5-2009

# Quantifying dust emissions from pre and post Stryker transformation at Pohakuloa Training Area, Hawaii

Naga Swapna Potteti
*University of Tennessee*

## Recommended Citation

Potteti, Naga Swapna, "Quantifying dust emissions from pre and post Stryker transformation at Pohakuloa Training Area, Hawaii. " Master's Thesis, University of Tennessee, 2009.
https://trace.tennessee.edu/utk_gradthes/5689

To the Graduate Council:

I am submitting herewith a thesis written by Naga Swapna Potteti entitled "Quantifying dust emissions from pre and post Stryker transformation at Pohakuloa Training Area, Hawaii." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering Technology.

Paul D. Ayers, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

To the Graduate Council:

I am submitting herewith a thesis written by Naga Swapna Potteti entitled "Quantifying Dust Emissions from Pre and Post Stryker Transformation at Pohakuloa Training Area, Hawaii". I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering Technology.

Paul D. Ayers, Major Professor

We have read this thesis
and recommend its acceptance:

John B. Wilkerson

Joanne Logan

Accepted for the Council:

Carolyn R. Hodges
Vice Provost and Dean of the Graduate School

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

# QUANTIFYING DUST EMISSIONS FROM PRE AND POST STRYKER TRANSFORMATION AT POHAKULOA TRAINING AREA, HAWAII

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Naga Swapna Potteti
May 2009

# Acknowledgements

I would like to thank Dr. Paul Ayers for providing such a great opportunity to work on this project. He provided immense support and guidance during this project. I am grateful to him. Thank you to Alan Anderson, and Heidi Howard, with the U.S. Army Corp of Engineers, Construction Engineering Research Laboratory for their efforts in making this project feasible. I would also like to thank Dr. John Wilkerson and Dr. Joanne Logan for serving on my committee and providing valuable suggestions and inputs for the project. Thank you to Dave Faucette of Integrated Training Area Management at Pohakuloa Training Area, Hawaii for providing cooperation and assistance in delivering this project. I am extremely thankful to The University of Tennessee Department of Biosystems Engineering and Soil Science for giving the opportunity to avail this project in furthering my education. I would like to thank my friends Matthew Rice, Kun Liu and Curtis Million for their help and support.

I would like to thank my parents, Eashwar and Uma Poteti for shaping me into a person I am today. I appreciate their love and affection. Special thanks to my brother Santhosh Poteti, for his unyielding encouragement and support. I would also like to thank my love Ram Nagasani for his patience and support. Thank you to God for blessing me with a wonderful family and friends.

# Abstract

Dust generated from military vehicle maneuvers on unpaved roads and trails is a serious issue that affects military readiness, human health and safety, and environmental quality. Dust emissions from military training exercises at Pohakuloa Training Area (PTA) was one of the concerns identified by U.S. Army in maintaining environmental compliance during the Stryker transformation. A comparative evaluation of the influence of transformation on dust generated at Pohakuloa Training Area (PTA), Hawaii was performed. Stryker transformation was a process involving the shift of the 25th Infantry, 2nd Brigade from a Light Infantry to a Stryker Brigade. Vehicles were tracked using GPS vehicle tracking systems. A pre transformation study was conducted in November 2006 using Garmin 18 GPS receivers to track Medium Tactical Vehicles, (MTV-M1083) and High Mobility Multipurpose Wheeled Vehicles, (HMMWV- M998), belonging to the 1-21 Battalion of the 2nd Brigade. A post transformation tracking study involved 8-wheeled Infantry Carrier Vehicles (ICV) called Strykers (M1126) of 1-21 Battalion, 2nd Brigade, conducted in April 2007.

The relative amount of dust generated pre and post transformation exercise on different unpaved road segments at PTA was estimated using dust emission estimation model, developed by US EPA (1979). During the pre transformation exercise, 11 vehicles (HMMWV's and MTV's combined) traveled an estimated 221.5 km for a period of 10 days with an average velocity of 5.79 m/s and generated 2,090 kg/km dust per Battalion day. During the post transformation exercise, 16 vehicles (Strykers) traveled 128 km for a period of 10 days with an average velocity of 5.45 m/s and emitted 24,654 kg/km dust per Battalion day. Dust emissions were sensitive to soil silt and average velocity. Critical road segments of PTA having greater potential for dust emissions were identified using ArcGIS 9.1, mostly on Redleg trail and Lava road. Critical road segments constituted nearly 2 % of the roads at PTA and contributed about 42% of the total dust generated during pre and post transformation exercises. Training after post transformation generated about 10 times more dust when compared to pre transformation.

# Table of Contents

# List of Tables

# List of Figures

# Chapter 1 Introduction

## Background

Pohakuloa Training Area (PTA) is a sub-installation of Schofield Barracks (U.S. Pacific Command, 1995b). It is located on the Big Island of Hawaii in the Humuula Saddle between three volcanoes: Mauna Kea, Mauna Loa, and Hualalai. The training area is located on a roughly hexagonal tract of land that extends 15 km from north to south and 17 km from east to west. The total area of PTA is approximately 108,800 acres (U.S. Army Garrison, Hawaii, and U.S. Army Corps of Engineers, 1997b). The Department of Defense (DOD) advocates maintaining biodiversity to provide realistic, sustainable training resources. Effective DOD land management practices have created highly biodiverse training areas (Dale and Warren, 2004).

The mission of PTA is to provide training of full-scale live firing exercises for the 25th Infantry Division (Light), U.S. Army Garrison, Hawaii. PTA also provides training facilities for other branches of the U.S. military and friendly foreign forces. Training units up to 2,500 personnel are assigned to carry out different vehicle maneuvers, usually for a 3- or 4-week rotation (U.S. Pacific Command, 1995b). Training points are areas where military units train or camp (Gleason et al., 2007). Being the largest training area in Hawaii, PTA is used to accomplish nearly all of the varying types of training required by the military forces. There are approximately

129,499,404 $m^2$ free of recent lava flows which are considered fully usable for large maneuver exercises (Global Security Organization, 2008).

There is a need to understand the landscape processes to minimize military-induced impact and increase environmental management to stewardship status while at the same time maintaining mission readiness requirements (Albertson, 2001). Military forces can use geologic knowledge of the land surface to military advantage and must be able to train on diverse and realistic terrain to adequately prepare for their military mission. Training and testing lands are increasingly becoming critical and finite resources. Military training lands are a part of the public land trust, valuable natural resources that must be protected. At the same time, that land space is shrinking, and impacts grow as the intense pressure applied by modern military equipment increasingly wears on training lands (Albertson, 2001).

Military installations within the United States and abroad contain a vast network of roads and trails. Outside the cantonment area road surfaces are predominantly unpaved and unimproved and surpass the paved road network in total mileage (Svendsen, 2007). Dust is a major particulate emitted from military installations, especially those that perform extensive training with tracked vehicles and high explosive artillery ranges. Concerns are frequently raised when dust exiting a military reservation consistently exceeds particulate sampling standards, when local natural vistas appear to be degraded, and especially when visible dust plumes significantly restrict local visibility for a period of time (Cionco and Hoock, 2002).

Particulate Matter (PM) emission is a critical problem for the Department of Defense (DoD). PM emitted during DoD testing and training activities threatens the safety and respiratory health of military personnel and can impact the health of urban populations encroaching on military installations. Military activities create unique dust emission sources not encountered in the civilian environment and which have not been accurately characterized and quantified (Gillies et al., 2007). Without source specific emissions factors of known precision and accuracy, the uncertainties on these estimates are high. Understanding of the atmospheric and surficial influences on the amount of the dust available for longer distance transport as well as the modeling of this phenomenon remains poor. As a result emission factors applied without proper consideration of the factors that control the transportable fraction of PM will produce overestimates of these contributions (Gillies et al., 2007).

Dust generated from military vehicle maneuvers on unpaved roads and trails is a serious issue that affects military readiness, human health and safety, and environmental quality. Furthermore, dust migration from unpaved roads to nearby surfaces impairs plant growth, degrades stream quality and decreases road stability throughout unpaved road corridors. Gleason et al. (2007) studied the direct effects of windblown soil on established plants via damage to leaves or reduction in photosynthesis appear small and can probably be avoided further if the plant is tall (ca. 20 cm). Additionally, soil transport off roads decreased exponentially as vegetation density increased. Thus by keeping roads and training points at a distance, most direct and indirect impacts of windblown soil on plant communities can be reduced to negligible rates.

PTA and majority of the land surrounding it is designated a conservation district. Species are normally the units of biodiversity and conservation (Wilson, 1992). PTA has the highest concentration of endangered species of any Army installation in US, with ten plants and nine animals on the endangered species list. A critical habitat exists in the northeastern portion of the site for the endangered Palila bird (Global Security Organization, 2008). PTA was surveyed for a biological resource baseline in 1997. Ten distinct habitats were identified, five of which were considered rare by the Hawaii Natural Heritage Program. The area has been disturbed by an influx of alien weedy vegetation and feral animals, particularly ungulates such as goats and sheep. The majority of the training area is vegetated with native plants, collectively identified as subalpine dryland. Many native forest bird and plant species in the area are rare or endangered. Many of the species occurring at PTA are unique to the Island of Hawaii; several exist only in the Saddle Region surrounding Pohakuloa Training Area, while others are specific to the PTA itself (U.S. Army Garrison, Hawaii, and U.S. Army Corps of Engineers, 1998).

