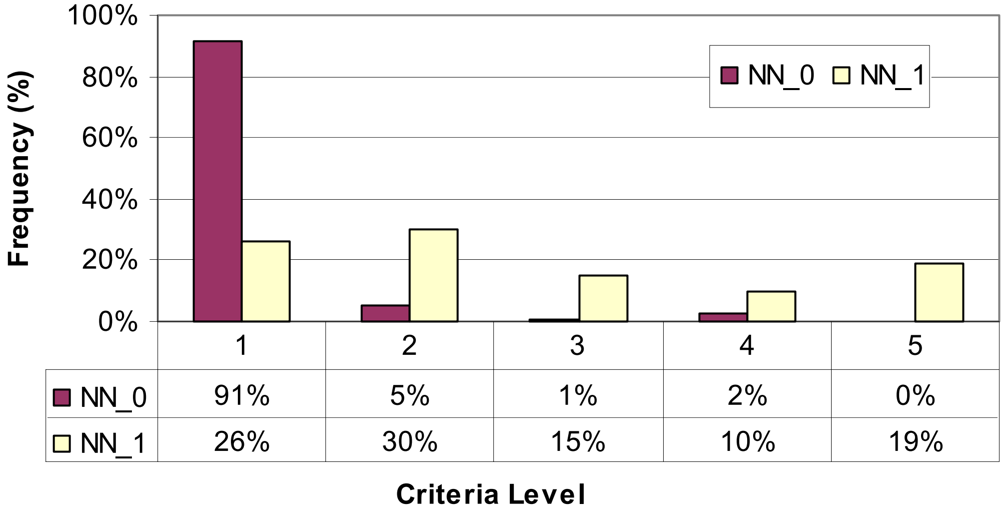


*Figure 7-9 Comparison of NN prediction and Multi-criteria*

NN predicted road grids were observed for different criteria levels from Figure 7-9. The observation again indicates that the NN method has different emphasis on the factors for detecting the potential road grids.

Analysis on correlation coefficient of training data was conducted and results are shown in Table 7-5. Strong correlation (0.82) is seen between standard deviation of COG (SD_COG) and the potential road existence (PR). As expected, relatively high correlations between the parameters of five criteria (Points, V_num, Diff_day, and Troops) and PR are also observed. The relatively low correlation coefficient values between Ave_COG and PR, Ave_TR and PR, SD_TR and PR indicate that these parameters may have limited benefit the neural network. The utilization of these less correlative parameters as inputs for the neural network could be one of the reasons resulting in the differences between the potential road prediction from NN and the five

*Table 7-5 Correlation coefficients of NN training data*

| | **Points** | **Ave_COG** | **SD_COG** | **Ave_TR** | **SD_TR** | **Ave_V** | **SD_V** | **V_num** | **Diff_day** | **Troops** | **PR** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Points** | 1.00 | | | | | | | | | | |
| **Ave_COG** | 0.00 | 1.00 | | | | | | | | | |
| **SD_COG** | 0.59 | 0.22 | 1.00 | | | | | | | | |
| **Ave_TR** | 0.04 | 0.08 | 0.24 | 1.00 | | | | | | | |
| **SD_TR** | 0.31 | -0.12 | -0.06 | -0.60 | 1.00 | | | | | | |
| **Ave_V** | 0.04 | -0.01 | 0.47 | 0.52 | -0.53 | 1.00 | | | | | |
| **SD_V** | 0.64 | 0.07 | 0.64 | 0.12 | 0.25 | 0.23 | 1.00 | | | | |
| **V_num** | 0.74 | -0.19 | 0.47 | 0.15 | 0.20 | 0.23 | 0.62 | 1.00 | | | |
| **Diff_day** | 0.63 | -0.04 | 0.64 | 0.16 | 0.19 | 0.31 | 0.71 | 0.79 | 1.00 | | |
| **Troops** | 0.62 | -0.11 | 0.56 | 0.14 | 0.19 | 0.27 | 0.59 | 0.86 | 0.84 | 1.00 | |
| **PR** | 0.45 | 0.21 | 0.82 | 0.19 | -0.02 | 0.44 | 0.63 | 0.30 | 0.51 | 0.39 | 1.00 |

criteria method. In addition to the five criteria parameters, average velocity (Ave_V) and standard deviation of velocity (SD_V) are also correlated to the existence of a potential road. Since the velocity has not been included in the five criteria method for identifying potential road, it may also cause the different predictions between the two methods.

Overall, based on the comparison, the NN method may be considered as the method with higher accuracy, but less efficient. The NN method identified all the new roads, but also identified many non-road areas as potential roads. The two potential road identification methods may be improved in the future by excluding the Ave_COG, Ave_TR, and SD_TR from the neural network inputs, and adding a velocity factor to the multi-criteria method. The NN method can also be improved by using the site visited grids with known results as training data.

## *7.2 Simplified Methods*

Both five criteria method and the NN method for identifying the potential roads from the GPS vehicle tracking data used multiple variables. This section simplifies the potential road identification method by reducing multiple variables into a single variable. The parameters investigated include the point density, vehicle velocity, and the number of passes at a certain study unit. The potential road identification method was simplified to be an uni-variable method by using only one of the three parameters as the predictor. The results were evaluated and compared using the site visit data.

### 7.2.1 Point density

Concentrated off-road traffic can result in potential roads. The possibility of a potential road existence hence is expected highly related to the traffic density, which can be characterized by the GPS point density. Point density usually refers the density of the point features in a certain area; it can be estimated by calculating the ratio of the number of the points inside a study unit over the area of the study unit. In this study, the point density was approximated by counting the number of the points within a study unit since all study units are in the same size (25 by 25 square meter). Details for calculating the point density can be found in Section 4.2.1.

As presented in Figure 4-3 in Chapter 4, the frequencies for on-road and off-road moving data were distinguished at two groups: the point density less than 20 and the density greater than 40. The off-road grids for the entire training center then can be classified into three groups based on the point density: less than 20, between 20 and 40, and greater than 40. Those grids with the point density greater than 40 were expected to have high possibilities to be a portion of a potential road. The criterion for identifying the potential road grids then can be set as: the number of points within the grid is greater than 40. Appling this point density criterion to 12,862 off-road grids resulted in 686 potential road grids. Figure 7-10 shows the predicted potential road areas in the screen line area.

Comparing Figure 7-10 to the identified potential road areas that met five criteria in the screen line area (shown in Figure 5-16), same number of potential road segments was observed. The similarity of the predictions in screen line area from the two methods

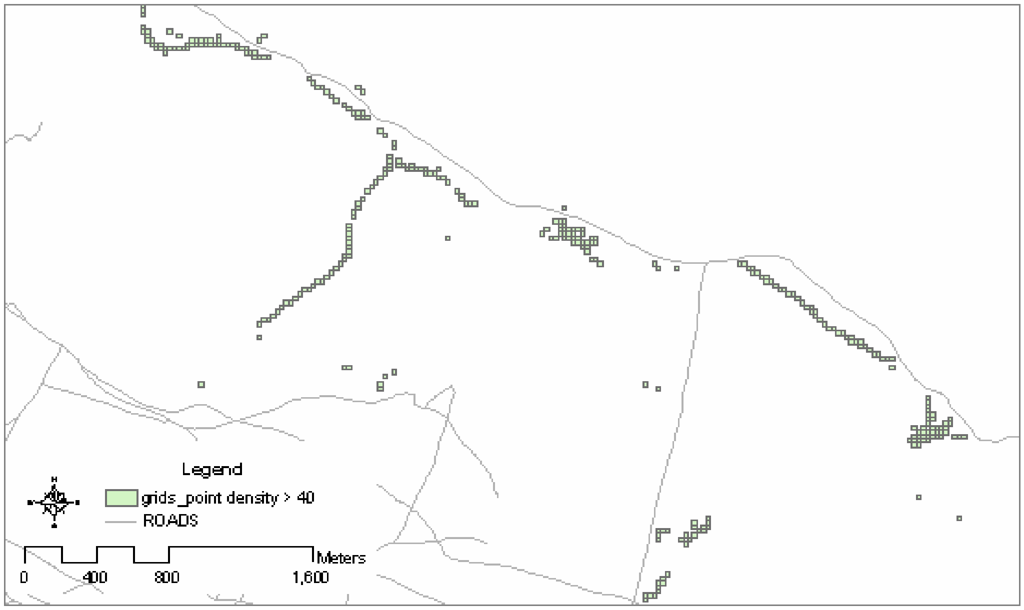


*Figure 7-10 Potential road grids predicted by point density method in the screen line area*

indicates a strong relation between the point density and criteria levels. The comparison of the point densities and the criteria levels based on all off-road grids is shown in Figure 7-11. A trend can be observed that the point density increases with the criteria level, except a deviation at criteria level four. This deviation may indicate that one of the five criteria may not relate to the point density.

The prediction from the point density method for each visited road segment was compared to the site observed result to evaluate this simplified method. Results are shown in Table 7-6 and Figure 7-12 . The point density method was able to identify the potential road segments with high concentrated traffic with 100% accuracy; but can not identify the segments with low point densities.

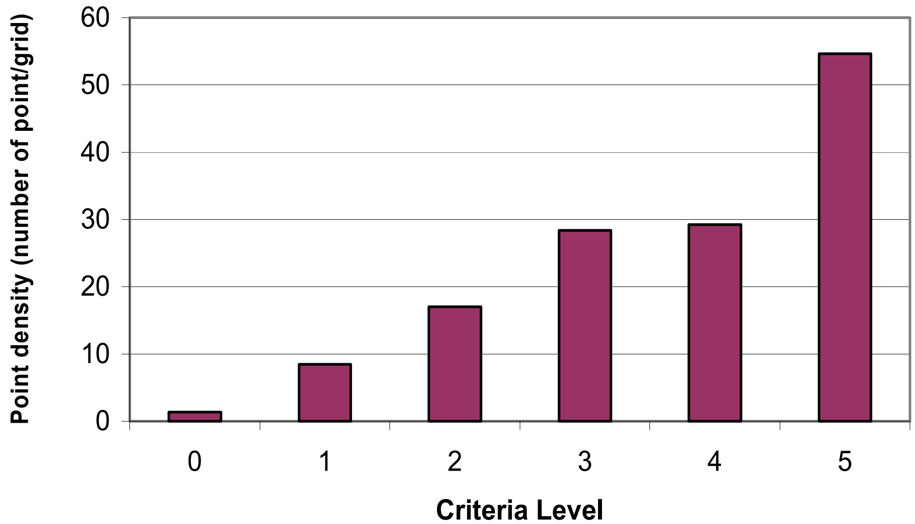


*Figure 7-11  Point density vs. criteria level*

*Table 7-6 Accuracy of the point density method prediction*

| Point density | Number of visited roads | Number of observed roads | Possibility for road existence (%) |
|---|---|---|---|
| <20 | 14 | 6 | 42.9 |
| 20-40 | 10 | 1 | 10 |
| >=40 | 10 | 10 | 100 |

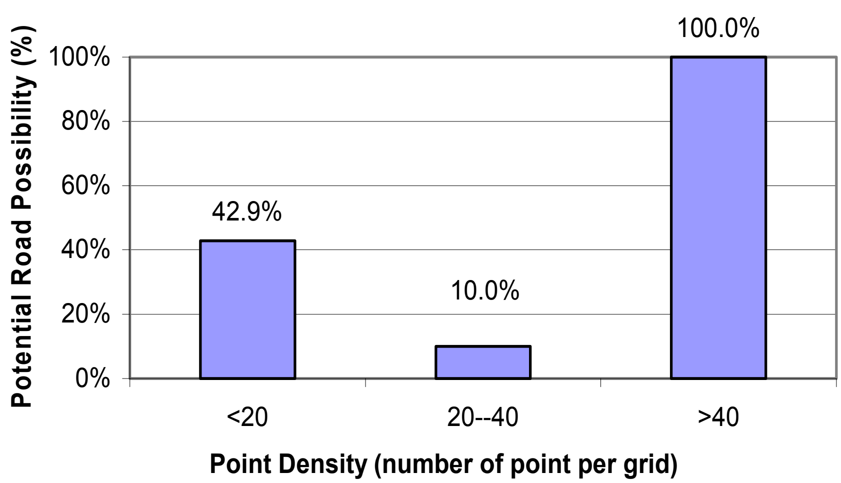


*Figure 7-12 Potential road possibility vs. point density*

### 7.2.2 Velocity

As described in Section 7.2.1, the point density method was not able to identify the road segments with low density. Considering that the velocity is inversely related to point density, the velocity used as the uni-variable to identify the potential roads is discussed in this section. Analysis of the average velocity for the grids met different criteria levels for all off-road grids shows a relationship presented in Figure 7-13: velocity on these areas met less than four criteria is slightly lower; the overall variation between the average velocities is not large. A correlation coefficient calculated for the average velocity and criteria levels is less than 0.12, indicating a weak relation between these two. It is expected since the velocity factor was not included in the multicriteria method. Velocity is expected to be more informative for identifying the rerouted roads instead of newly formed roads by repeated traffic during the exercise.

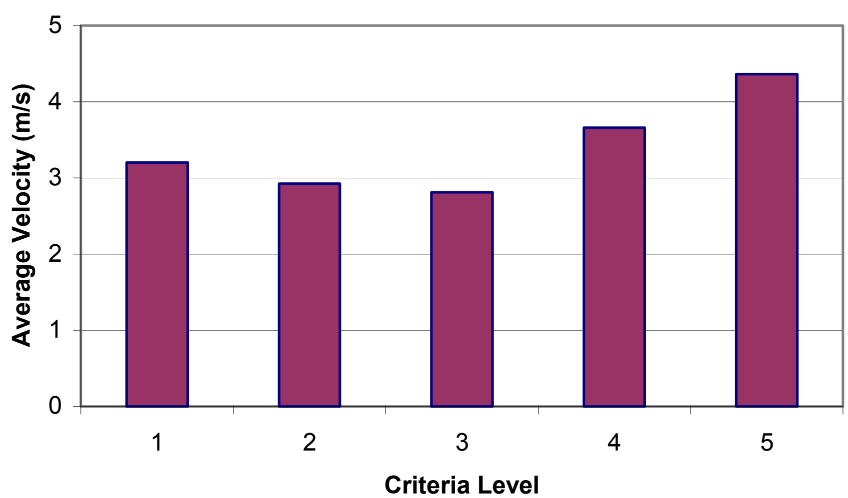


*Figure 7-13 Relationship between velocity and criteria levels*

The velocity analysis for the visited grids was conducted to estimate the efficiency of the simplified method by using only one parameter velocity to identify potential roads. Table 7-7 shows the observed results for the visited areas at different speed levels; and Figure 7-14 shows the possibility of road existence. Based on the results, the possibility of a grid to be identified as potential road grids can be estimated as a function of the average velocity within the grid. Locations with the average velocity greater than 6 m/s are expected to have good opportunity for a road existence.