A plan was in place to expand the boundaries and the number of vehicles passing through PTA (Cole, 2002). This move was a matter of concern for the neighboring residents as the plan might lead to an increase in the amount of noise, dust, and erosion. Army is specifically concerned about their maneuvers on powder-fine volcanic pumice soil that could generate large dust storms and affect native species. The Army spends $2 million to $3 million annually at the training area for environmental stewardship (Cole, 2002). In 2002, the 25th Infantry Division (Light) initiated a $ 693 million transformation, the biggest Army construction project in Hawaii since World War II. As part of the Army's new fast-strike concept, the 2nd Brigade would be scaled to 3,580 soldiers and equipped with about 380 of the 19-ton Strykers and 500 to 600 HMMWV’s and trucks (Cole, 2002). Transformation of the second Brigade was complete from the conversion of 25th Light Infantry Division (HMMWV and MTV) to a bigger and faster Stryker Brigade Combat Team. Balancing the training requirements of the military while promoting environmental sustainability practices is a top priority for the Army Installation Management Agency (McElroy, 2006).

The Army conducted an air quality assessment to monitor the environment. Monitoring dust emissions from military vehicles is one aspect of maintaining environmental compliance with air quality standards. The Army identified potential significant impacts from dust. The draft Environmental Impact Statement (EIS) quoted that dust generated directly by vehicle travel on unpaved roads or off-road maneuver areas as one of the components of dust impacts. In response to agency and public comments, the Army conducted modeling which provided a better understanding of the on-site conditions and potential adverse impacts from dust. The Army acknowledged and considered the public's concern that annoying dust will be intermittently produced by training and convoy activities at PTA (Tetra Tech Inc., 2004).

Dust emissions associated with tactical vehicle use have been based on US EPA methodologies for vehicle travel on unpaved roads (US EPA, 1998). Dust is the dust generated from open sources and it is not discharged to the atmosphere in a confined flow stream (US EPA, 1998). Emissions from personal vehicles were estimated using US EPA vehicle emission rate model. Stryker Brigade Combat Team (SBCT) final EIS presented particulate matter emissions as PM10 (particulate matter having an aerodynamic diameter of $\leq 10\ \mu m$) estimates because that is the most appropriate size fraction to address dust issues. In response to US EPA and public comments, the Army conducted a more detailed modeling and analysis of dust issues (Tetra Tech Inc., 2004). Dispersion modeling analyses were performed to better evaluate the potential for violations of the federal PM10 standard due to dust emissions associated with military vehicle use. To determine the degree of impact and the geographic extent of the impact, Army used a widely accepted standard dispersion model (Tetra Tech Inc., 2004).

## Summary of the chapter

SBCT final EIS provided a summary of dust emissions that would be generated by military vehicle travel on unpaved roads or on unpaved vehicle maneuver areas under all project alternatives. The emission estimates were based on current AP-42 procedures (US EPA, 1998). It is believed that dust PM10 emissions from military vehicle used on unpaved roadways and off-road areas would increase by about 429 tons per year (390 metric tons per year) (Tetra Tech Inc., 2004). Visible dust is a clear indicator of airborne PM10 concentrations that are typically in the range of several thousand micrograms per cubic meter. It takes only a few hours of such concentrations to produce a 24-hour average that exceeds the state and federal 24-hour average PM10 standard of 150 micrograms per cubic meter. PM10 emissions represent the size fractions of suspended particulate matter that are likely to penetrate into the lower respiratory tract creating potential adverse health effects. The substantial augmentation in fugitive PM10 emissions from military vehicles used occurred at PTA. The potential for exceeding the federal 24-hour PM10 standard, and the potential impacts on quality of life to surrounding communities resulted in a significant air quality impact at PTA (Tetra Tech Inc., 2004).

From the review of SBCT final EIS, it was underscored that gauging dust emissions especially from military vehicles traveling on unpaved roads would play a crucial role in developing dust management and mitigation plan.  Data obtained from pre- and post transformation provided a basis for conducting a discourse analysis to address the problem of dust emissions. Spatial distribution analysis was used to implement dust control interventions. Table 1-1 provided a summary of projected dust emissions that would be generated by military vehicle travel on unpaved roads or on unpaved vehicle maneuver areas under all project alternatives. Emission estimates were presented for travel on gravel roads, dirt roads, and off-road maneuver areas at each installation under each alternative. The summarized emission estimates were based on current AP-42 standards (US EPA, 1998), which were estimates of dust prediction. No protocol was in place to evaluate the accuracy of these estimates during military transformation exercises. There was a need to accurately estimate the increase in dust generation due to Stryker transformation.

*Table 1-1: Vehicle mileage assumptions, proposed action and reduced land acquisition (Tetra Tech Inc., 2004).*

| **Vehicle type** | **Number of vehicles** | **Annual use days per vehicle** | **Per vehicle km /use-day** | **Assumed mi/yr/veh** | **% Vehicle mile traveled (VMT) by veh type** |
|---|---|---|---|---|---|
| STRYKER | 296 | 150 | 10 | 1,500 | 24.24% |
| HMMWV | 490 | 185 | 12 | 2,220 | 59.39% |
| LMTV | 105 | 180 | 8 | 1,440 | 8.26% |
| MTV | 75 | 150 | 8 | 1,200 | 4.91% |
| HEMTT | 25 | 60 | 25 | 1,500 | 2.05% |
| PLS, HET | 14 | 50 | 30 | 1,500 | 1.15% |
| **TOTALS** | 1,005 | 167 | 11 | 1,822 | 100.00% |

Notes:

HMMWV = high mobility multipurpose wheeled vehicle (humvee)

LMTV = light medium tactical vehicle (2.5 ton truck)

MTV = medium tactical vehicle (5 ton truck)

HEMTT = heavy expanded mobility tactical truck (10 ton truck)

PLS = palletized load system truck (25+ ton capacity)

HET = heavy equipment transporter (60+ ton capacity)

# Chapter 2: Literature Review

## Dust field Studies

A number of field research studies have been conducted in the past to define and test new methodologies and innovations in dust emission measurements from military vehicles. Even though soil-derived dust generated by vehicular traffic on unpaved roadways in arid regions contributes little to the total atmospheric dust burden (Hall, 1981), it can still affect local visibility and degrade air quality (Pinnick et al., 1985). The most common dust suspending activity is vehicular movement on paved roads, unpaved roads, parking lots, and construction sites. Vehicle shape, speed, weight, number of wheels as well as previous history (e.g., dust acquisition for trackout) interact with different road surfaces to change the particle size, surface loading, wind effects, and surface moisture (Watson and Chow, 2000). Specifically, vehicles traveling on dry, unpaved roads generate copious amounts of dust that contributes to soil erosion, and potentially threatens human health and ecosystems.

Most unpaved roads consist of a graded and compacted roadbed usually created from the parent soil-material. The rolling wheels of the vehicles impart a force to the surface that pulverizes the roadbed material and ejects particles from the shearing force as well as by the turbulent vehicle wakes (Nicholson et al., 1989). A low-cost technique (“sticky-trap” collectors) for monitoring road dust was used to enable land managers estimate soil loss (Padgett et al., 2007).

Etyemezian et al. (2003) produced methods and calibration of a vehicle-based road dust emission measurement technique called the Testing Re-entrained Aerosol Kinetic Emissions from Roads (TRAKER). They found that the emission factor for road dust was proportional to the cube root of the TRAKER signal. The results also showed a linear relationship between unpaved road dust PM10 emissions and vehicle speed. In another study, the effects of speed, traffic volume, location, and season on PM10 road dust emissions were described (Etyemezian et al., 2003). Kuhns et al. (2005) studied the spatial variability of unpaved road dust PM10 emission factors near El Paso, Texas using TRAKER technique. Ayers et al. (2005) analyzed vehicle use patterns during field training exercises to identify potential roads. Wu (2007) identified potential roads by validating a GIS-based multi-criteria method. Etyemezian et al. (2004) showed the measurement and model results of deposition and removal of dust in the arid southwestern US. The study explained the extent of particle deposition expected to occur under most unpaved road emission scenarios. Dornbusch et al. (1988) developed a functional equation for dust emissions from tracked vehicles and an emission equation was also formulated by means of dimension analysis to predict dust propensity for military operations in Desert areas.

Studies have found that dust emission rates depend on the fine particle content of the road (Cowherd et al., 1990; Midwest Research Institute, 2001), soil moisture content, vehicle speed (Nicholson et al., 1989; Etyemezian et al., 2003a and Etyemezian et al., 2003b), and vehicle weight (U.S. EPA, 1996; U.S. EPA, 2003 and Midwest Research

Institute, 2001). AP 42, section 11.2.1, 9/88 (unpaved roads), and draft AP 42, section 11.2.x, 3/93 (paved roads) stated that the dust calculations were based on roadside measurements of ambient particulate near the vehicles. These measurements were used to calculate a fleet average vehicle gram/mile emission factor. This type of measurement was inclusive of all forms of particulate generated from the vehicles traveling on the road. The AP 42 algorithms for dust were incorporated in PART5 with little modification. PART5 model calculated dust emission factors by using overall fleet average weight and an overall fleet average number of wheels as inputs (US EPA, 1994).