### 7.2.3 Number of passes

The density of off-road traffic can also be characterized as the number of vehicles' passes at a certain location. Based on the vehicles' maneuvers over the large scale training area during the training exercise, a method was developed for estimating the number of vehicle passes at a certain location. Since the GPS vehicle tracking data were collected every one second, the distance the vehicle traveled can be estimated as the sum of the velocities associated with the GPS points. Within a 10-meter search radius, the sum of the velocities for all the GPS points falling inside the search area provides the total travel distance within the certain location. The number of passes can be approximated by calculating the ratio of the total travel distance over the diameter of the search area. Low cross track error can increase the accuracy of the approximation. Assuming $n$ points fall within a area with a search radius denoted as $R$, the velocity for the $i^{th}$ point is $V_i$ , the passes for a certain location can be calculated as:

*Table 7-7 Accuracy of velocity method for potential road prediction*

| **Velocity** | **Number of visited roads** | **Number of observed roads** | **Possibility for road existence (%)** |
|---|---|---|---|
| <3 | 10 | 2 | 20.0 |
| 3--4 | 9 | 3 | 33.3 |
| 4--6 | 9 | 6 | 66.7 |
| >6 | 6 | 6 | 100.0 |

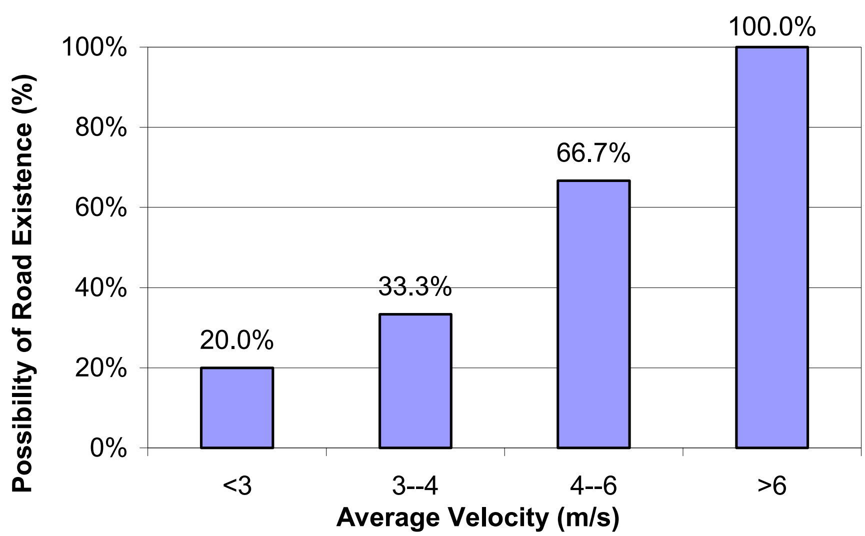


*Figure 7-14  Potential road possibility vs. velocity*

$$Passes = \frac{\sum_{i=1}^{n}(V_i)}{2*R}. \quad (3)$$

Figure 7-15 shows an example for approximating the number of passes at a certain location. The Neighborhood Statistics function provided by ArcGIS enables this approximation. As a result, a raster file was created indicating the number of passes for each 10 by 10 square meter area (the output raster file cell size was set to be 10 by 10 square meter). The off-road grids can be classified into locations with different traffic levels based on the number of passes: single pass, two passes, three passes, four passes, and more than four passes. Figure 7-16 shows the locations with more than two passes in the screen line area; it identified most of the visited segments for this training zone. The comparison of the identified potential road segments by only considering the number of passes and the site visit result is shown in Table 7-8. The prediction accuracy is shown in Figure 7-17. Clearly, the possibility of the potential road existence increases with the number of passes: a simple linear relation can be observed in Figure 7-17.

Due to the different size of the grids (10 by 10 square meter) used for estimating the number of passes, additional procedure is required to assign the number of passes averaged from 10 by 10 square meter grids to the 25 by 25 square meter grids. The center point for each 10 by 10 square meter grid was extracted and assigned the value representing the number of passes within to form a point shape file. Each of the 25 by 25 square meter off-road grids averaged the values from the points falling inside to estimate the number of passes.

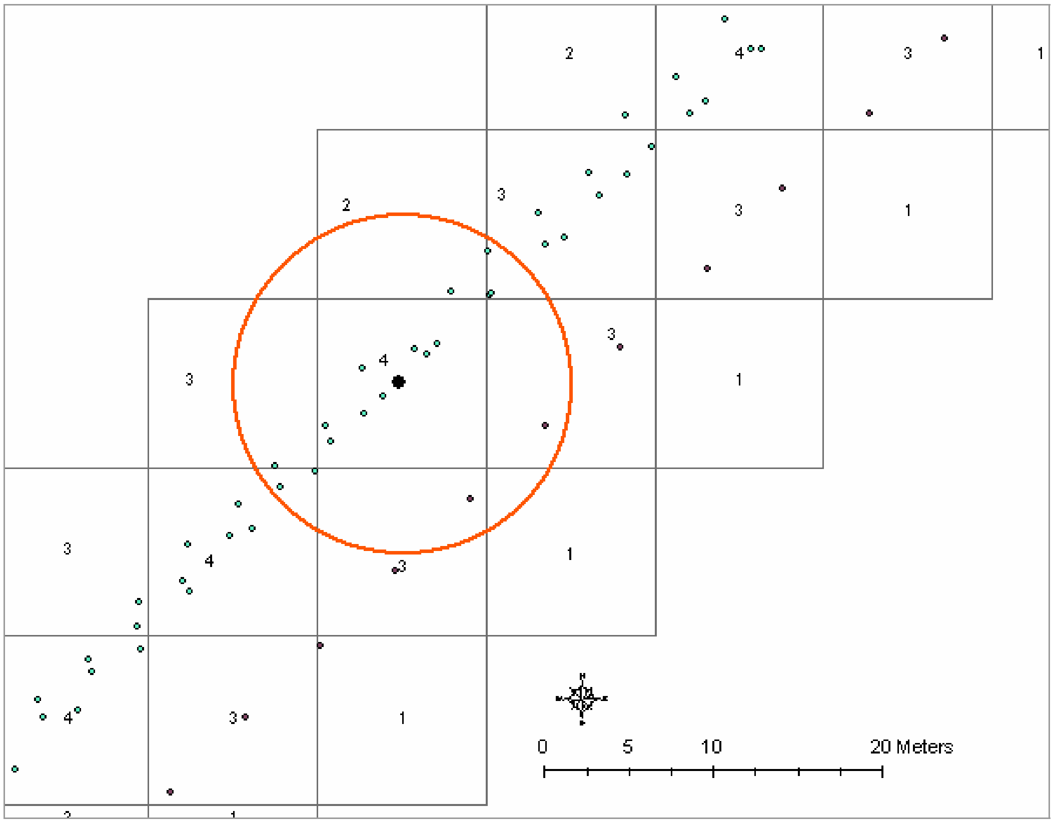


*Figure 7-15 An example for approximating the number of passes*

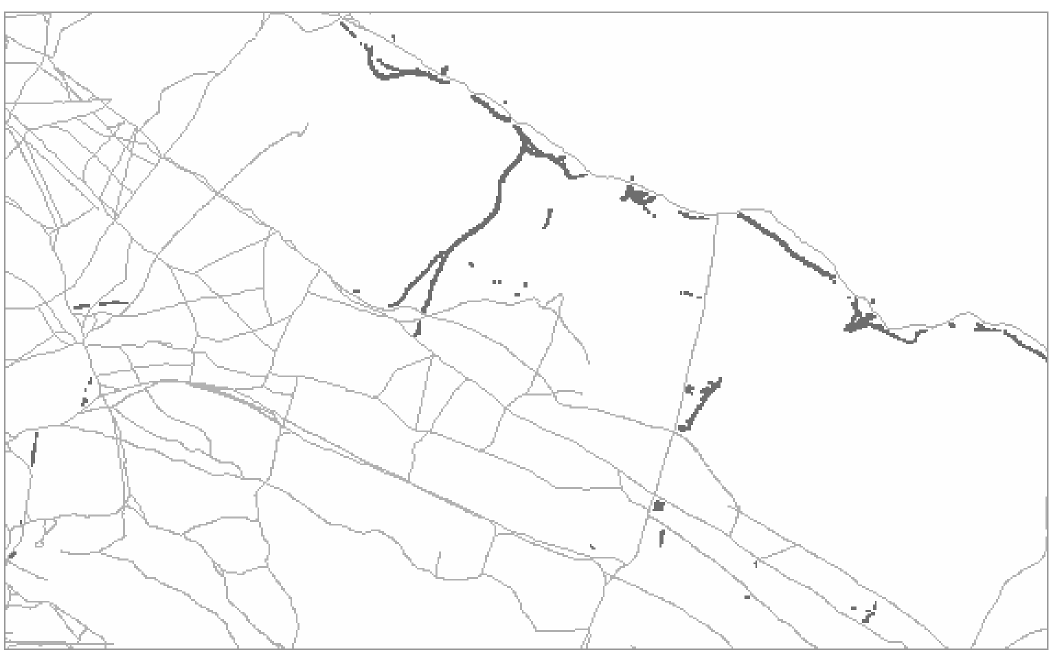

*Figure 7-16 Locations with more than two passes in the Screen line area*

*Table 7-8 Comparison of number of passes method to site visit results*

| Number of Passes | Number of visited roads | Number of observed roads | Possibility for road existence (%) |
|---|---|---|---|
| 1~2 | 9 | 0 | 0 |
| 2~3 | 11 | 4 | 36.4 |
| 3~4 | 4 | 3 | 75 |
| >4 | 10 | 10 | 100 |

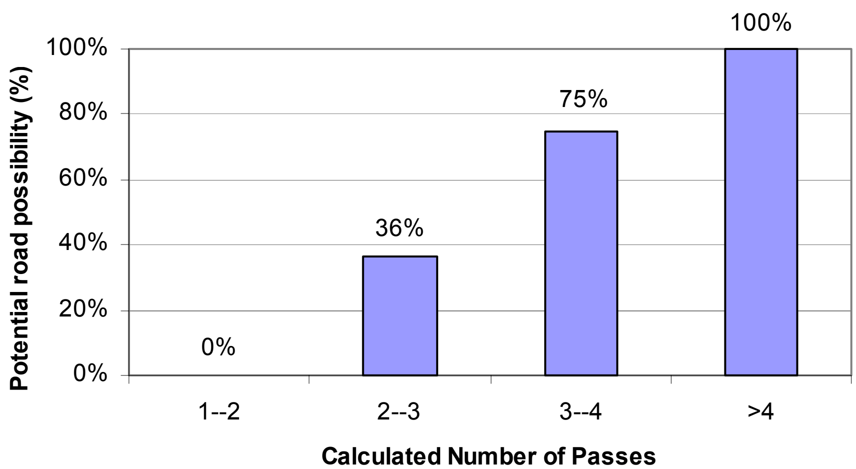


*Figure 7-17 the prediction accuracy for the number of passes method*

The relation between the number of passes and the criteria levels were analyzed for all off-road 25 by 25 square meter girds; the result is shown in Figure 7-18. Clearly, the number of passes at a certain grid increases as the number of criteria met by a grid increases; or as the vehicles' passes increases in a certain location may result in a higher criteria level met by the location. The correlation coefficient for the number of passes and criteria level is 0.6, which is the highest among the three variables used to simplify the potential road method.

## *7.3 Comparison and Recommendation*

The correlation coefficients for different criterion for the multicriteria method and the three variables for simplifying the method were calculated in Excel and are

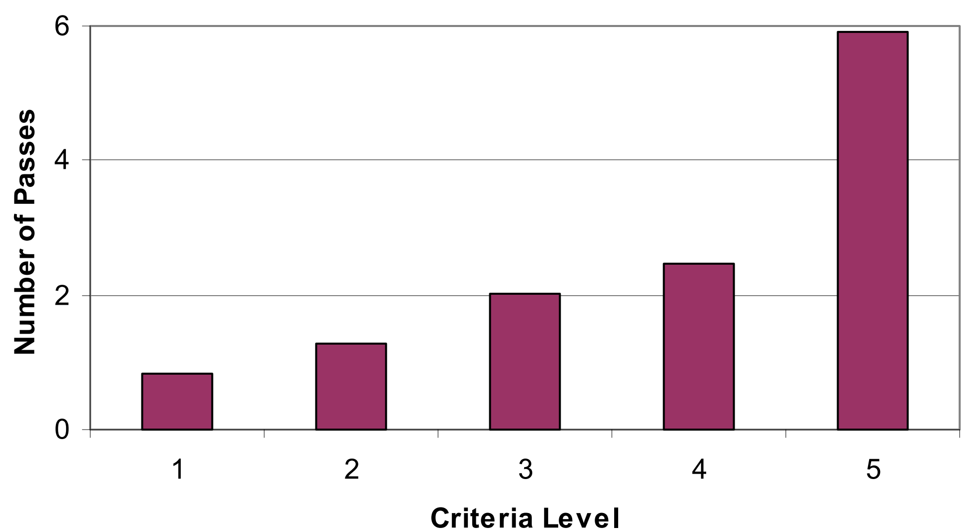


*Figure 7-18 Number of passes vs. criteria level*

shown in Table 7-9. It can be observed from Table 7-9 that the point density, the number of passes, and the criteria level were highly related: the correlation coefficients are close to 0.6. Comparing Figure 7-17 to Figure 7-14 and Figure 7-12, the simplified method using the number passes as uni-variable for potential road identification (termed as "passes method") seems to be the most efficient among the three.

Comparing the NN method to the passes method, the passes method may also be considered as the better method because that: 1) the passes method requires only one variable for inputs; 2) the relation between the number of passes and the possibilities of road existence is simpler; 3) the predicted results are more flexible: different certainty levels can be assigned to a grid based on the simple linear relation (Figure 7-17); 4) the passes method is more practical than the NN method. The passes method is suggested to be applied for identifying the potential roads. Considering that the uncertainties associated with the passes method has not been investigated in detail, further study is needed to be conducted to explore the source of the uncertainties and to quantify them.

*Table 7-9 Correlation coefficients for criteria and variables*

| | Criteria Level | Pnt_2 | V_num | dif_trp | dif_day | dif_dir | Point Density | Velocity | Number of Passes |
|---|---|---|---|---|---|---|---|---|---|
| **Criteria Level** | 1 | | | | | | | | |
| **Pnt_2** | 0.00 | 1 | | | | | | | |
| **V_num** | 0.84 | -0.07 | 1 | | | | | | |
| **dif_trp** | 0.80 | -0.03 | 0.65 | 1 | | | | | |
| **dif_day** | 0.88 | -0.04 | 0.65 | 0.74 | 1 | | | | |
| **dif_dir** | 0.75 | -0.04 | 0.44 | 0.36 | 0.52 | 1 | | | |
| **Point Density** | 0.56 | 0.04 | 0.46 | 0.42 | 0.48 | 0.46 | 1 | | |
| **Velocity** | 0.11 | -0.07 | 0.10 | 0.18 | 0.14 | 0.01 | -0.14 | 1 | |
| **Number of Passes** | 0.60 | 0.00 | 0.48 | 0.53 | 0.53 | 0.41 | 0.67 | 0.25 | 1 |

# CHAPTER 8 - KERNEL SMOOTHING APPLIED IN POTENTIAL ROAD IDENTIFICATION

Considering the discrete situation in the predicted potential road areas, a kernel smoothing technique was introduced and applied to smooth the results to improve the continuity of the potential roads. Results show that by selecting reasonable bandwidth, the kernel smoothing technique can obtain continuous potential road grids.

## *8.1 Kernel Smoothing*

Kernel smoothing (or kernel density estimator) refers to a general class of techniques for nonparametric estimation of functions (Wand and Jones, 1995). The value of the estimate at certain point is obtained by using weighted least squares, where the weights are chosen according to the height of the kernel function. This means that the data points closer to the estimated location have more influence on the fitting than those far away from the location. This local auto correlation is also a fundamental geographic principal (Tobler, 1970).