Studies were conducted at Fort Stewart, Georgia, to evaluate air borne concentrations of particulates less than 10 µm (PM10) and 2.5 µm (PM 2.5) with respect to conditions and training activities on the installation (Kirkham, et al., 2005). When unpaved roads are involved in the activities, AP 42 emission factors will be used for the closest type of activity listed (US EPA 1995). The EPA recommends using site-specific emission factors because the AP 42 values are based on averages. The emission factor equation in AP 42 includes factors for silt content, vehicle speed, vehicle weight, and number of wheels. The calculated emission factor is adjusted by a particle size multiplier (increases to 1 at 30 µm) appropriate for the emission size fraction of interest. The emissions might be calculated for the amount of km of road surface with different road surface silt content. "*Silt consists of particles less than 75 µm in diameter, and silt content can be determined by measuring the proportion of* *loose dry surface dust that passes through a 200-mesh screen, using the ASTM-C-136 Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates"* (Midwest Research Institute, 1998).

Campbell and Shimp (1998) related PM10 suspension potential to the silt measurements in California soil surveys to improve their PM10 emission estimates. Silt fractions or quantities appear as explicit variables in many of the emission factors equations. The processes related to particle size indicate that actual emissions of PM10 and PM2.5 are influenced more by size distributions above and below the 75 µm geometric diameter than by the percent silt content.

## Emission Factor Equations

For unpaved roads, an emission factor equation was found to be successful in predicting particulate emissions at different sites with varying source parameters. Various road surface and vehicle characteristics are likely to have an impact on the particulate emissions from unpaved roads. Those parameters most likely to influence the emissions, while at the same time are able to be measured in a practical manner, are considered for the emission factor equation development. For instance, the measure of source activity accounts for the speed and weight of the vehicles traveling on the unpaved road and the number of wheels of the vehicles in contact with the unpaved road (Midwest Research Institute, 1998). Similarly, properties of the material being disturbed, a parameter comprising moisture content and the content of the suspendable fines in the surface material. The parameters readily measurable and applicable to a general unpaved road equation include silt content, surface moisture content, mean vehicle weight, mean vehicle speed, and mean number of wheels. Studies showed that unpaved road emission factor model currently contained in AP-42 performed well in predicting emissions (Midwest Research Institute, 1998).

Although the emission factor equation for unpaved roads has been modified over the past years, all versions have important common features. All were developed using multiple linear regression of the suspended particulate emission factor against correction parameters that describe source conditions. The silt content has consistently been found to be of critical importance in the predictive equation. The first version of the predictive equation (and each subsequent refinement) included a roughly linear (power of 1) relationship between the emission factor and the road surface silt content. Dust emission rates and particle size distributions are difficult to quantify because of diffuse and variable nature of the sources and a wide range of particle sizes are involved including particles which deposit immediately adjacent to the source (Midwest Research Institute, 1998).

Other variables are important in addition to the silt content of the road surface material. For example, at industrial sites, where haul trucks and other heavy equipment are common, emissions are highly correlated with vehicle weight. On the other hand, there is far less variability in the weights of cars and pickup trucks that commonly travel on publicly accessible unpaved roads throughout the United States. For those roads, the moisture content of the road surface material may be more important in determining differences in emission levels between a hot desert environment and a cool moist location (US EPA, 2006).

## *Emission Factor Equation (US EPA 1979 model)*

The earliest emission factor equation for unpaved roads first appeared in AP-42 in 1975. It included the first two correction terms shown in Equation 1 (i.e., silt content and mean vehicle speed). However, the data base for that version was limited to tests of publicly accessible unpaved roads traveled by light-duty vehicles and had a small range of average travel speeds (48 to 64 kph). Subsequent emission testing expanded the ranges for both vehicle weight and vehicle speed. In 1978, a modified equation that included silt, speed, and weight was published in an EPA report. In 1979, the current version (Equation 1) was first published. It incorporated a slight reduction in the exponent for vehicle weight and added the wheel correction term (Midwest Research Institute, 1998).

The PM10 emission factors were based on stepwise linear regressions of field emission test results of vehicles traveling over unpaved surfaces. Due to a limited amount of information available for PM2.5, the expression for that particle size range was scaled against the PM10 results. The source characteristics silt content (s), vehicle weight (W) and moisture content (M) are referred to as correction parameters for adjusting the emission estimates to local conditions (US EPA, 2006).

In addition to the unpaved road emission factor equation discussed above, other studies have been undertaken to model emissions from unpaved road vehicular traffic. Equation 1 was recommended over the other candidates on the basis of its wider applicability. Additional studies addressed emissions from restricted classes of unpaved roads. No other equation bore resemblance to the generic unpaved road emission factor (Equation 1) (Midwest Research Institute, 1998).

The AP-42 unpaved road emission factor equation for dry condition has the following form:

$$E = K\ 5.9\ (s/12)\ (S/30)\ (W/3)^{0.7}\ (w/4)^{0.5} \qquad (1)$$

Where:

E = emission factor, pounds per vehicle-mile-traveled, (lb/VMT)

k = particle size multiplier (dimensionless)

s = silt content of road surface material (%)

S = mean vehicle speed, km per hour (mph)

W = mean vehicle weight, ton

w = mean number of wheels (dimensionless)

Similarly,

$$E10 = 0.36*5.9\ (s/12)\ (S/30)\ (W/3)^{0.7}\ (w/4)^{0.5} \tag{2}$$

$$E30 = 1.0*5.9\ (s/12)\ (S/30)\ (W/3)^{0.7}\ (w/4)^{0.5} \tag{3}$$

The EPA AP 42 discusses how Equation (1) can be extrapolated to annual conditions through the simplifying assumption that emissions are present at the "dry" level on days without measurable. Predictive accuracy is the goal of any emission factor equation.

*Table 2-1: Constants for Equation 1 based on the stated aerodynamic particle size (Midwest Research Institute, 1998)*

| **Constant** | **PM-2.5** | **PM-10** | **PM-30** |
|---|---|---|---|
| K (lb/VMT) | 0.38 | 2.6 | 10 |
| a | 0.8 | 0.8 | 0.8 |
| b | 0.4 | 0.4 | 0.5 |
| c | 0.3 | 0.3 | 0.4 |
| Quality Rating | C | B | B |

## *Revised Emission Factor Equations*

The development of a revised unpaved road emission factor equation was built upon findings from the previous data sets available. An updated version of the emission factor equation does not include speed and mean number of wheels as parameters.

*US EPA 1998 Emission Estimation Model (US EPA, 1998)*: The new equation allowed for the emission calculations of different particle sizes (PM-2.5, PM-10, and PM-30) with the use of appropriate constants (Table 2-1). To calculate the particulate emissions (PM10) from unpaved roads, AP-42 13.2.2 provided the following equation:

$$E = K\,(s/12)^{a}\,(W/3)^{b} / (M/0.2)^{c} \qquad (4)$$

Where: k, a, b, and c are empirical constants references in AP-42 Table 13.2.2-2

E = size-specific emission factor

S = surface material silt content

W = mean vehicle weight

M = surface material moisture content

The recommended emission factor equation for estimating PM-10 emissions from vehicles traveling over unpaved surfaces

$$E10 = 2.6\,(s/12)^{0.8}(W/3)^{04} / (M/0.2)^{0.3} \qquad (5)$$

Where:

E10 = PM-10 emission factor (lb/VMT)

s = surface material silt content (%)

W = mean vehicle weight (tons)

M = surface material moisture content (%)

Similarly, the PM-30 emission factor equation is represented by:

$$E30 = 10(s/12)^{0.8}(W/3)^{0.5}/ (M/0.2)^{0.4} \qquad (6)$$

All previous versions of the AP 42 unpaved road emission factor have included the road surface silt content as an input variable. AP 42 Section 13.2 has always stressed the importance of using site-specific input parameters to develop emission estimates (Midwest Research Institute, 1998). The constants for PM10 extracted from AP-42 Table 13.2.2-2 were as follows: k = 2.6 lb/VMT, a = 0.8, b = 0.4, c = 0.3. The range for surface material silt content in AP-42 13.2.2 is 1.2-35 %. In a report written by Desert Research Institute, Dust and Other Source Contributions to PM10 in Nevada's Las Vegas Valley, April 1997, the average silt content measured for unpaved roads was about 9.8%. The range for surface moisture contents from AP-42 is 0.03% to 20% with 0.2% presented as the default value in the absence of appropriate site-specific information. Due to a lack of specific local data, the EPA default value of 0.2% was used (Pahrump Regional Planning District, 2004).

*US EPA 2006 Emission estimation model:* The dust emissions from the unpaved road can be calculated using an emission estimation algorithm. For vehicles traveling on unpaved surface at industrial sites, US EPA has an empirical equation used in calculating the quantity in pounds (lb) of size specific particulate emissions from

*Table 2-2: Constants for Equation 7 based on the aerodynamic particle size (US EPA, 2006)*

| Constant | PM2.5 | PM10 | PM |
|---|---|---|---|
| K (lb/VMT) | 0.15 | 1.5 | 4.9 |
| A | 0.9 | 0.9 | 0.7 |
| B | 0.45 | 0.45 | 0.45 |

*Table 2-3: Range of source conditions required to apply the above equation (Industrial roads) (US EPA, 2006)*

| Surface Silt Content, % | Mean Vehicle Weight (ton) | Mean Vehicle Speed (mph) | Mean No. of Wheels | Surface Moisture Content, % |
|---|---|---|---|---|
| 1.8 – 25.2 | 2 – 290 | 5 – 43 | 4 – 17 | 0.03 – 13 |

an unpaved road per vehicle kilometer traveled (VMT) (US EPA, 2006). The US EPA empirical equation for the unpaved road is given as follows:

$EF = k\ (s/12)^{a}\ (W/3)^{b}$ (7)

Where EF = size-specific emission factor, lb/VMT

s = Surface material silt content, %

W = Mean vehicle weight, tons

The 2006 version of the EPA equation modified PM-2.5 particle size multipliers and upgraded quality ratings based on the wind tunnel studies of a variety of dust emitting surface materials (US EPA 2006). Few other alternative equations are available for estimating PM10 from vehicle use on unpaved areas (unpaved roads, tank trails, or off-road areas) (Tetra Tech Inc, 2004):

Emission rate equation in AP-42 Fifth Edition, Volume I, Section 13.2.2 (US EPA 1995):

PM10 tons/day = 0.36*5.9*[(%silt+clay)/12]*(mph/30)*[(tons GVW/3)^(0.7)]*[(#wheels/4)^(0.5)]*[(365-precip days)/365]*(VMT/day)/(2000 lbs/ton) (8)

Emission rate equation in AP-42 Fifth Edition, Volume I, Supplement E, Section 13.2.2 (US EPA 1998):

PM10 tons/day = 2.6*[((%silt+clay)/12)^(0.8)]*[(mean vehicle weight in tons/3)^(0.4)]*[(365-precip days)/365]*(VMT/day)/([(surface moisture %/0.2)^(0.3)]*(2000 lbs/ton)) (9)

Note: this equation overpredicts emissions at speeds below 15 mph. An optional multiplier of (mean vehicle speed)/15 can be used as a correction factor.

Emission rate equation A in proposed revision to AP-42 Fifth Edition, Volume I, Section 13.2.2 (US EPA 2001):

PM10 tons/day = 1.5*[((%silt+clay)/12)^(0.9)]*[(mean vehicle weight in tons/3)^(0.45)]*[(365-precip days)/365]*(VMT/day)/(2000 lbs/ton) (10)

Where "mean vehicle weight in tons" is a weighted average of all vehicle traffic on a particular road segment or off-road area.

Emission rate equation B Option 1 in proposed revision to AP-42 Fifth Edition, Volume I, Section 13.2.2 (US EPA 2001):

PM10 tons/day = 1.8*[(%silt+clay)/12]*[(mean vehicle speed in mph/30)^(0.5)]*[(365-precip days)/365]*(VMT/day)/([(surface moisture %/0.5)^(0.2)]*(2000 lbs/ton) (11)

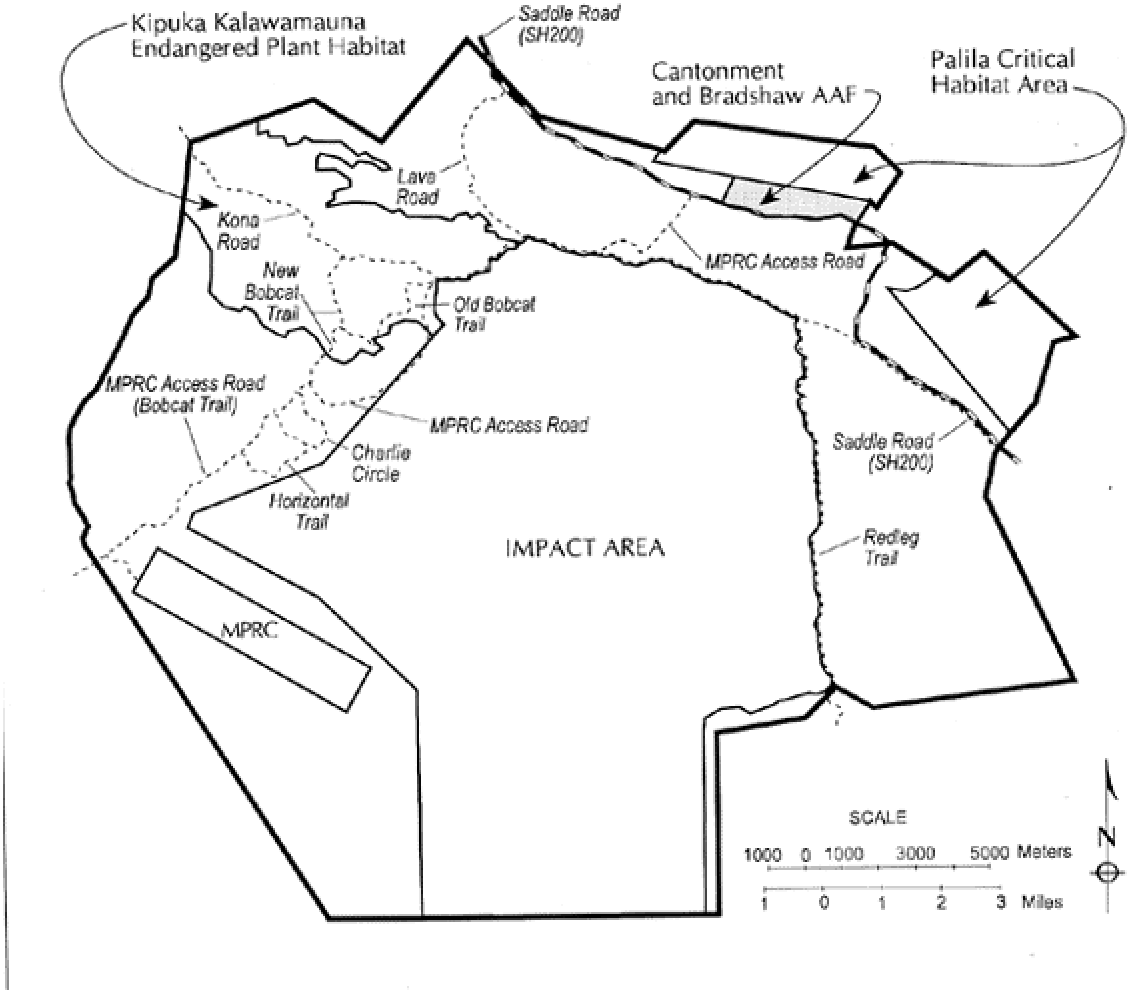
Emission rate equation B Option 2 in proposed revision to AP-42 Fifth Edition, Volume I, Section 13.2.2 (US EPA 2001):

PM10 tons/day = 1.7*[((%silt+clay)/12)^(0.8)]*[(mean vehicle speed in mph/30)]*[(365-precip days)/365]*(VMT/day)/([(surface moisture %/0.5)^(0.2)]*(2000 lbs/ton)) (12)

Where "mean vehicle speed in mph" is a weighted average of all vehicle traffic on a particular road segment or off-road area.

# Pohakuloa Training Area, Hawaii

The study area for pre and post transformation was Pohakuloa Training Area, (PTA). The landscape of PTA is characterized by panoramic views of the broad open area between Mauna Kea and Mauna Loa. The gently sloping form and smooth line of Mauna Kea to the north and Mauna Loa to the south are dominant background features of the visual landscape. The cantonment area is a visually distinct element of the landscape. Vegetation is dominated by grasses and shrubs that tend to be sparse and generally low in height. Terrain in the PTA area is gently sloping and open, periodically interrupted by remnant volcanic cones (puu). Lava flows create dark visually receding areas throughout PTA (Shaw and Castillo, 1997). Figure 2-1 shows Major Roads, trails, landmarks and training features on PTA, Hawaii. The extremely uniform vegetation and topography result in middle ground and background views of PTA that lack visual complexity but that are dramatic in their expansiveness. There are few human features in the area except roads and support facilities within the training area and structures, roads, and an airfield within the cantonment area of PTA. Figure 2-2 shows PTA range office locations. The panoramic views, the integrated visual space, and the unity of the natural features give this area a high overall visual quality, despite the uniformity of the landscape (Shaw and Castillo, 1997).



Source: Center for Ecological Management of Military Lands, Department of Forest Sciences, Colorado State University

*Figure 2-1: Major roads, trails, landmarks and training features on Pohakuloa Training Area, Hawaii.*

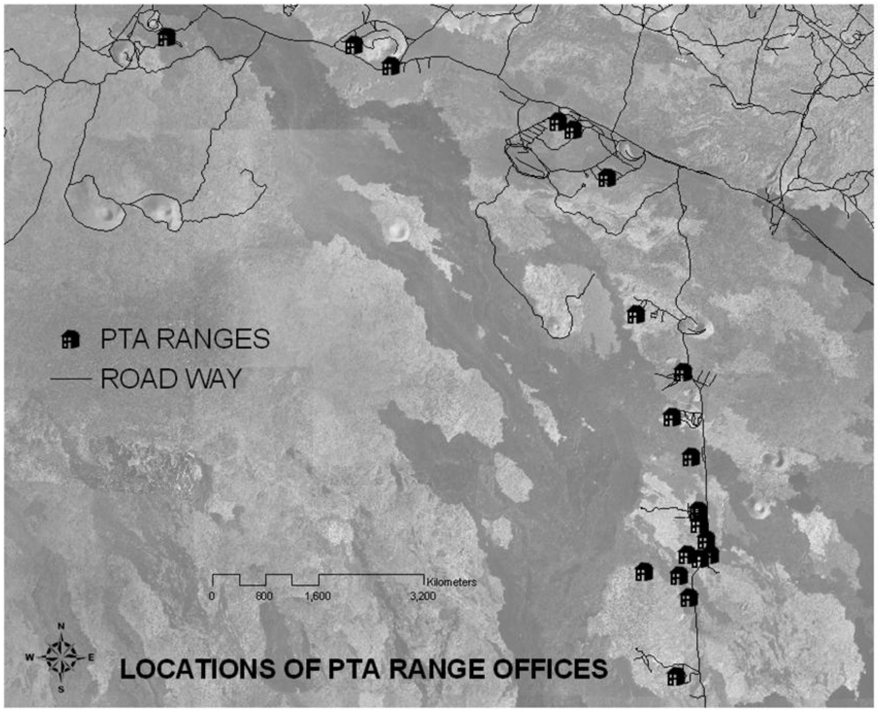


*Figure 2-2: PTA Range office locations*

## *PTA Climate*

The climate at PTA is classified as cool tropical (upper montane to alpine) (Loope and Scowcroft 1985). The 29-year average annual precipitation at Bradshaw Army Airfield (Elevation, 1862 m) on the northern edge of the installation is 37.4 cm. Most of the installation is above the thermal inversion layer, thus, it is not influenced by the tradewind-orographic rainfall regime. Moisture characteristically carried by the summer easterly tradewinds is lost as precipitation with an augment in elevation and rarely reaches PTA. Highest monthly precipitation generally occurs in the winter months (Nov-Feb) in conjunction with Kona storms (Table 2-4).