Kernel smoothing has been widely used to solve spatial related problems. Seaman et al. (1998) developed a Kernel Home Range program KERNELHR to estimate animal home ranges by using fixed or adaptive kernel. Borruso and Schoier (2004) used kernel

density estimation to detect areas of high services' supply in an urban environment. Lindenmayer *et al.* (1995) applied a kernel method for predicting the spatial distribution of arboreal marsupials. Rakha *et al.* (2001) compared several smoothing techniques, and found that a robust smoothing (kernel of exponential) can remove invalid GPS data without significantly altering the underlying measured speed profile.

## *8.2 Choosing the Kernel Function*

Spatial smoothing or estimation problems can be considered as multivariate kernel estimation problems. Several studies showed that the kernel density estimator is an effective tool for displaying structure in bivariate samples ( Silverman, 1986; Scott, 1992), and even for in three and four dimensional data sets (Scott, 1992).

The most general form of d-dimensional kernel density estimator is

$$\hat{f}(X;H) = \frac{\sum_{i=1}^{n} K_H(X - X_i)}{n} \quad \textit{(Deheuvels, 1977),} \tag{4}$$

where H is a symmetric positive definite $d \times d$ matrix called the bandwidth matrix, $K_H(X) = |H|^{-1/2} K(H^{-1/2} X)$, and K is a d-variate kernel function satisfying $\int K(x)dx = 1$. The kernel function is often taken to be a d-variate probability density function. A popular choice for K is the standard d-variate normal density:

$$K(X) = (2\pi)^{-d/2} \exp(-\frac{1}{2} X^T X). \tag{5}$$

When d = 2, the standard bi-variate normal density becomes:

$$K(X) = (2\pi)^{-1/2} \exp(-\frac{1}{2} X^T X) . \qquad (6)$$

In ArcGIS, Spatial Analyst (ESRI, 2002) supports only two kernels. One is the unweighted circular kernel:

$$\begin{cases} \mathrm{K}(\mathrm{r},\theta) = \dfrac{1}{\pi \mathrm{R}^2} & (r < R) \\ \mathrm{K}(\mathrm{r},\theta) = 0 & (r \geq R) \end{cases} \qquad (7)$$

where $r$ is the distance from a location to the point; $R$ is the search radius. The other is a quartic approximation to a Gaussian kernel (ESRI, 2004; Silverman, 1986):

$$\begin{cases} \mathrm{K}(\mathrm{r},\theta) = \dfrac{3}{\pi}(1-(\dfrac{r}{R})^2)^2 & (r < R) \\ \mathrm{K}(\mathrm{r},\theta) = 0 & (r \geq R) \end{cases} . \qquad (8)$$

Most calculations in the Spatial Analyst are based on raster data. A space with a given extent will be divided into cells with user defined cell size before conducting the analysis. Conceptually, the kernel density estimation includes two major steps: First, a smoothly curved surface is fitted over each point: the highest value at the location of the point; the surface value diminishes with the increasing distance from the point. Second, the density at each output raster is calculated by adding the values of all the kernel surfaces where they overlay the raster cell center. As an example, a single point was used to calculate the density in ArcGIS using kernel density estimation function with a 10-meter search radius. The cell size was set to be 1 by 1 square meter for the output density

raster file.  Figure 8-1 demonstrates the example: the red point in the middle is the sample point; the three blue points are the center points of three randomly selected cells; the surface on the top demonstrates the resulted kernel density surface; the marked values show the density value calculated for the three selected cell.  Adding up the values for all the cells resulted in a value approximately equal to 1 (0.999958).

As mentioned by Wand and Jones (1995), the choice of the shape of the kernel function is not a critical issue.  The kernel density estimation function in ArcGIS will be directly used to improve the continuity of the identified potential road grids.

## *8.3 Bandwidth Selection*

The efficiency of using kernel smoothing methods depends on the selected bandwidth. Bandwidth $h$ is usually called a smoothing parameter due to that it controls the amount of "smoothing" being applied to the data. Bandwidth selection is one of the critical central issues in kernel smoothing. If a bandwidth is too small, the resulting density or regression estimate is too rough, and may also cause overfitting. If a bandwidth is too large, important features of the underlying structure are smoothed away.

The bandwidth selection is an area well studied in kernel estimation.  Jones *et al.* (1996) presented a brief survey of bandwidth selection for density estimation. Relevant summary can also be found in the book “kernel smoothing” (Wand and Jones, 1995), and in the report of Turlach (1993). These bandwidth selection methods include: rule of thumb; least-squares cross-validation (Rudemo, 1982; Bowman, 1984); biased cross-validation (Scott and Terrel 1987); plug-in bandwidth selection (Sheather and Jones 1991); smoothed cross-validation (Hall et al., 1992); root-n bandwidth selection

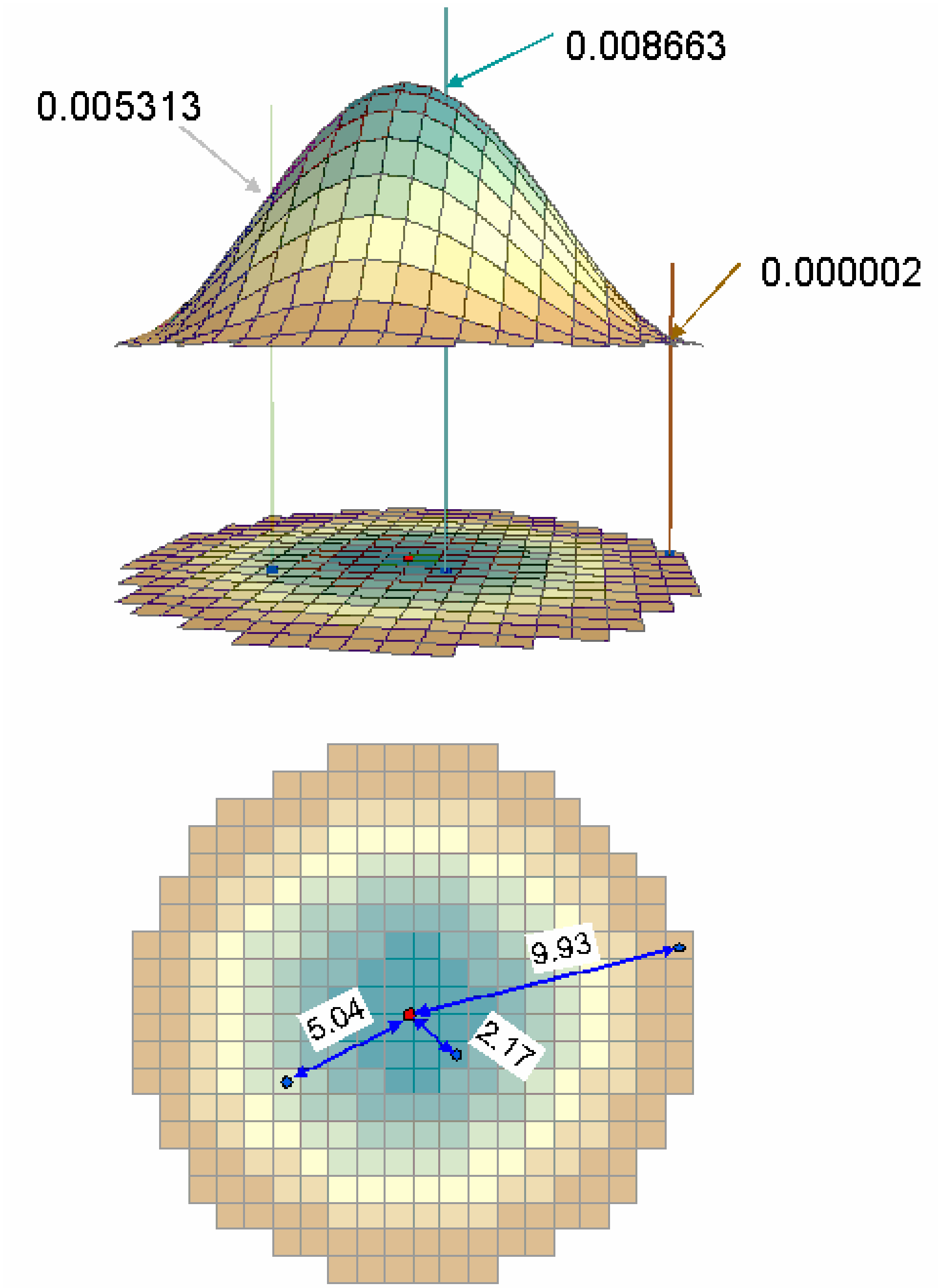


*Figure 8-1 A demonstration for kernel density estimation in ArcGIS*

(Hall et al., 1991); and The Contrast Method (Ahmad and Ran, 2004)  Jones *et al.* (1996) grouped the bandwidth selection methods into two generations: "first generation" and "second generation": most of the "first generation" methods were developed before 1990; the "second generation" refers to those methods with superior performance, both theoretically and practically.  Most of the bandwidth selection methods are based on minimizing the MSE or the MISE (Mugdadi and Ahmad, 2004).

For the Gaussian kernel and a normal reference distribution, the rule of thumb is to choose a bandwidth:

$$h_G = 1.06 * \hat{\sigma} * n^{-1/5} \text{ (Härdle and Simar. 2003),} \quad (9)$$

where $\hat{\sigma} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}}$ denotes the sample standard deviation. This $h_G$ optimizes the integrated squared error between the estimator and the true density.

For the quartic kernel, the modified rule of thumb is:

$$h_Q = 2.62 * h_G = 2.78 * \hat{\sigma} * n^{-1/5} \text{ (Härdle and Simar, 2003).} \quad (10)$$

Considering that the criteria for selecting the potential road areas were created subjectively and qualitatively. A variety of uncertainties exist in the input factors and in the method itself. It is difficult to select a bandwidth by using foresaid analytical bandwidth selection methods. Different bandwidths were selected based on experience for generating the density surface and the smoothing results were compared.

### *8.4 Application in PR ID*

As mentioned in Section 6.5, the map with a 5 by 5 square meter resolution resulted in discrete potential road grids (Figure 6-30). Kernel smoothing method was applied to improve the continuity of the potential road grids that were identified by using the 5 by 5 square meter study units. This kernel smoothing technique was only applied to the screen line area (Figure 8-2).

In order to use the kernel density function in ArcGIS, each 5 by 5 square meter grid was converted to a point, which is the position averaged from the GPS vehicle tracking data fall inside the grid. Each point will contain a potential road possibility calculated based on the criteria level met by the grid.

Based on the results from the multi-criteria method evaluation, the criteria level can be associated with a possibility for potential road existence (Figure 8-3). Notice that the possibilities shown in Figure 8-3 were calculated based on grids instead of segments; they are slightly different from what was shown in Figure 6-16, which were calculated based on road segments. All the 5 by 5 square meter grids in the screen line area can be represented by the sampling points (shown in Figure 8-4). Figure 8-5 demonstrates an area for the sampling points and grids in detail.

The kernel density surface was generated based on the sampling points that used the potential road possibility as the population. The population is the item used in kernel density estimation in ArcGIS to determine the number of times to count the point; it can be used as the weight to determine the contribution from each point. As a result, the locations with higher density values indicated the higher possibility to be potential roads.

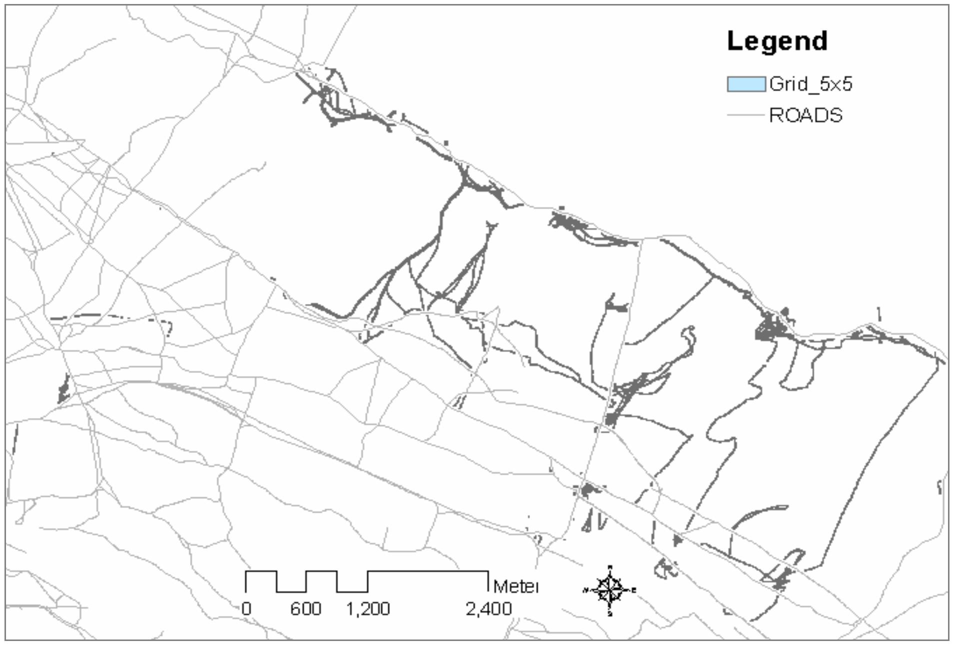


*Figure 8-2 Selected grids with size 5 by 5 square meter in the screen line area*