*Table 2-4: Climatological data of Hawaii (World Meteorological Organization, 2009)*

| Month | Mean Temperature (deg C) | | Mean Total Precipitation (mm) | Mean Number of Precipitation Days* |
|---|---|---|---|---|
| | Daily Min | Daily Max | | |
| Jan | 18.7 | 26.7 | 90.2 | 7.0 |
| Feb | 18.6 | 26.9 | 56.1 | 5.2 |
| Mar | 19.6 | 27.6 | 55.9 | 6.0 |
| Apr | 20.4 | 28.2 | 39.1 | 5.2 |
| May | 21.3 | 29.3 | 28.7 | 3.3 |
| Jun | 22.3 | 30.3 | 12.7 | 2.1 |
| Jul | 23.1 | 30.8 | 15.0 | 2.9 |
| Aug | 23.4 | 31.5 | 11.2 | 2.6 |
| Sep | 23.1 | 31.4 | 19.8 | 3.5 |
| Oct | 22.4 | 30.5 | 57.9 | 4.6 |
| Nov | 21.3 | 28.9 | 76.2 | 6.1 |
| Dec | 19.4 | 27.3 | 96.5 | 6.9 |

*Climatological information is based on WMO Climatological Normals (CLINO) for the 30-year period 1961-1990.*

** Mean number of precipitation days = Mean number of days with at least 1 mm of precipitation.*

*Precipitation includes both rain and snow.*

Occasionally, moist air trapped below the inversion layer will rise into the saddle area in the late afternoon. Precipitation from condensation on vegetation can then occur and may even equal that from rainfall (Sato et al., 1973). The average annual temperature is 12.8 degree C with little monthly fluctuation. Diurnal temperature variation is greater than seasonal variations (Figure 2-3) (Shaw and Castillo, 1997).

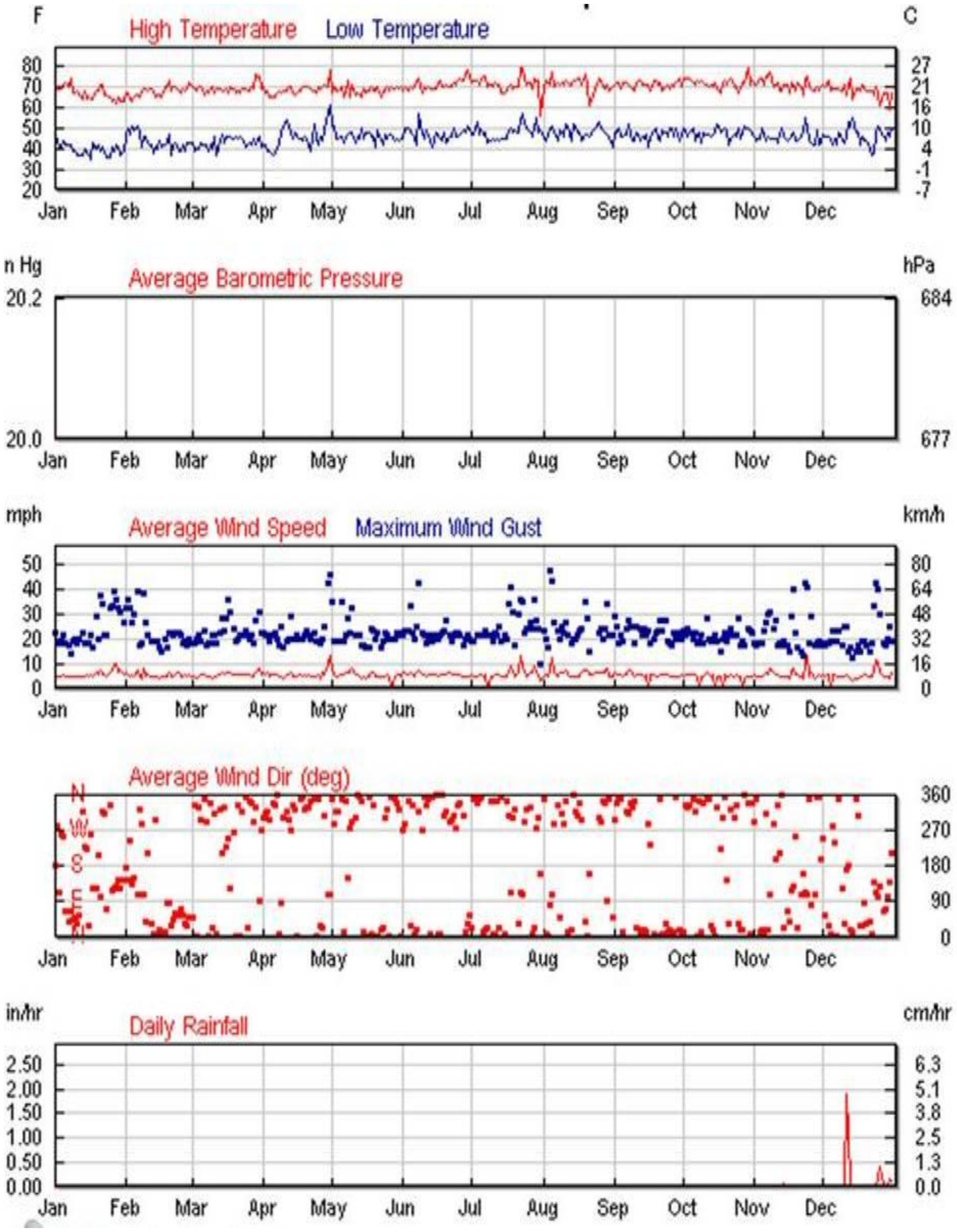


*Figure 2-3: Weather graph of PTA for year 2008 (Weather Underground, Inc., 2008)*

## *PTA Soils*

Soils are poorly developed on the installation due to the very recent (Pleistocene and Holocene) deposition of the majority of the substrates. Sato et al. (1973) broadly classified the soils on PTA as lava flow associates. These associates are typically gently sloping to steep, excessively drained, and nearly barren lava flows. Ten such soil types have been designated on the installation; however, two lava types (pahoehoe and aa) cover a wide portion of the area (Shaw and Castillo, 1997). Many of the soils are in their early formative stages, and because of this and low precipitation they have developed only rudimentary soil horizons. A large portion of the installation, particularly the eastern edge and within the impact area is barren lava or only sparsely vegetated. These areas comprise the most poorly developed soils, while areas on the western and northern ends of PTA contain some of the deepest soils. Localized ash and cinder deposits also exist throughout the installation (Beavers, 2000). The most highly developed soils occur on the older Mauna Kea substrates, which usually consist of a thin layer of soil, cinder, or ash deposits. Eolian sands are also found at the installation in small amounts. The low precipitation, rapid runoff, and high altitude reduce the rate of weathering, and the high slope and wind tend to prevent soils from accumulating (Shaw and Castillo, 1997).

## *PTA Roads*

Unpaved roads are major features on military lands. A road segment is identified as section of road having generally uniform characteristics along its length. Criteria that distinguish road segments include surfacing material, road size, traffic use, topography, road condition, and construction history (Eaton and Beaucham, 1992). The length of the road segments meeting a given criteria can be summed to provide a quantitative measure of condition (e.g., within a watershed or training area) and document improvement or lack of progress over time. Adding and linking the digital photograph for each road segment and site specific problem to the geodatabase will also aid in the maintenance scheduling and planning (Kunze and Jones, 2004). There were 2,585 road segments found at PTA with an overall length of 541.5 km (Figure 2-4 shows the road map of PTA). PTA roads were grouped into three categories, unimproved, secondary, and tertiary.