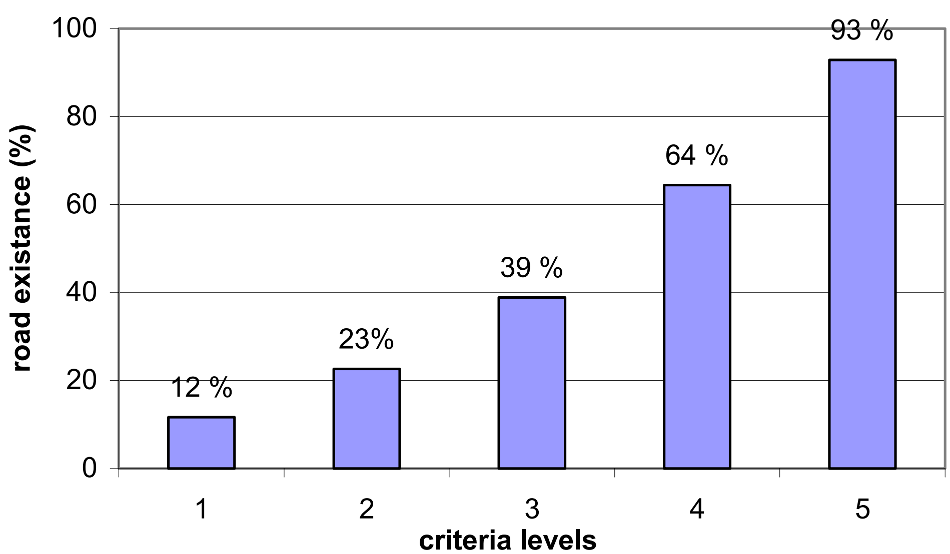


*Figure 8-3 Criteria levels vs. potential road possibility*

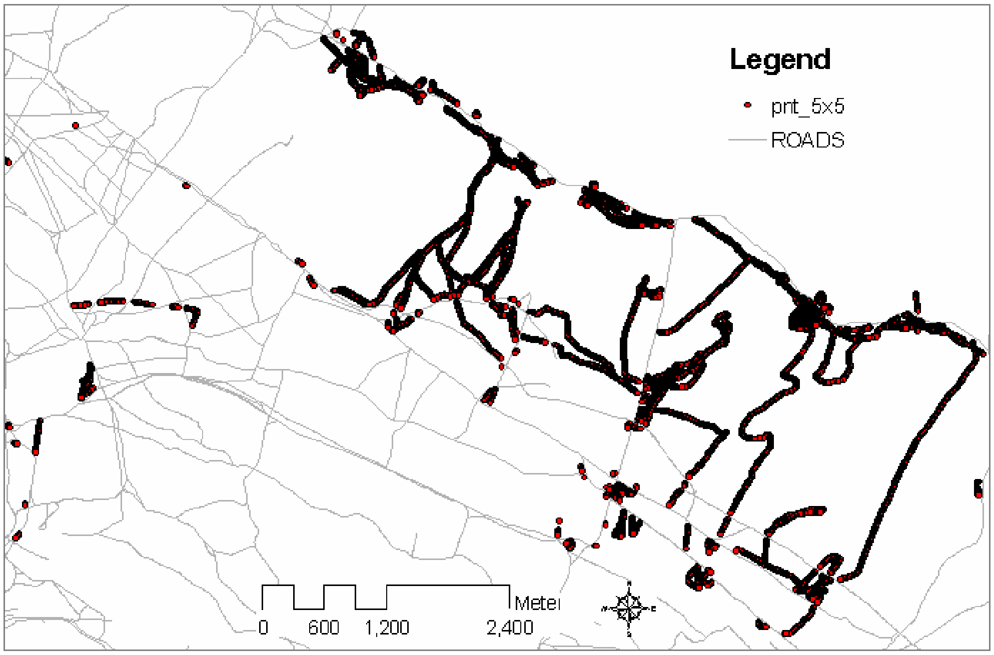


*Figure 8-4 Sampling points created from the selected grids*

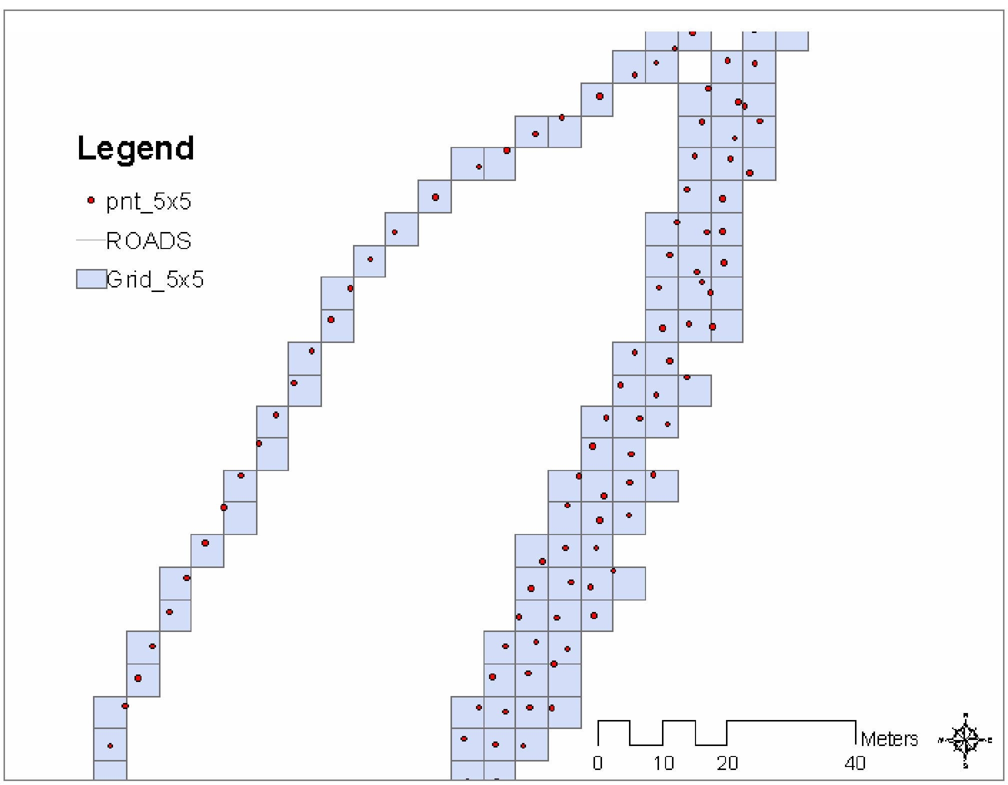


*Figure 8-5 A detailed part shown the sampling points in the screen line area*

Figure 8-6 shows an example for generating the kernel density surface from five sample points (shown in Figure 8-7): each point was assigned the potential road possibility value as the population.

The different bandwidths (or search radii) selected for calculating the kernel density surfaces increase from 5 m to 50 m, the output cell sizes were set to be the same: 5 by 5 square meter. The smoothing results for different kernel density surfaces were compared visually instead of quantitatively. The kernel density results by using different search radii are shown as following: Figure 8-8 for 10 m bandwidth, Figure 8-9 for the 20 m bandwidth, Figure 8-10 for the 30 m bandwidth, and Figure 8-11 for the 40 m bandwidth. From Figure 8-8 to Figure 8-11, the density surface changes from sharp to smoother; but the important features in the middle area was gradually smooth away when the bandwidth was getting larger. The areas with relatively higher density value were selected from the density result using a 20 m bandwidth and compared to the results from the multi-criteria method; the comparison (Figure 8-12) shows the improvement on the continuity of the potential roads. Due to the manipulation method used by Spatial Analyst in ArcGIS, the cell size was found also influence the smooth of the resulted surface.

This chapter introduced basic concepts of kernel smoothing and the kernel density estimation in ArcGIS. It demonstrated the application of kernel smoothing techniques as an approach for improving the continuity of potential road grids. The continuity of potential road grids could be improved by selecting a reasonable search radius. ArcGIS Spatial Analyst also provides several focal functions that allow smoothing the output

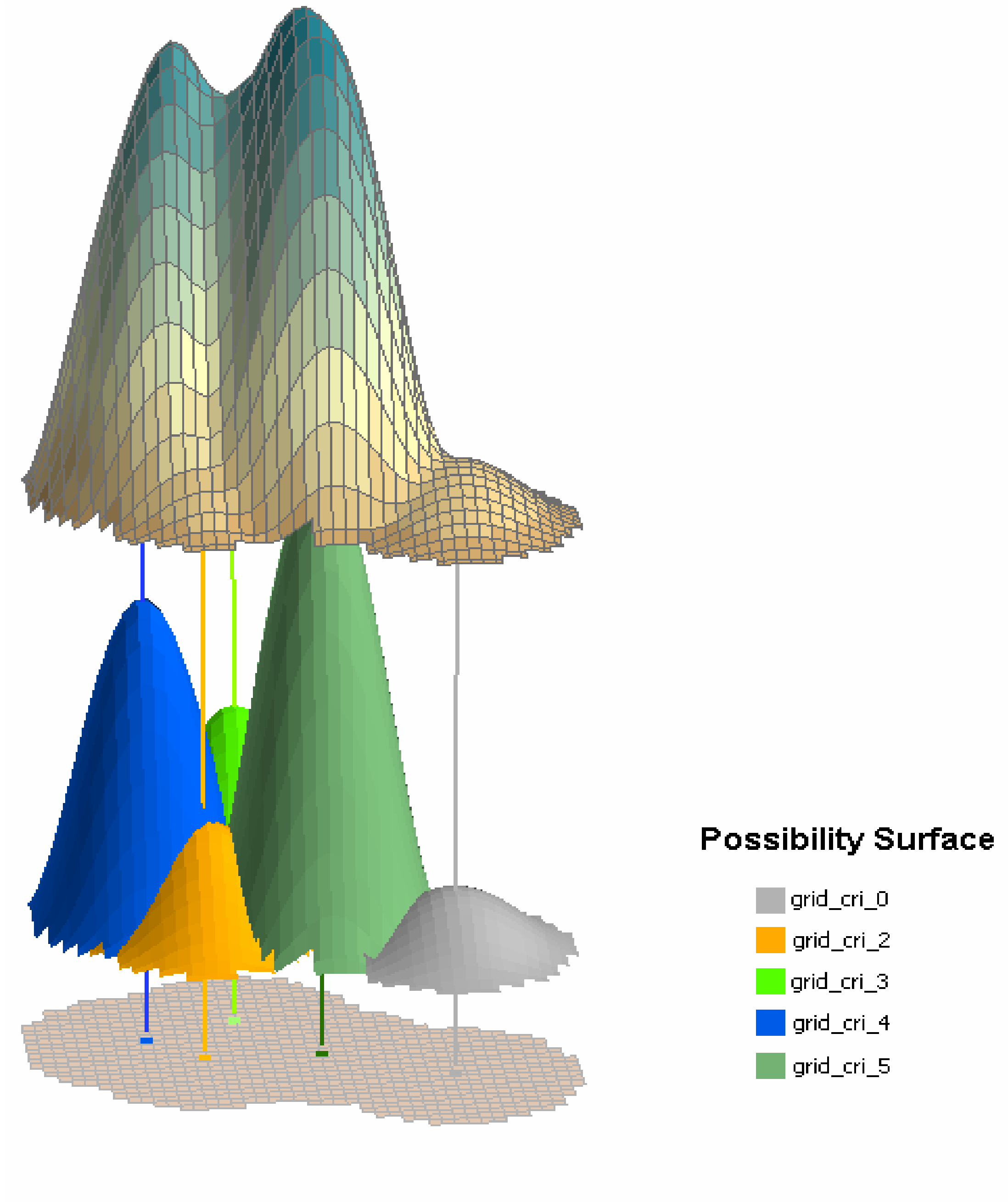


*Figure 8-6 Kernel density surface demonstration*

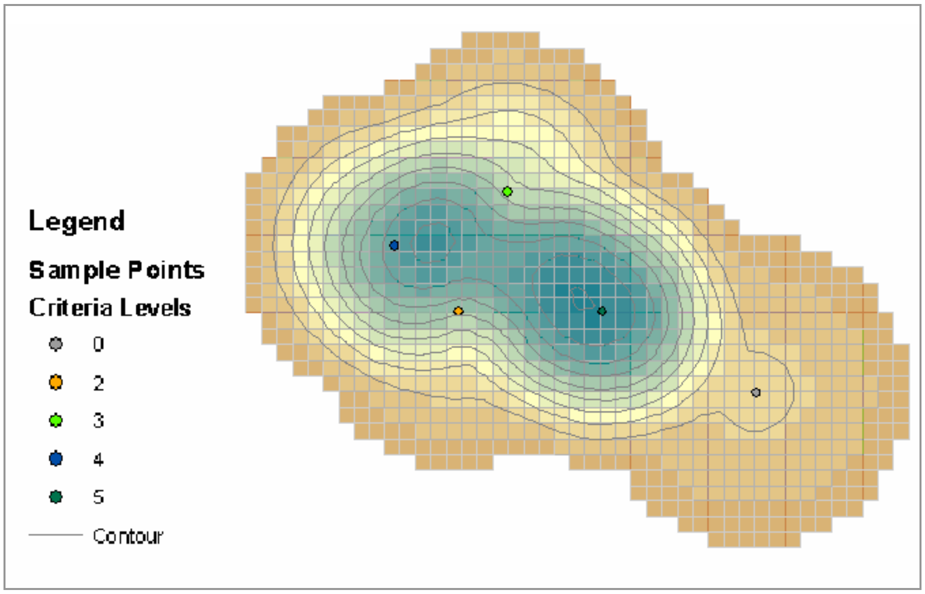


*Figure 8-7 Sample points met different criteria levels*

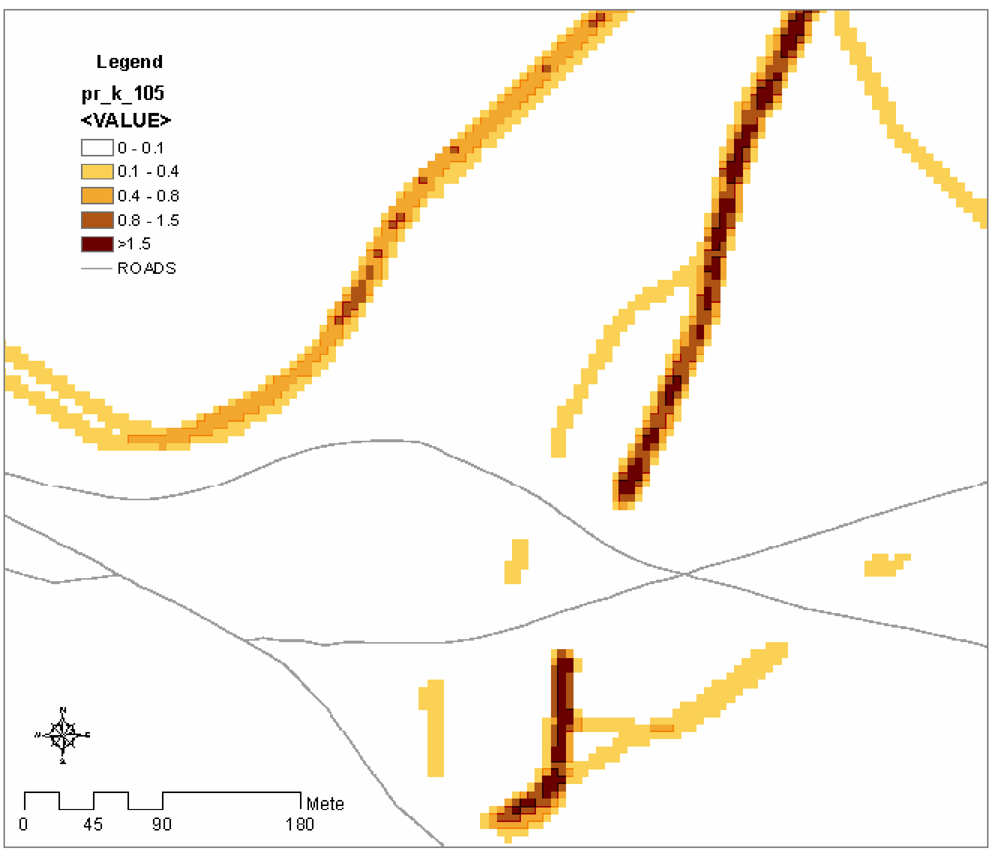


*Figure 8-8 Smoothing result by using the 10 m bandwidth*

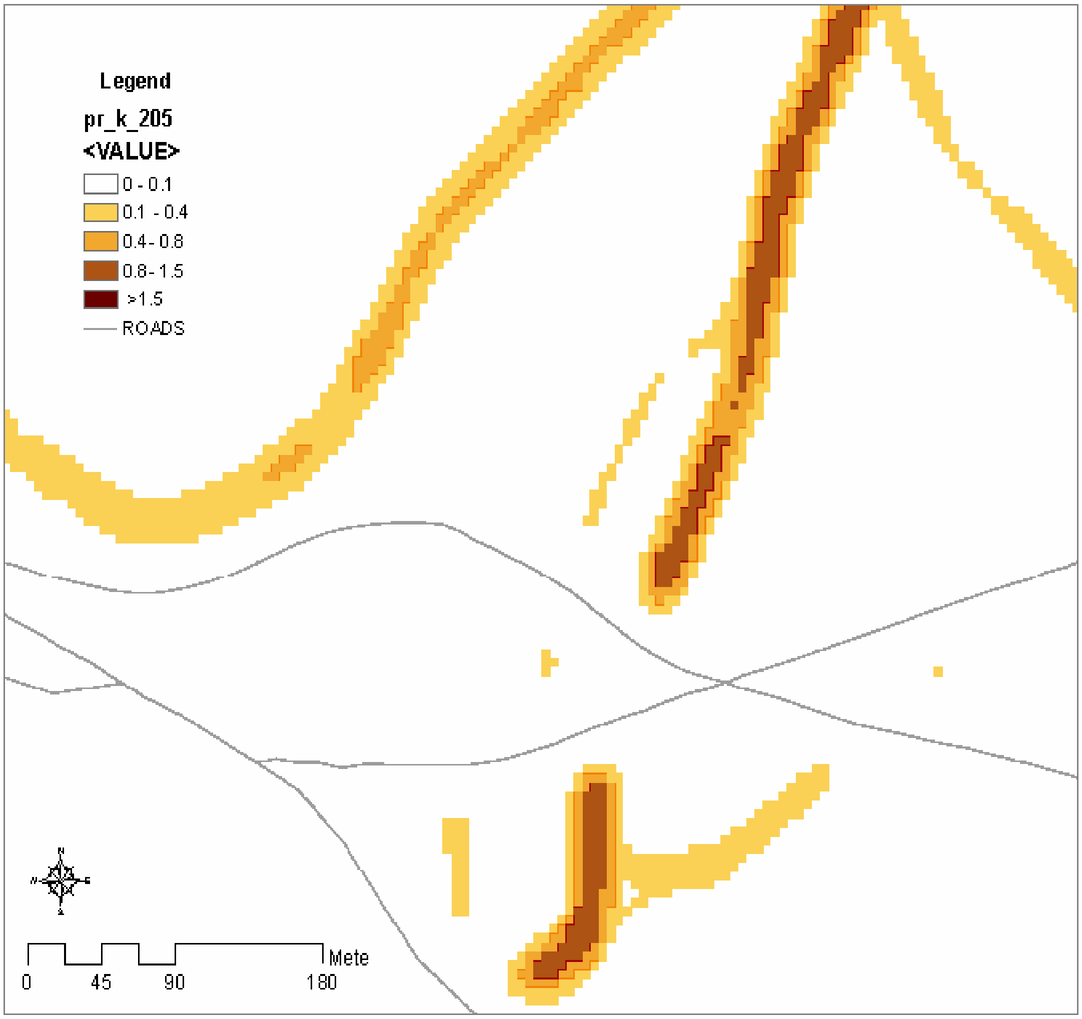


*Figure 8-9 Smoothing result by using the 20 m bandwidth*

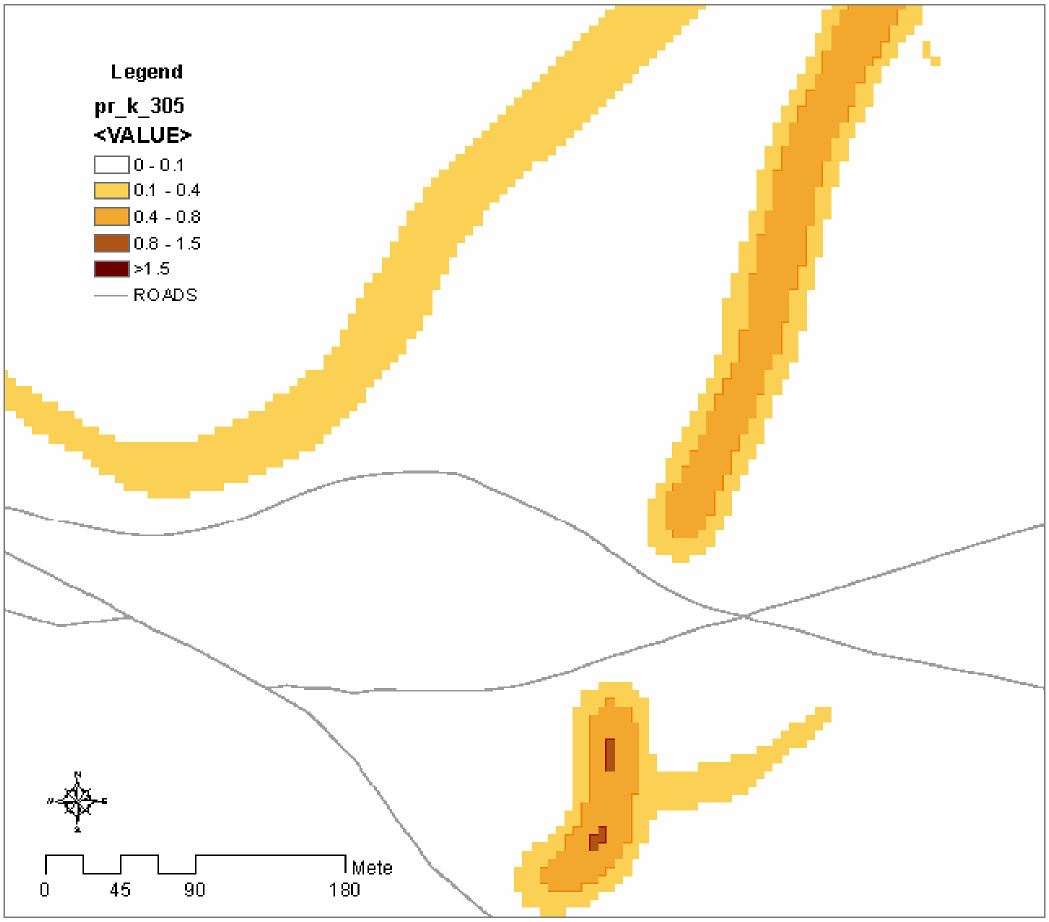


*Figure 8-10 Smoothing result by using the 30 m bandwidth*

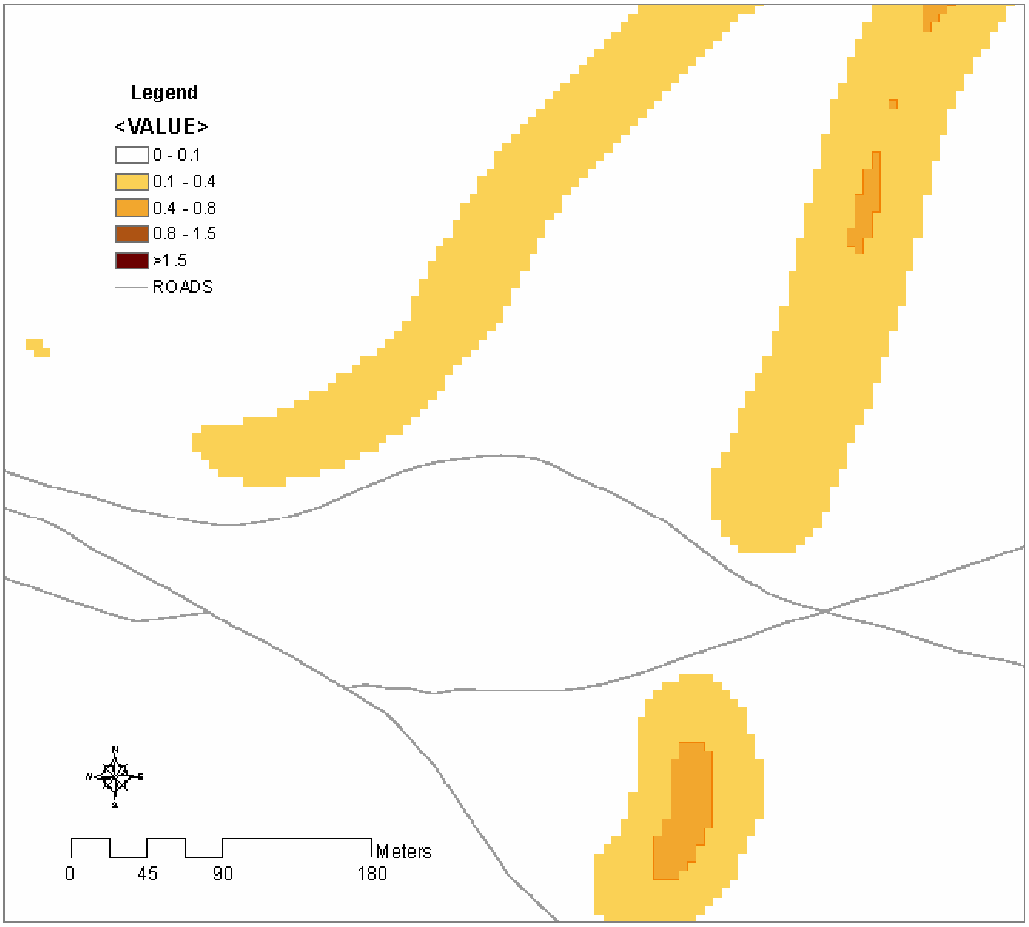


*Figure 8-11 Smoothing result by using a 40 m bandwidth*

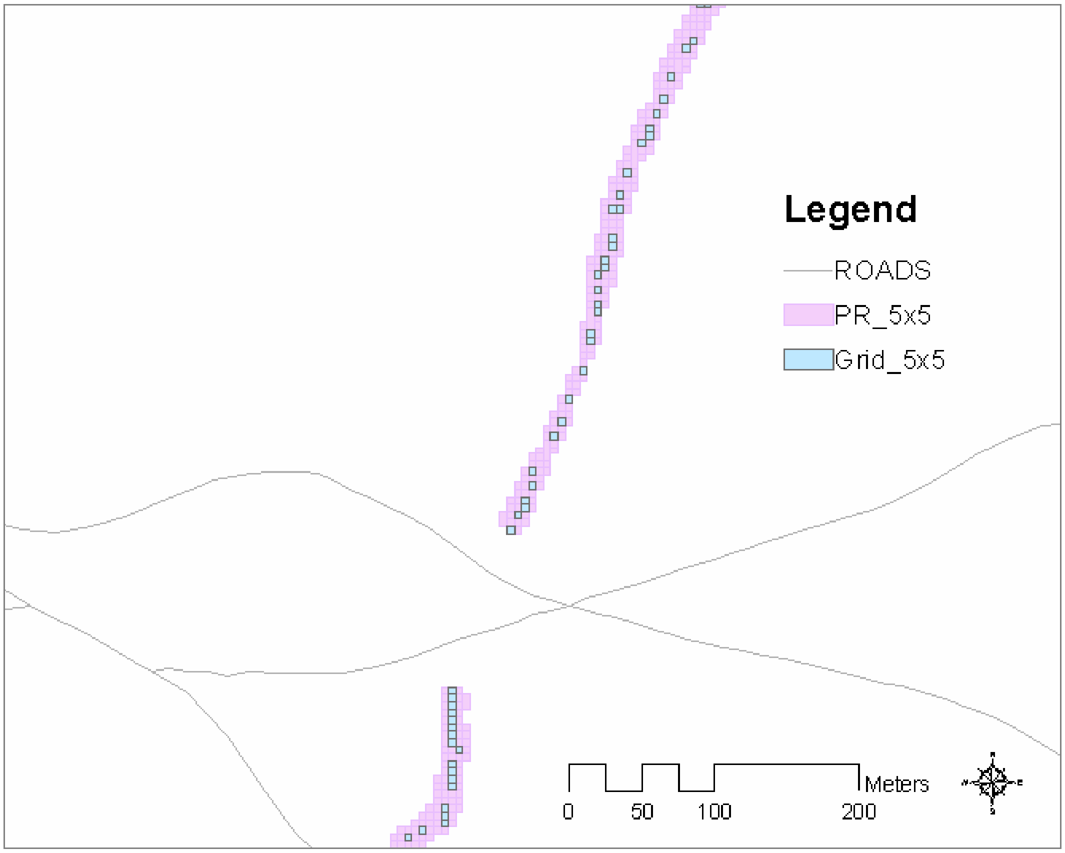


*Figure 8-12 Potential road selected after the kernel smoothing*

surface. For example, the Neighborhood Statistics computes an output raster where the value at each location is a function of the input cells in some specified neighborhood of the location; also surface interpolation functions create a continuous (or prediction) surface from sampled point values. The smoothness and contiguity of the potential road segments can be improved by using an integrated method combining the foresaid techniques.

# CHAPTER 9 - CONCLUSION

## *9.1 Summary of the Study*

Military training is an intensive land use and may cause negative environmental effects. Many studies have been conducted under Integrated Training Area Management (ITAM) to quantify the impacts resulted from the military training exercise. Results show that off-road vehicular activities during training exercises cause the major impact to the training land. Vehicle land use pattern at a certain location is one of the important factors determining the impact severity: concentrated and repeated traffic create more serious damage to the land than dispersed off-road vehicle movements. Those areas heavily disturbed by off-road traffic may require longer time or special treatments for the land to return to its pre-disturbed status. Based on the severity and the shape of the land disturbance, some areas can be considered as potential roads, defined as the roads formed by concentrated off-road traffic during the military training exercises, or the roads currently exist but not indicated on the road map. Potential roads need to be rehabilitated, have traffic dispersed to return the land to its natural status, or to be included in the established road construction and maintenance programs.

Global Positioning System (GPS) can be used for monitoring vehicle activities during military training exercises; it enables the analysis of vehicle movement patterns

during training exercises. GPS vehicle tracking data collected during an eight-day reconnaissance training exercise in Yakima Training Center (YTC) in October 2001 was analyzed for vehicle movement patterns. Vehicle movement patterns were characterized as the percentage of vehicle travel per day, vehicles' on and off road travel, the frequencies of vehicle's off-road velocity and turning radius.

Comparison of the on-road off-road movement patterns indicates that potential roads may exist where the concentrated traffic or a high speed movement occurred. Based on the analysis of the movement patterns, factors were extracted to characterize and relate vehicle movement patterns to potential roads. These factors include: 1) the number of different vehicles passed a certain location; 2) if the vehicles that passed the area belong to the same troop or different troops; 3) if the vehicles passed the location within one day or during different days; and 4) if the vehicles passed the location in the same direction or in two opposite directions. Criterion based on summarized GPS vehicle tracking data was developed to characterize each of the factors. The total number of criterion met by a location indicates the possibility to be a portion of a potential road.

The YTC was divided into small study units (25 by 25 square meter grids), and a multicriteria method was developed to identify if a study unit is a portion of a potential road or not based on the vehicle movement patterns occurred within the study unit. As a result each grid obtained a value indicating the number of criteria met by the grid. Those contiguous grids with similar criteria levels were clustered as potential road clusters. The length and elongation of the clusters were investigated to select those with relatively larger length and elongation values to finally form the potential road segments.

The multicriteria method was evaluated by comparing the predictions to the site visit results on 34 selected road segments meeting different criteria levels. A total of 17 roads were observed during the site visit, including three military road classes: class 2, class 3, and class 4. Results show that locations meeting higher criteria levels have higher possibilities to be roads: the location met all five criteria has an approximately 91% possibility for road existence; those met four criteria has an approximately 55% possibility; and for those met criteria level two or three, there is an approximately 14% probability for road existence. The analysis of updated off-road shows the percentage of vehicle off-road movement drops from 20.0% to 15.8% after excluding the potential road moving data. The comparison of velocity distribution for updated on-road and off-road data indicates the velocity is an important feature to characterize the vehicles' movement patterns.

As an alternate method, a neural network approach for identifying the potential roads was introduced and compared to the multicriteria method. The neural network method obtained an approximately 85% accuracy when tested by on-road grids, successfully identified the highway segment as road, and predicted approximately 31% off-road grids as potential road grids. Results show that the neural network method, although emphasized in factors different from the multicriteria method, has approximately 78% accuracy for identifying the potential road locations. The prediction from the neural network method was found highly correlated to the one of the criterion: different direction.