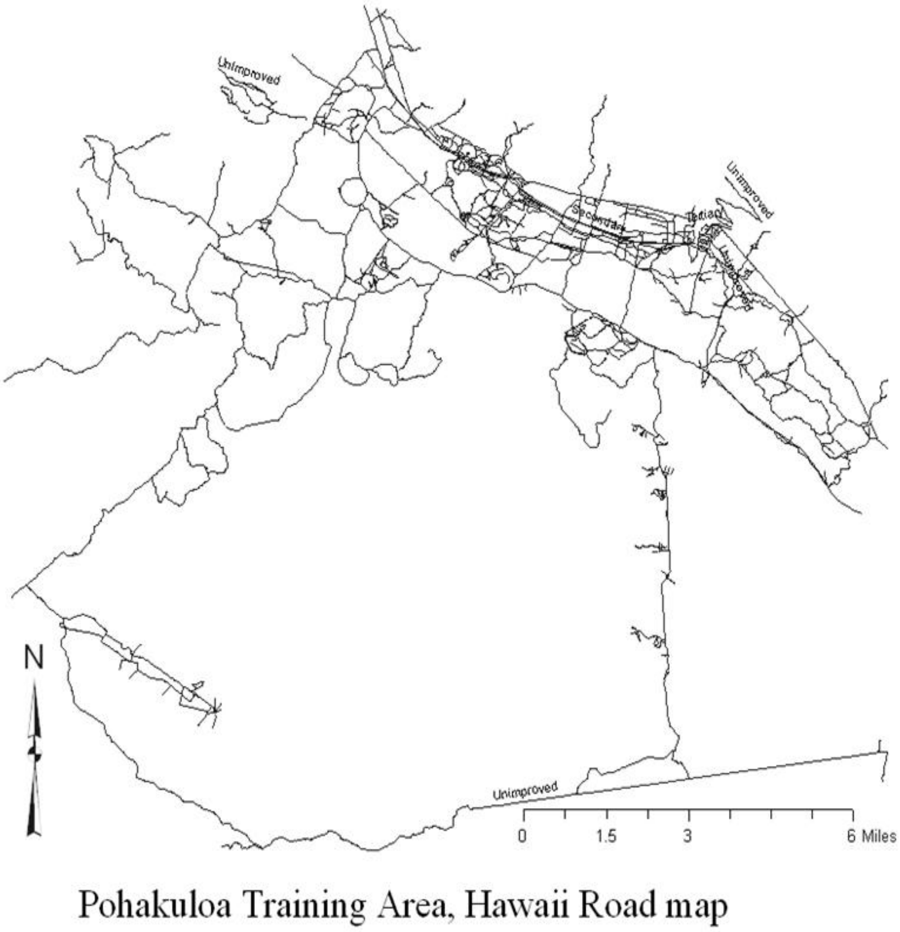


*Figure 2-4: Road map of PTA, Hawaii*

# Vehicle Tracking Studies

Vehicle tracking has been one of the primary approaches in understanding environmental impacts by the military vehicles. McDonald and Fulton (2004) introduced a data acquisition system which converts movement and positional data collected using GPS receiver mounted on harvesting equipment like skidders, into time study information. Vehicle Tracking studies were conducted at Yakima Training Center, Washington in October 2001 (Haugen, 2002); Fort Riley Military Installation, Kansas in May 2005; and Fort Lewis Military Installation, Washington in October 2005. Vehicle position, speed and distance traveled were determined. Li et al. (2003) used vehicle tracking for the assessment of environmental impacts by army vehicles to sustainably manage military lands. Ayers et al. (2004) have investigated the feasibility of determining vehicle movement patterns and identifying column movement.

Ayers et al. (2005) and Wu (2005) have tracked military vehicles for the purpose of identifying potential roads. An algorithm was developed by Wu (2005) to identify potential roads using Global Positioning System (GPS) based tracking data from a field training exercise at Yakima Training Center. Studies were conducted to evaluate the use of GPS for vehicle tracking and to determine dynamic properties of the vehicles, such as velocity, turning radius, and acceleration (Ayers et al., 2000 and Haugen et al., 2000). Haugen (2002) utilized autonomous Garmin GPS35-HVS GPS receivers to analyze vehicle dynamic properties and to assess vehicle position during a military training exercise at Yakima Training Center, Washington.

## Summary of the chapter

In summary, previous studies of vehicular dust were primarily concerned with their atmospheric transport and down-wind deposition (Becker and Takle, 1979), and with their contribution to atmospheric pollution (U.S. EPA, 1974). Dyck and Stukel (1976) have made estimates of the total dust emission from vehicles operated on unpaved roads as a function of vehicle mass and speed, but these studies are devoid of information on particle size characteristics. Earlier research concentrated on introducing and validating different dust models to assess emission estimates from offroad and onroad mobile sources.  They emphasized identifying methods to estimate different components of the emission and calibrating the factors associated with it. Methods have been developed to evaluate and calculate dust emissions. Preliminary studies were conducted to measure emission rates based on factors such as particle sizes, wind speed and surface conditions. Although dust emission models were developed and evaluated, combining GPS vehicle tracking with these models can be used to more accurately predict site specific dust emission changes during Army transformation at PTA.

# Chapter 3: Objectives

Tracking military vehicles pre and post transformation at Pohakuloa Training Area (PTA) was a tenable approach to quantify environmental impacts. A comprehensive objective of this study was to evaluate the influence of Stryker transformation on potential dust generated at PTA during training maneuvers. Stryker transformation, therefore involved the shift of the 25th Infantry, 2nd Brigade from a Light Infantry (Mobile tactical vehicle, MTV and High mobility multi wheeled vehicle, HMMWV) to a Stryker Brigade.

The specific objectives of this study were to,

- Determine the movement of military vehicles pre and post transformation at PTA using a GPS Vehicle Tracking System (VTS).
- Estimate and quantify the amount of dust generated from the pre and post transformation exercises using an equation developed by US EPA using an unpaved road emission factor equation for dry conditions (Midwest Research Institute, 1998).
- Represent the spatial distribution of dust emission potential by military vehicles from different road segments at PTA, using a GIS-based dust allocation program.
- Identify critical road segments with the highest potential for dust emissions during both pre- and post- Stryker transformation.
- Determine the expected dust emission rates from the vehicles involved in pre- and post- Stryker transformation.

- Provide a comparative research analysis on pre- and post transformation training maneuvers by comparing the amount of total dust estimated for the pre transformation as opposed to the post transformation.
- Statistical hypothesis test to predict the influence of transformation on dust generation.
- The last objective was to conduct a sensitivity analysis using silt percentage, vehicle speed and US EPA unpaved road emission equations to understand the variability of unpaved road silt percentage and vehicle speed on predicted dust analysis.

# Chapter 4: Materials and Field Implementation

## Components of a Vehicle Tracking System

### *Introduction*

The system developed for vehicle tracking consists of a WAAS Differential Global Positioning System (DGPS) receiver, a serial data recorder, a data storage card, batteries, and a case (Figure 4-1). The system was developed to be lightweight, mobile, and flexible. It is a completely self-contained system requiring no electrical connection to the vehicle power supply and can collect 10 days of GPS positional data.

### *Global Positioning Receiver*

The Garmin GPS18-PC GPS receiver was selected for the vehicle tracking system because it is lightweight (3.9 oz), small in size (1.05"x3.79"x2.22"), can be attached to the vehicle with a magnet, has a wide range of operating temperature (-30°C to 85°C), and a wide range of input voltage (6 VDC to 40VDC unregulated). The Garmin GPS18 GPS receiver has one cable through which the power is supplied to the receiver. GPS data is output in the form of $GPGGA and $GPRMC National Marine Electronics Association (NMEA) strings at 1 Hz, to the storage card on a Serial Data Recorder (SDR).

Figure 4-1: Components of Vehicle Tracking System

## Power Supply and Power Accessories

The Odyssey rechargeable Drycell 12 volt battery (PC625) was selected for the vehicle tracking system because the battery can provide 12 volts for 17 amp-hours, which corresponds to approximately 17 hours of power to the Garmin GPS18-PC and SDR. The Odyssey rechargeable Drycell 12Vdc battery is of starved electrolyte dry cell electrochemical design and can be air-freighted.

## Serial Data Recorder (SDR)

The Acumen Serial Data Recorder was used for the vehicle tracking systems. A 128 MB Compact Flash cards were used for data storage in the vehicle tracking system.

The SDR's can operate on 8 to 15 volt DC power and can collect about 10 days of continuous GPS data.

### *Protective Case*

The impact resistant, water-proof case holds two batteries, GPS, SDR, and an outside magnet for GPS attachment.  It is strapped to the outside of the vehicle, usually in the cargo holding areas for about 10 days of operation.

## **Vehicle Tracking at PTA**

### *Pre Transformation Tracking*

A pre transformation vehicle tracking study was conducted at Pohakuloa Training Area (PTA), Hawaii, featuring the light armored vehicles (LAV), the M998 high mobility multipurpose wheeled vehicles (HMMWV) and the M1083 medium tactical vehicle (MTV). The HMMWV (Figure 4-2) has a weight of 2,358 kg. The overall length of the HMMWV was 4.52 m, a height of 1.82 m reducible to 1.37 m, and width of 2.1 m (Table 4-1). It can attain a maximum speed of 104 kph. HMMWV’s are designed for use over all types of roads, in all weather conditions and are extremely effective in the most difficult terrain. The HMMWV’s high power-to-weight ratio, four-wheel drive and high ground clearance combine to give it outstanding cross-country mobility. MTV has a curb weight of 8,889 kg. The overall length of the MTV was 6.9 m, a height of 2.8 m, and a width of 2.4 m (Table 4-1). It can attain a maximum speed of 93 kph. The M1083 Standard Cargo Truck is designed to transport cargo and soldiers. The M1083 has a payload capacity of 4536 kg. It had 6 wheels with a wheel base of 4 m (Federation of American Scientists (FAS), Military Analysis Network, 1998).

Figure 4-2: HMMWV’s in a motor pool at PTA

*Table 4-1: Pre and post transformation vehicle's characteristics (US Army, 2008)*

| Vehicle type | Vehicle weight (kilogram) | Number of wheels | Vehicle dimensions (meter) (length*width*height) |
|---|---|---|---|
| HMMWV | 2,358 | 4 | 4.52*1.82*2.1 |
| MTV | 8,889 | 6 | 6.9*2.8*2.4 |
| STRYKERS | 16,128 | 8 | 6.98*2.3*2.64 |

Garmin 18 GPS receivers programmed to be WAAS differentially corrected were used in the PTA tracking study. During the tracking study, one VTS was mounted on each of the 11 vehicles tracked (Table 4-2). The vehicles were equipped with the VTS units (Figure 4-3) on November 28, 2006, and units were turned on to record the positional data. This recording continued till December 10, 2006, when the VTS's were retained from the vehicles.

*Table 4-2: Vehicles tracked during pre transformation at PTA*

| **Bumper #** | **Vehicle type** | **Platoon** | **VTS** |
|---|---|---|---|
| B-60 | MTV | Anti-tank | 2 |
| B-7 | MTV | Anti-tank | 3 |
| A-6 | HMMWV | Alpha | 4 |
| A-2 | MTV | Alpha | 5 |
| B-1 | MTV | Bravo | 7 |
| B-7 | HMMWV | Bravo | 9 |
| C-2 | MTV | Charlie | 11 |
| C-3 | MTV | Charlie | 12 |
| A-7 | HMMWV | Alpha | 15 |
| HHC-64 | MTV | Headquarters | 16 |
| HHC-63 | MTV | Headquarters | 17 |

In the table 4-2, the bumper number depicts the company, platoon, and position. The letters stand for the troops. In this case, A, B, C, and HHC correspond to Alpha, Bravo, Charlie, and Head Quarters, respectively. The number corresponds to the vehicle number.

*Figure 4-3: Vehicle Tracking Systems line up at PTA*

## *Post Transformation Tracking*

A vehicle tracking study was conducted at PTA, Hawaii from April 10, 2007 through April 21, 2007. A total of 16 Strykers were tracked for ten days using the vehicle tracking systems (VTS) during military training exercise. The Strykers (Figure 4-4) are diesel fueled eight-wheeled vehicles with a maximum curb weight of 16,128 kg and a maximum gross weight of 18,502 kg. The vehicle length was 6.98 m, and the tread width was 2.3 m (center to center) with a height of 2.64 m. The tires were Michelin X, with a width of 0.28 m and diameter of 1.11m. The vehicle was capable of varying tire pressure. During the tracking study, one VTS was mounted on each of the 16 vehicles tracked (Table 4-3). The vehicles were equipped with the VTS units on April 10, 2006 (Figure 4-5), and units were turned on to record the position data.

This recording continued till April 21, 2006, when the VTS's were removed from the vehicles.

In the table, the bumper number depicts the company, platoon, and position. The letters stand for the troops. In this case, A, B, C, and HHC correspond to Alpha, Bravo, Charlie, and Headquarters, respectively. The first number corresponds to the platoon and the second corresponds to the position of vehicle in the platoon.

*Table 4-3: Vehicles tracked during the post transformation at PTA*

| **Bumper #** | **Vehicle Type** | **Platoon** | **VTS** |
|---|---|---|---|
| C-66 | Stryker | Charlie | 1 |
| C-11 | Stryker | Charlie | 2 |
| C-12 | Stryker | Charlie | 3 |
| C-14 | Stryker | Charlie | 5 |
| C-21 | Stryker | Charlie | 6 |
| A-12 | Stryker | Alpha | 9 |
| A-14 | Stryker | Alpha | 11 |
| A-21 | Stryker | Alpha | 12 |
| A-31 | Stryker | Alpha | 13 |
| B-32 | Stryker | Bravo | 14 |
| HHC-71 | Stryker | Headquarters | 15 |
| HHC-74 | Stryker | Headquarters | 16 |
| HHC-73 | Stryker | Headquarters | 17 |
| HHC-72 | Stryker | Headquarters | 18 |
| B-12 | Stryker | Bravo | 19 |
| B-14 | Stryker | Bravo | 21 |

*Figure 4-4: Strykers in a motor pool at PTA*

*Figure 4-5: VTS mounted on a Stryker during post transformation*

# Chapter 5: Discussion of Methods and Results

## Assessment of GPS Data

Data retrieved from the pre and post transformation exercises was used to assess the quality of GPS vehicle tracking. Data was stored in SanDisk™ compact flash cards. Once the data was uploaded on to a PC, the start and stop dates and times were determined. The percent valid data was determined by identifying missing or "No fix" GPS data (invalid data) by using (equation 13). An average of 99.8 % of data was found to be valid for the pre transformation exercise (Table 5-1). Similarly, for the post transformation analysis (Table 5-2), an average of 99.9 % of data was found to be valid, indicating a valid position at each time and a good reception of GPS satellites. The assessment of GPS data quality also included combining $GPRMC and $GPGGA National Marine Electronics Association (NMEA) strings from the GPS data. At every second, each string provides valuable GPS data. A large portion of the data was no-move data as VTS recorded position of vehicles every second, therefore, move-data was separated from the no-move data. A Speed over Ground (SOG) of less than 1 knot (0.51 m/s) was considered as 'no-move' data.

$$\% \text{ Valid data} = [1-(\text{Invalid data count}/(\text{Total data count}/2))] \tag{13}$$

The world coordinates (WGS 84) were transformed to northing (meter) and easting (meter) coordinate pairs using Universal Transverse Mercator (UTM). Data with UTM velocities less than 0.5 m/s were removed from the dataset and the remaining data was considered ‘move’ data. The process also involved conversion of coordinates in a spreadsheet format to a shapefile (.shp) format for ESRI ArcView GIS software. It was ensured that the coordinate file was well-structured so that the first column contained the unique identification codes, or primary key. The second and third columns contained the x (longitude) and y (latitude) coordinates, respectively. Additional data fields followed in remaining columns. Coordinate columns were formatted as numeric with the appropriate number of decimal places prior to saving the file (Ehlen and Harmon, 2001). The file was saved as delimited text (.txt) file which was supported by ArcGIS 9.1. In the pre transformation analysis (Table 5-1), an average of 5.4% of data was regarded move-data, for the 11 GPS datasets. The post transformation analysis contained 16 GPS datasets and an average of 2.9% of them provided move-data.  The percent of data differentially corrected was also determined to indicate GPS data quality. An average of 70.7 % and 94.6% of data were differentially corrected for pre transformation and post transformation respectively (Table 5-1 and Table 5-2).

## Vehicle Movement Determination

Vehicle movement determination was performed on the moving GPS data set. The distance traveled was determined between each point. Since the data was collected every second, the distance between two consecutive data points divided by the 1 second time increment yielded velocity at that particular data point.

*Table 5-1: GPS data assessment during pre transformation vehicle tracking exercise at PTA*

| VTS # | Bumper # | Vehicle Type | Days of data | Percent Valid | Percent Moving | Percent Differential | Total Distance (km) | Average Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|
| 2 | B-60 | MTV | 10.00 | 99.93 | 3.22 | 95.36 | 134.87 | 6.50 |
| 3 | B-7 | MTV | 8.54 | 99.80 | 3.39 | 96.64 | 103.51 | 6.38 |
| 4 | A-6 | HMMWV | 9.70 | 99.51 | 4.12 | 73.29 | 360.10 | 5.00 |
| 5 | A-2 | MTV | 10.18 | 99.94 | 5.84 | 67.42 | 97.20 | 6.01 |
| 7 | B-1 | MTV | 10.33 | 99.73 | 5.96 | 49.83 | 100.70 | 6.15 |
| 9 | B-7 | HMMWV | 10.15 | 100.00 | 13.25 | 22.32 | 367.43 | 5.94 |
| 11 | C-2 | MTV | 10.32 | 99.83 | 5.31 | 90.30 | 519.15 | 3.83 |
| 12 | C-3 | MTV | 10.33 | 99.85 | 4.64 | 70.57 | 94.90 | 5.80 |
| 15 | A-7 | HMMWV | 9.02 | 99.23 | 6.78 | 58.52 | 486.33 | 5.11 |
| 16 | HHC-64 | MTV | 8.94 | 99.70 | 4.15 | 74.33 | 92.26 | 5.63 |
| 17 | HHC-63 | MTV | 9.58 | 99.89 | 2.66 | 78.81 | 80.63 | 5.00 |