This study also attempted to develop a simplified method by investigating the applications of three variables individually for identifying potential roads. These variables investigated include the GPS point density, the average velocity, the number of passes. Comparison of the multicriteria method, the neural network method, and those simplified method suggest the passes method as the better method because that: 1) the passes method is the simplest method: it requires only a variable for inputs; 2) the relation between the number of passes and the possibilities of road existence is simpler; and 3) the predicted results are more flexible: different certainty levels can be assigned to a grid based on the simple linear relation. Although the velocity for identifying the potential roads may not be the best choose, the velocity is still considered as one of the most important features to characterize vehicle movements and to locate special movement patterns. Velocity may also be more valuable in locating high military class's potential roads (e.g. rerouted road) than newly formed roads, which usually can be classified as military class 4 or 5 roads.

Considering the discrete situation in the predicted potential road areas, a kernel smoothing technique was applied to smooth the results to improve the continuity of the potential roads. The application found the kernel smoothing technique was able to obtain continuous potential road grids by selecting reasonable bandwidth.

## *9.2 Potential Applications and Recommendations*

The study demonstrated the capability of manipulating GPS vehicle tracking data for analyzing vehicle movement patterns and for identifying potential roads. The GPS vehicle tracking data was from 20 tracked vehicles that were selected from a total of 60

vehicles involved in the reconnaissance training exercise. The successfully identification of potential roads in this study indicates that the potential road identification based on GPS vehicle tracking study is possible by tracking representative vehicles during training exercises. As a result, the identified 17 potential roads were identified over the training center. Identified potential roads need to be evaluated by the land managers and can be used to update current YTC road map. The observations for each potential road can help land managers make strategies to have the roads rehabilitated or included in the road maintenance program. The procedures developed in this study for analyzing the vehicle movement patterns and for identifying potential roads can be applied to other installations if the GPS data is available. Similar procedure can be applied for on-road moving data for analysis of vehicle traffic load in each individual road segments. As the GPS accuracy improved, the GPS vehicle tracking data is able to describe the vehicle movement patterns in a move detailed level (e.g. the in-line moving, in-column moving etc.).

The understanding of vehicle movement patterns during military training exercise, especially the velocity distribution and the number of passes, can help relevant studies under ITAM in designing their experiments. For road extraction from imagery, the imagery data from the identified potential road locations can be used as training data to extract the features describing the newly formed roads.

Because the tracked vehicles during the reconnaissance exercise are all wheel vehicles, the detail vehicle type was not considered in analysis of the vehicle movement patterns in this study. Considering that a training exercise may involve different types

vehicles (e.g. both tracked and wheeled vehicles), which usually create different impact on the training land, the vehicle type need to be considered in identifying the potential roads. The concept of Vehicle severity factor (VSF) (U.S. Army Environmental Center, 1999) can be adopted to extend the potential road identification method to the training exercises involving different type of vehicles. Similar to the VSF, the land conditions (e.g. vegetation cover, terrain slopes) were not involved in this study; it can also be included to extend the method to different installations.

A method combining multicriteria, fuzzy logic, and kernel smoothing techniques can be developed to predict the potential roads from analysis GPS vehicle tracking data more accurately. Each criterion, instead of using either "0" or "1", can be fuzzified to characterize the degree of the criterion is satisfied and to be related to the potential road possibilities. Smoothing techniques can be applied to consider the influence of the surrounding areas before integrating the difference criterion for a final criteria level. However, as mentioned by Bobba *et al.* (2000): sophisticated models are not always a necessity, sometimes the simpler method is the better.

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# APPENDICES

# APPENDIX I ADDITIONAL FIGURES FOR CHAPTER 4

## *Area Security*

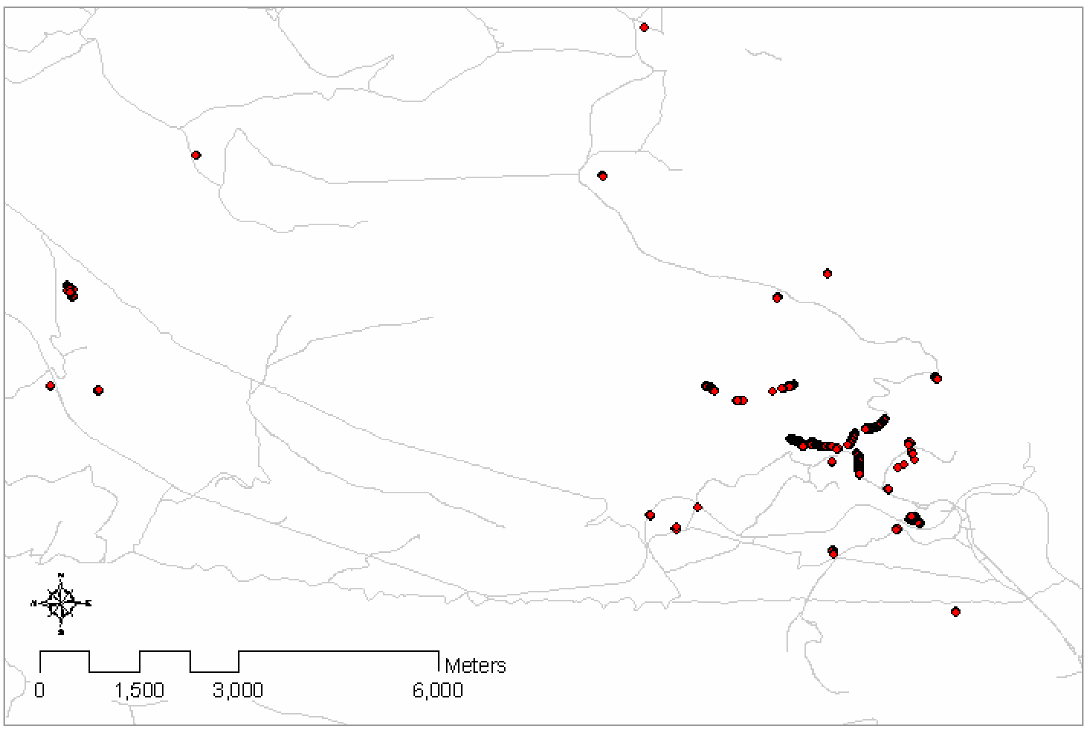


*Figure I-I Locations with high GPS point density in the area security*

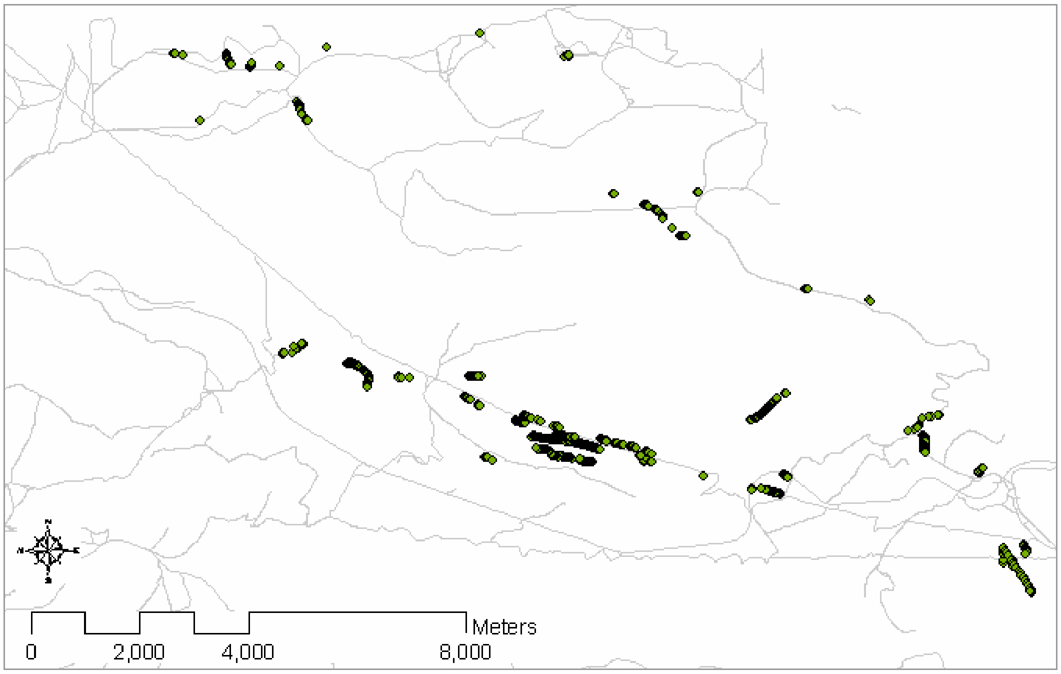


*Figure I-II Locations with high velocities in area security*

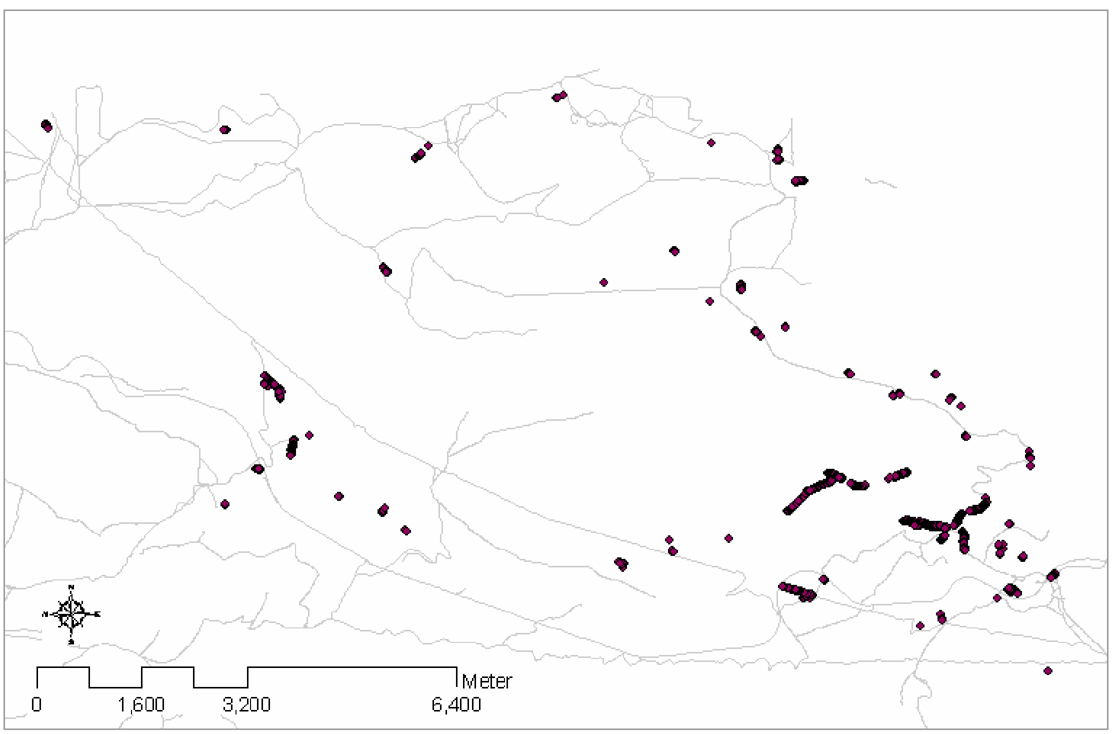


*Figure I-III Locations with STD COG close to 90 degree in area security*

## *Zone Reconnaissance*

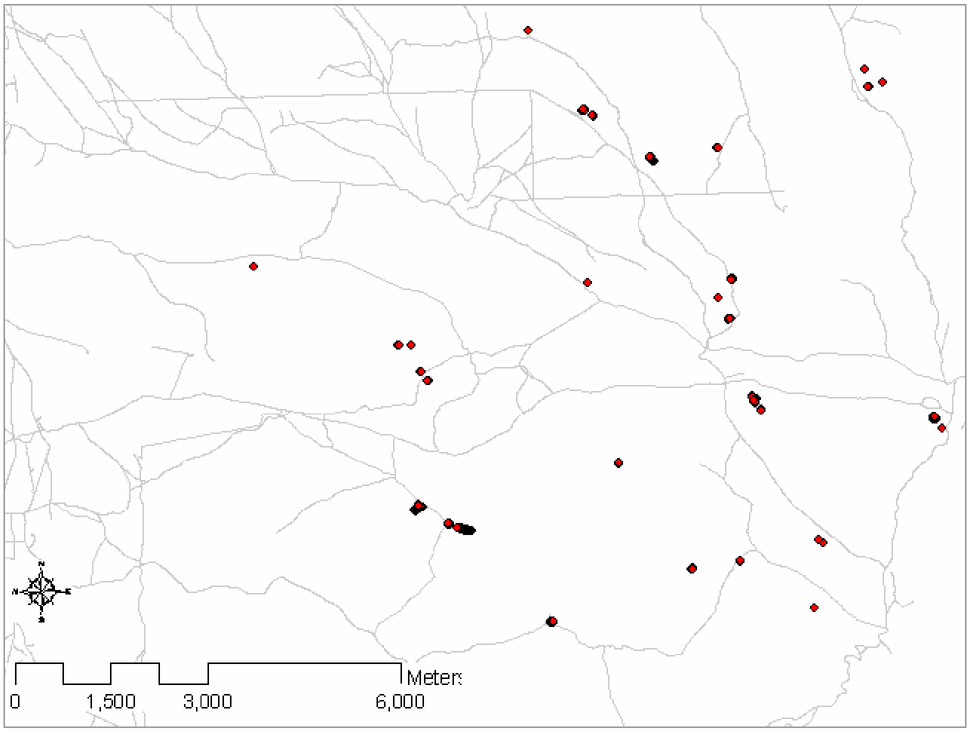


*Figure I-IV Locations with high GPS point density in zone reconnaissance*

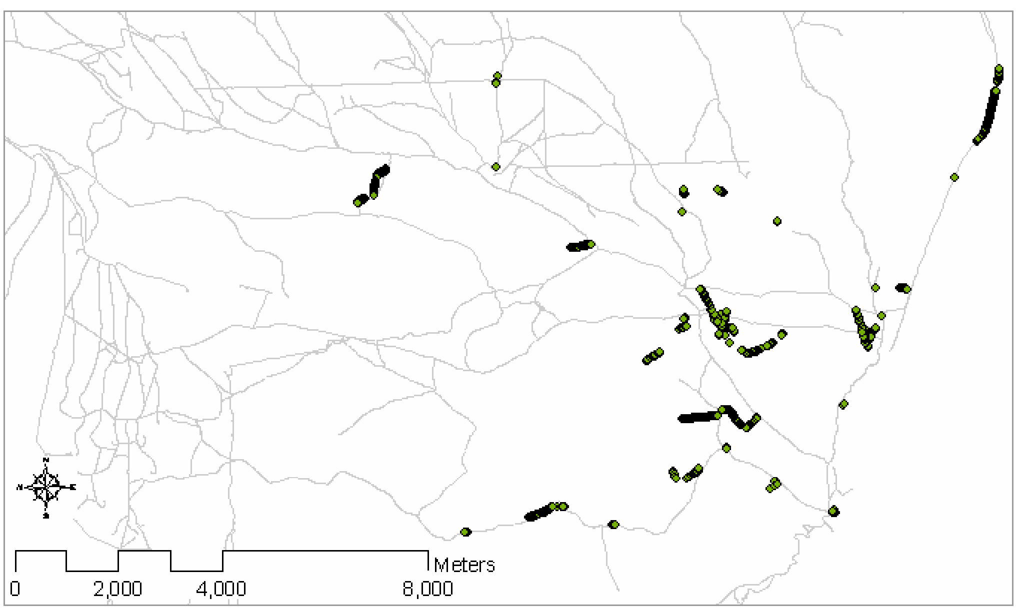


*Figure I-V Locations with high velocities in zone reconnaissance*

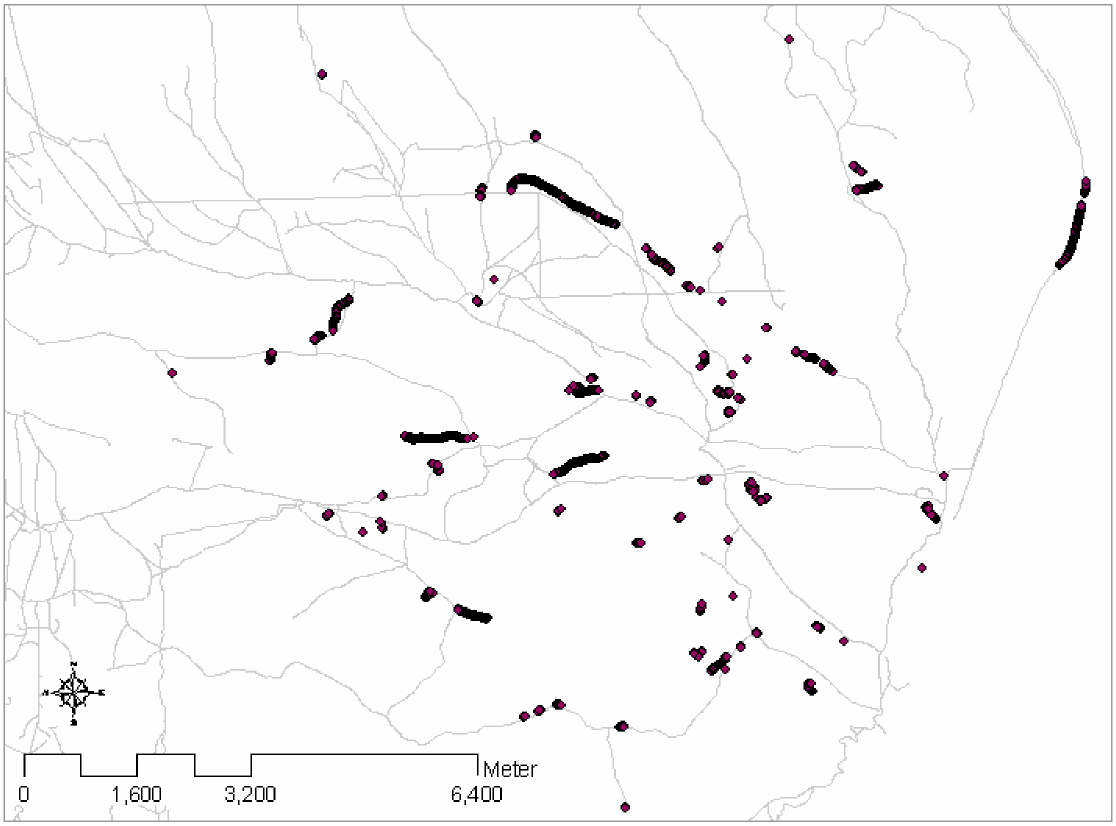


*Figure I-VI Locations with STD COG close to 90 degree in zone reconnaissance*

# APPENDIX II FIGURES FOR CHAPTER 5

## *Area Security*

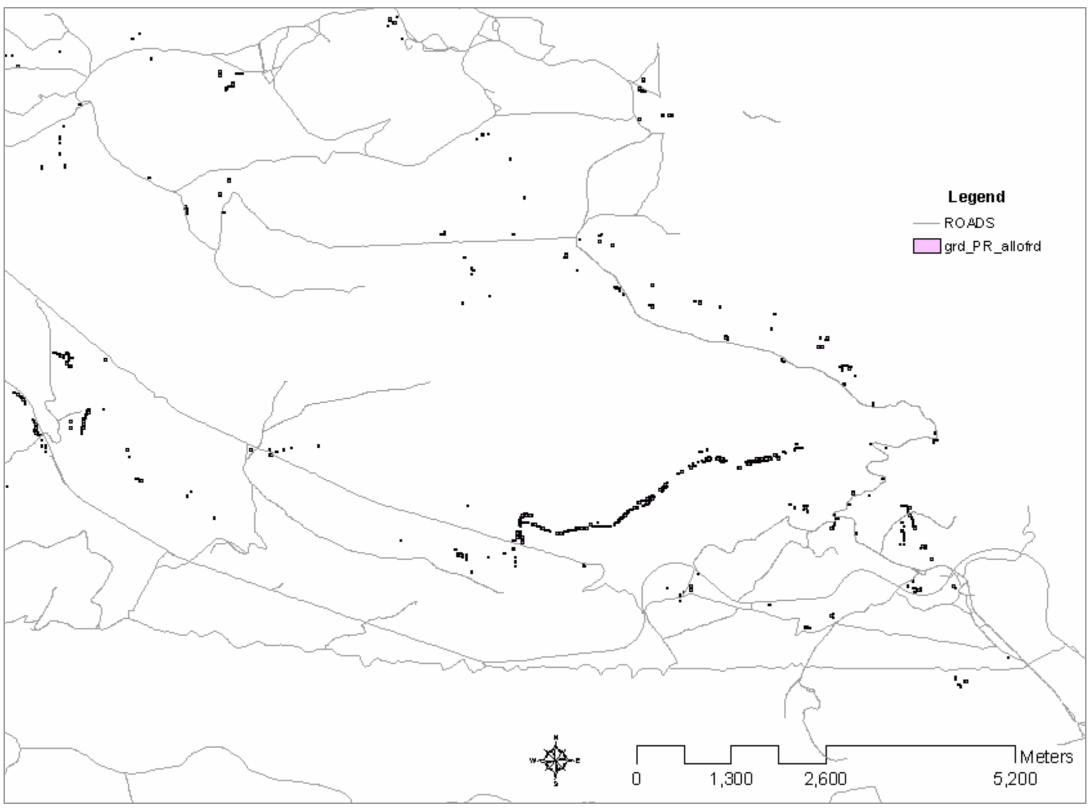


*Figure II-I Locations meet two criteria in area security*

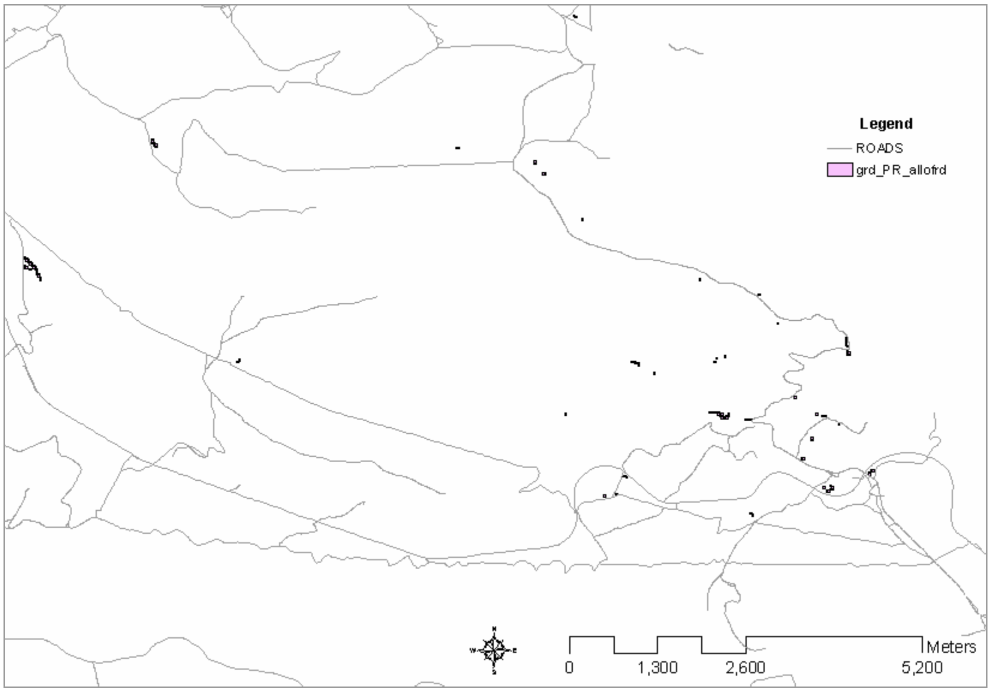


*Figure II-II Locations meet three criteria in area security*


*Figure II-III Locations meet four criteria in area security*

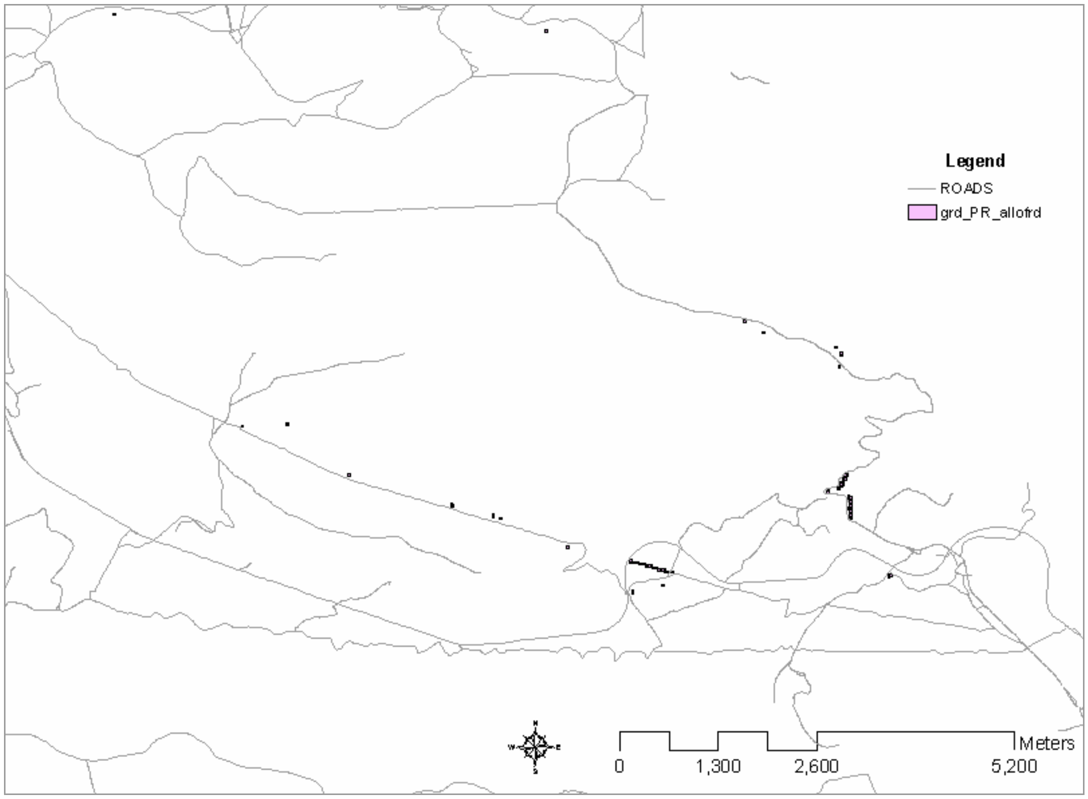


*Figure II-IVLocations meet five criteria in area security*

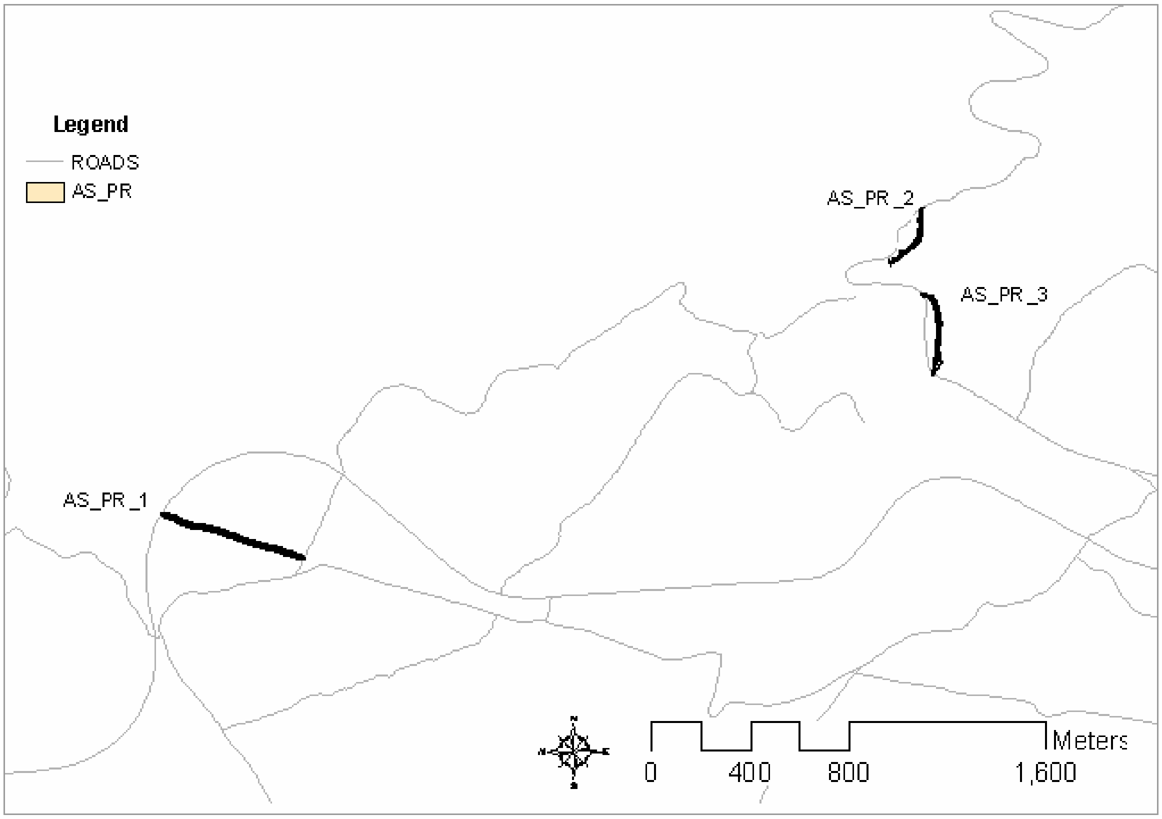

*Figure II-V Potential road segments predicted by multicriteria method in area security*

### *Zone Reconnaissance*

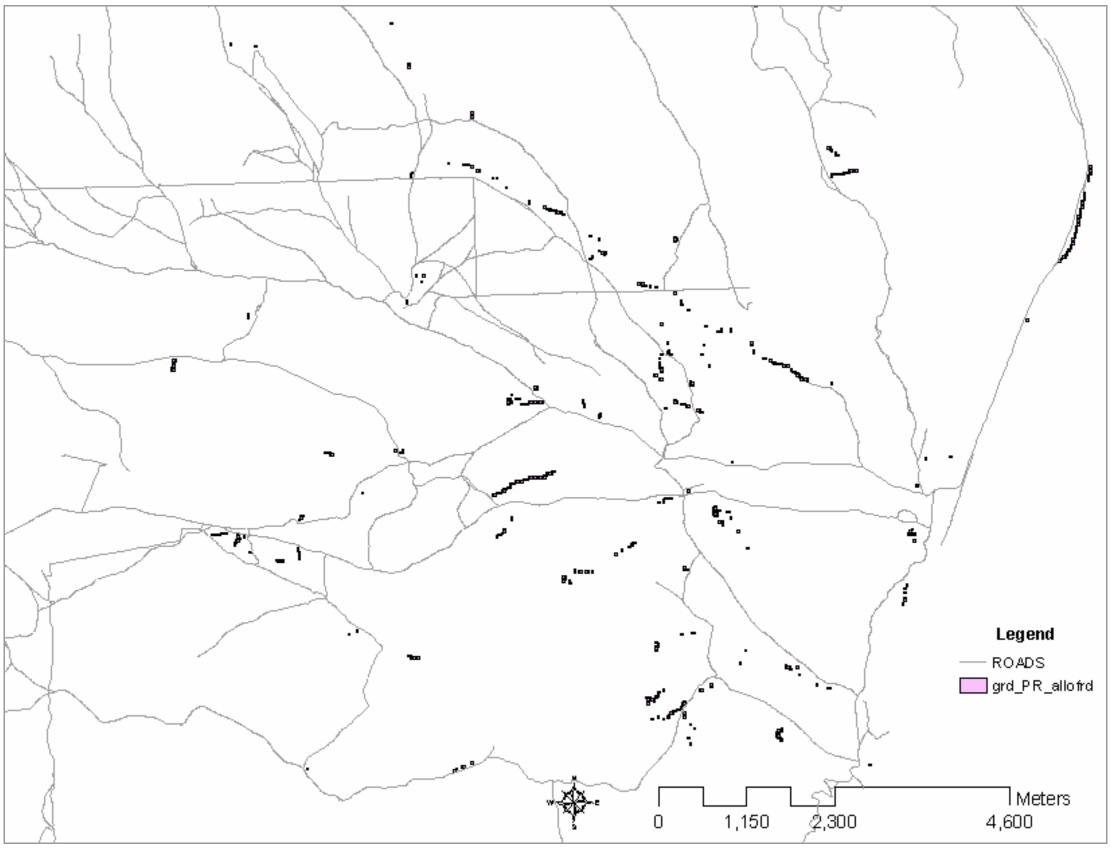


*Figure II-VI Locations meet two criteria in zone reconnaissance*

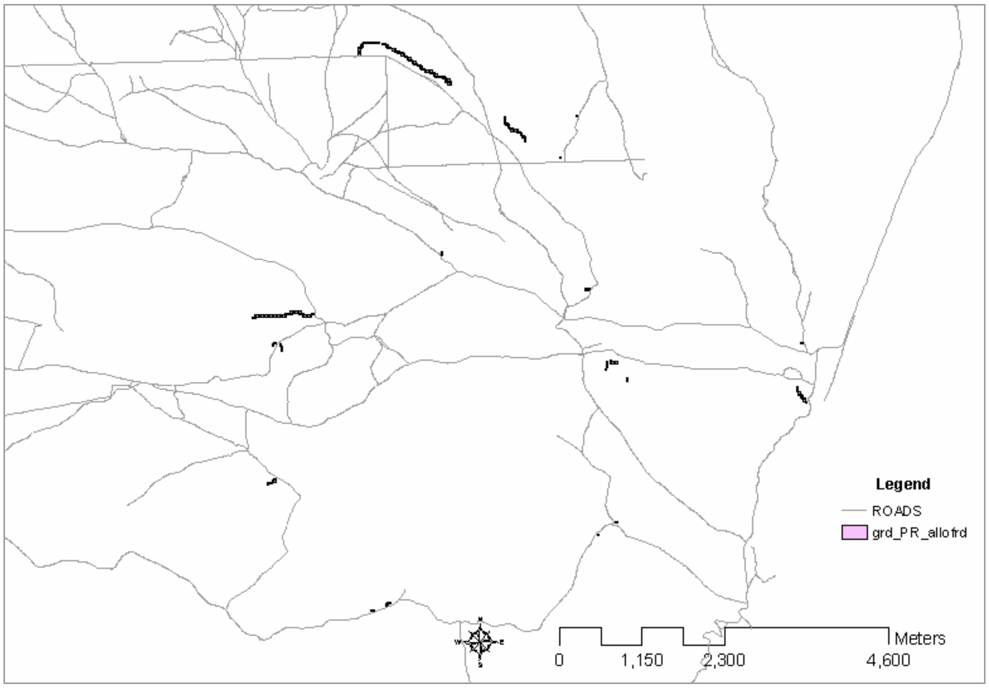


*Figure II-VII Locations meet three criteria in zone reconnaissance*


*Figure II-VIII Locations meet four criteria in zone reconnaissance*


*Figure II-IX Locations meet five criteria in zone reconnaissance*

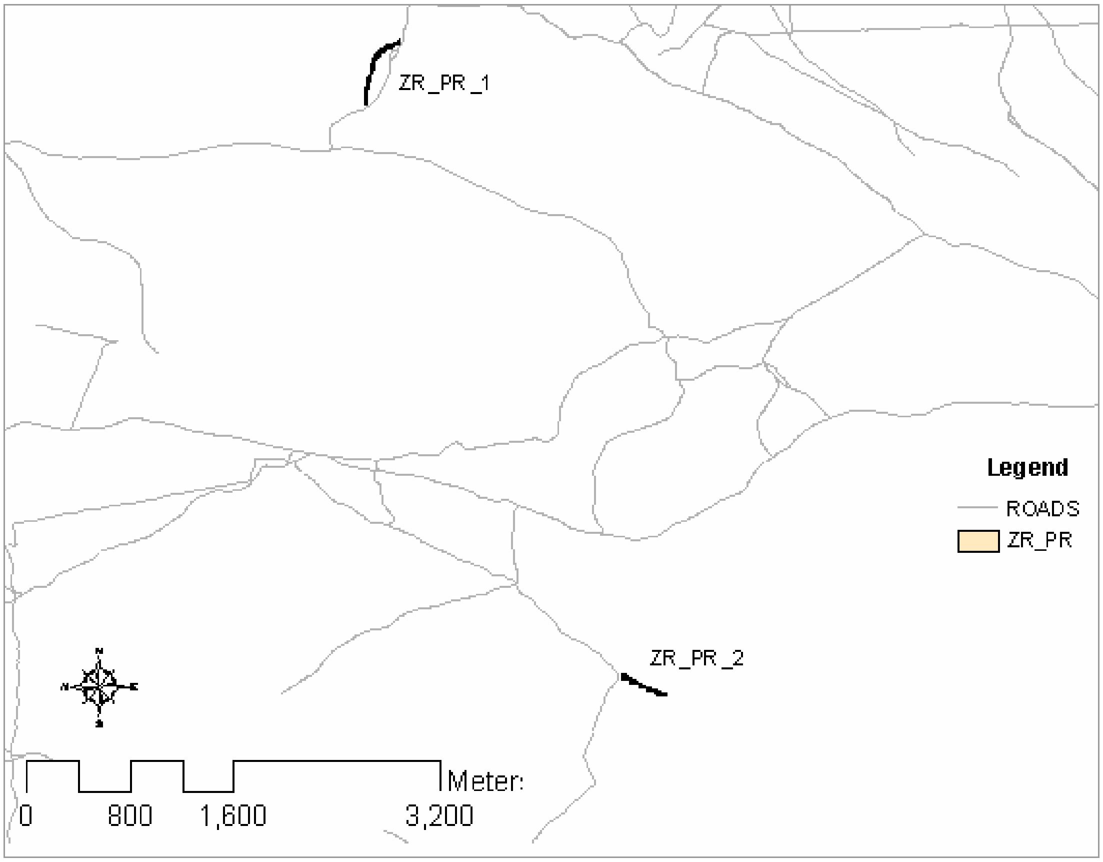


*Figure II-X Potential road segments predicted by multicriteria method in zone reconnaissance*

# APPENDIX III FIGURES FOR OBSERVED ROAD CONDITIONS

## *Screen Line*

*Figure III-I Observed road conditions for SL_02*

*Figure III-II Observed road conditions for SL_04*

*Figure III-III Observed road conditions for SL_05*

## *Area Security*

*Figure III-IV Observed road conditions for AS_06*

*Figure III-V Observed road conditions for AS_07*

*Figure III-VI Observed road conditions for AS_08*

*Figure III-VII Observed road conditions for AS_09*

## *Zone Reconnaissance*

*Figure III-VIII Observed road conditions for ZR_02 & ZR_021*

*Figure III-IX Abandoned road beside ZR_02*

*Figure III-X Observed road conditions for ZR_04*

*Figure III-XI Observed road conditions for ZR_06*

# APPENDIX IV NN PREDICTED POTENTIAL ROAD AREAS

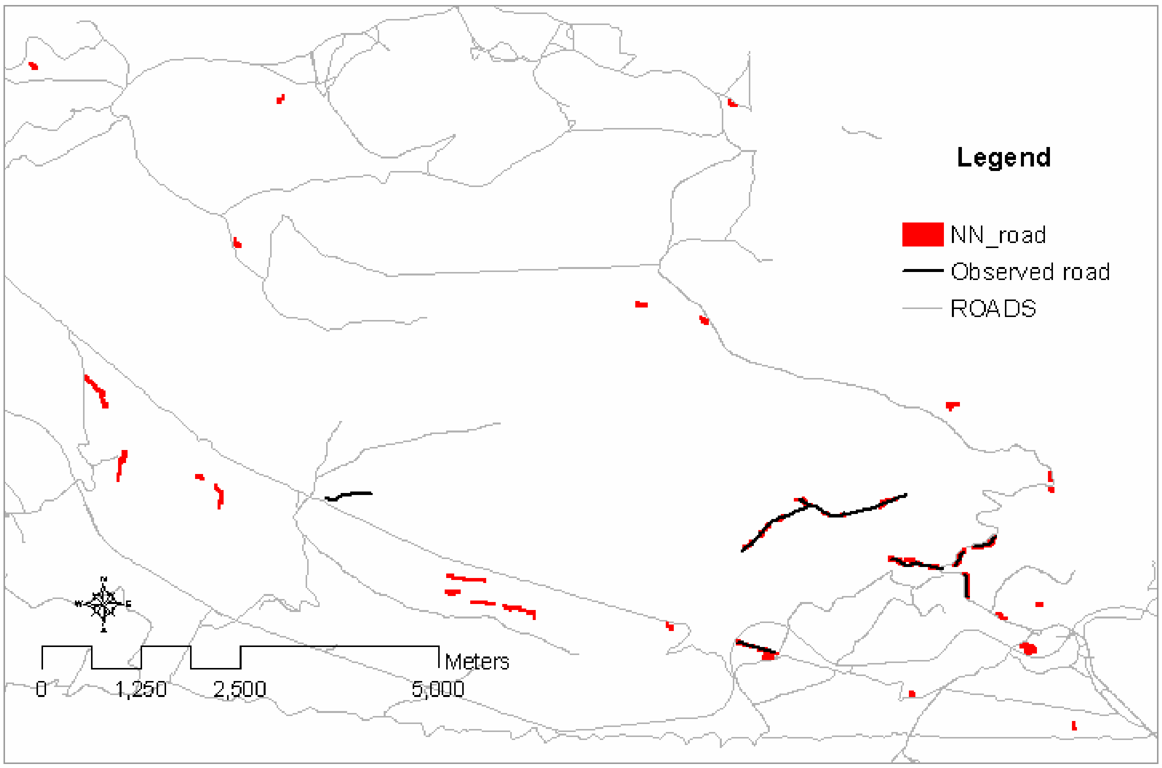


*Figure IV-I Comparison of potential roads predicted by NN and multicriteria in area security*

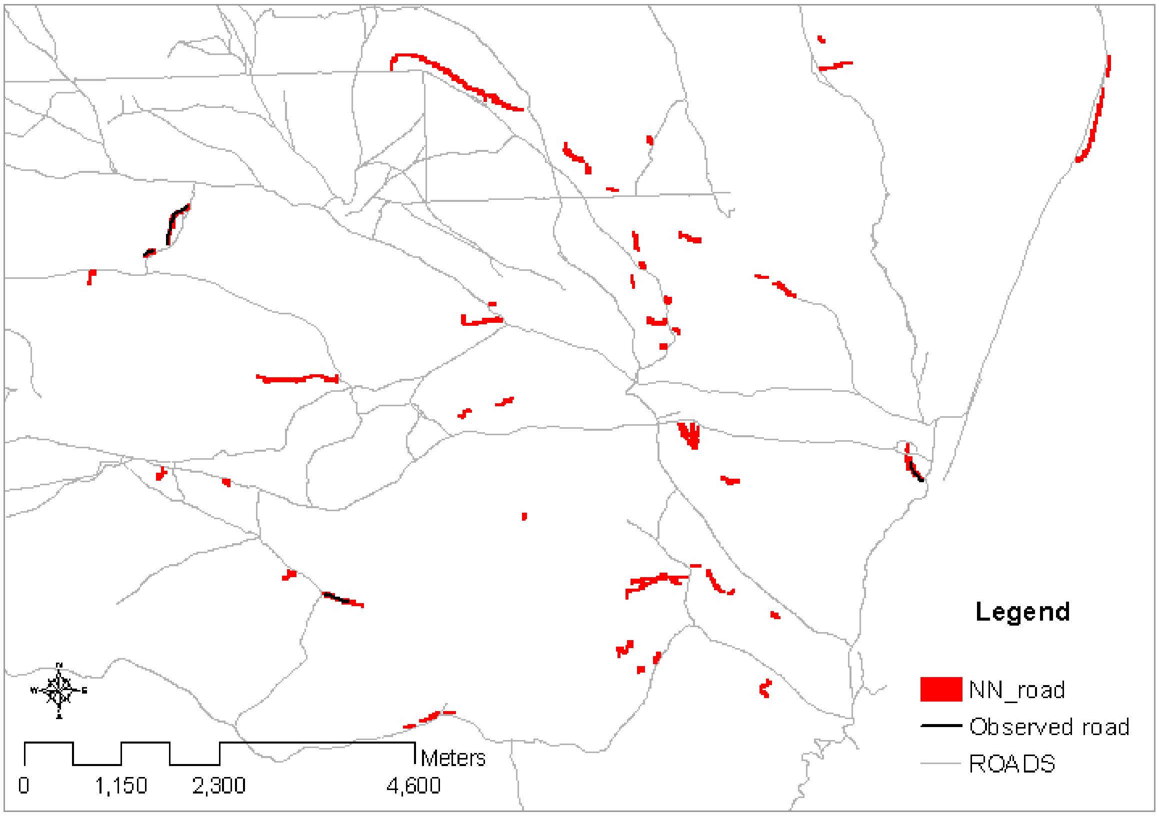


*Figure IV-II Comparison of potential roads predicted by NN and multicriteria in zone reconnaissance*

# VITA

Chunxia Wu was born and raised in Zhejiang, China. She received her Bachelor degree majoring in mechanical engineering from Hefei University of Technology in 1998. A year later, she entered the graduate school of Zhejiang University studying agricultural mechanization information management and received a master degree in 2002. She came to the United State August 2002 to pursue her PhD degree in University of Tennessee, Knoxville. Since then, she has been working on her Doctoral degree in Biosystems Engineering.