*Table 5-2: GPS data assessment during the post transformation vehicle tracking exercise at PTA*

| VTS # | Bumper # | Vehicle Type | Days of data | Percent Valid | Percent Moving | Percent Differential | Total Distance (km) | Average Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|
| 1 | C-66 | Stryker | 8.98 | 100.00 | 3.04 | 95.54 | 93.43 | 5.47 |
| 2 | C-11 | Stryker | 9.84 | 100.00 | 3.40 | 99.31 | 77.68 | 4.74 |
| 3 | C-12 | Stryker | 8.30 | 100.00 | 3.52 | 95.38 | 71.97 | 4.40 |
| 5 | C-14 | Stryker | 9.43 | 100.00 | 3.00 | 99.89 | 75.38 | 4.60 |
| 6 | C-21 | Stryker | 9.97 | 100.00 | 2.84 | 97.27 | 71.60 | 4.30 |
| 9 | A-12 | Stryker | 10.07 | 98.74 | 2.08 | 57.78 | 97.33 | 6.10 |
| 11 | A-14 | Stryker | 9.40 | 100.00 | 3.23 | 94.77 | 265.03 | 6.15 |
| 12 | A-21 | Stryker | 9.39 | 100.00 | 2.31 | 97.78 | 87.90 | 5.37 |
| 13 | A-31 | Stryker | 9.46 | 99.95 | 3.23 | 92.60 | 243.26 | 5.15 |
| 14 | B-32 | Stryker | 9.03 | 99.98 | 2.40 | 97.13 | 191.04 | 5.23 |
| 15 | HHC-71 | Stryker | 10.68 | 99.98 | 3.06 | 98.67 | 288.34 | 5.84 |
| 16 | HHC-74 | Stryker | 8.89 | 99.97 | 3.06 | 97.45 | 98.28 | 6.00 |
| 17 | HHC-73 | Stryker | 9.48 | 100.00 | 3.02 | 99.64 | 97.79 | 5.97 |
| 18 | HHC-72 | Stryker | 10.05 | 100.00 | 2.79 | 94.14 | 102.78 | 6.27 |
| 19 | B-12 | Stryker | 9.82 | 100.00 | 2.98 | 97.12 | 97.84 | 5.97 |
| 21 | B-14 | Stryker | 9.19 | 100.00 | 3.12 | 99.78 | 92.34 | 5.64 |

An average of 5.79 m/s was recorded for the complete dataset during the pre transformation exercise. Vehicles traveled an average of 221.5 km for a period of 10 days during the exercise. HMMWV's traveled an average of 42.41 km per vehicle day with a standard deviation of 9.97 km (Table 5-3) and MTV's traveled an average distance of 15.4 km per vehicle day standard deviation of 14.2 km (Table 5-4). Appendix A shows the vehicle movements during pre transformation. For the post transformation analysis, an average velocity of 5.45 m/s was recorded for the complete dataset. Strykers traveled an average of 128 km for a period of 10 days during the exercise whereas an average distance of 13.43 km per vehicle day with a standard deviation of 7.41 km (Table 5-5). Appendix B shows the vehicle movements during post transformation.

*Table 5-3: Distance traveled characteristics of HMMWV during the pre transformation exercise*

| **HMMWV** | **Total distance (km)** | **Days (#)** | **Distance per vehicle day (km/day)** |
|---|---|---|---|
| A-6 | 360.10 | 9.70 | 37.12 |
| B-7 | 367.43 | 10.15 | 36.20 |
| A-7 | 486.33 | 9.02 | 53.92 |
| Average | | | 42.41 |
| Standard Deviation | | | 9.97 |

*Table 5-4: Distance traveled characteristics of MTV during the pre transformation exercise*

| **MTV** | **Total distance (km)** | **Days (#)** | **Distance per vehicle day (km/day)** |
|---|---|---|---|
| B-60 | 134.87 | 10.00 | 13.49 |
| B-7 | 103.51 | 8.54 | 12.12 |
| A-2 | 97.20 | 10.18 | 9.55 |
| B-1 | 100.70 | 10.33 | 9.75 |
| C-2 | 519.15 | 10.32 | 50.30 |
| C-3 | 94.90 | 10.33 | 9.19 |
| HHC-64 | 92.26 | 8.94 | 10.32 |
| HHC-63 | 80.63 | 9.58 | 8.42 |
| Average | | | 15.39 |
| Standard Deviation | | | 14.20 |

*Table 5-5: Distance traveled characteristics of Stryker during the post transformation exercise*

| Stryker | Total distance (km) | Days (#) | Distance per vehicle day (km/day) |
|---|---|---|---|
| C-66 | 93.43 | 8.98 | 10.40 |
| C-11 | 77.68 | 9.84 | 7.89 |
| C-12 | 71.97 | 8.30 | 8.67 |
| C-14 | 75.38 | 9.43 | 7.99 |
| C-21 | 71.60 | 9.97 | 7.18 |
| A-12 | 97.33 | 10.07 | 9.67 |
| A-14 | 265.03 | 9.40 | 28.19 |
| A-21 | 87.90 | 9.39 | 9.36 |
| A-31 | 243.26 | 9.46 | 25.71 |
| B-32 | 191.04 | 9.03 | 21.16 |
| HHC-71 | 288.34 | 10.68 | 27.00 |
| HHC-74 | 98.28 | 8.89 | 11.05 |
| HHC-73 | 97.79 | 9.48 | 10.31 |
| HHC-72 | 102.78 | 10.05 | 10.23 |
| B-12 | 97.84 | 9.82 | 9.96 |
| B-14 | 92.34 | 9.19 | 10.05 |
| Average | | | 13.43 |
| Standard Deviation | | | 7.41 |

Vehicle movement determination from the pre and post transformation analysis showed that the Light Armored Vehicles (LAV) comprising HMMWV's and MTV's, traveled greater distances when compared to Strykers (Figure 5-1), with HMMWV's in the lead.

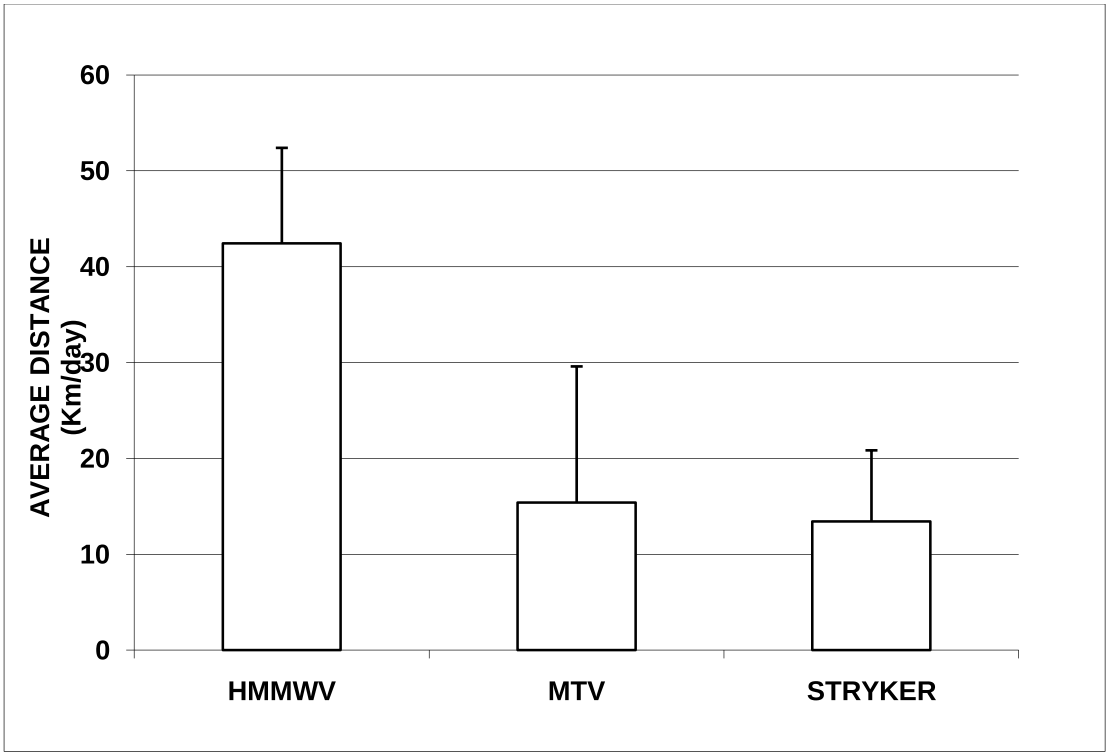


*Figure 5-1: Average distance traveled per vehicle day during pre and post transformation exercises*

# Dust Emission Estimation

Emissions can be estimated using emission factors which, when combined with site-specific information (eg. the silt and moisture content of material being handled), can be used to determine emissions from the particular operation being analyzed (Commonwealth of Australia, 2001). Unpaved road dust emissions are due to mechanical disturbance of the roadway and air turbulence effects generated by the vehicle. AP-42 Section 13.2.2 provided a good discussion of unpaved road emissions and a PM emission estimation equation (Canadian chemical producers association, 2001). The quantitative analysis of emissions may require field measurements or the use of computer models. The information required for calculating emissions varies depending on the nature of the emission sources and methodologies used (Ontario Ministry of Environment, 2007). Dust emissions were measured to quantify the amount of dust expelled from the pre and post transformation maneuvers. The emission factor equation (Equation 1) was used to estimate the amount of dust emitted for both the pre and post transformation exercises separately. The emission factor was calculated and dust generated as a function of silt content, vehicle speed, number of wheels and vehicle weight.

Silt percentages were obtained from the soil samples collected during vehicle tracking exercises pre and post transformation at PTA. Soil samples collected from different random unpaved road segments were analyzed by the soil testing services at the

University of Manoa, Hawaii. Detailed results on soil composition were obtained (Table: 5-6).

*Table 5-6: Results of soil sample analysis*

| Sample No. | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|
| 1 | 85.81 | 11.29 | 2.9 |
| 2 | 83.28 | 14 | 2.72 |
| 3 | 87.48 | 8.16 | 4.36 |
| 4 | 88.17 | 9.22 | 2.61 |
| 5 | 89.32 | 8.72 | 1.96 |
| 6 | 86.15 | 11.94 | 1.91 |
| 7 | 88.33 | 9.91 | 1.76 |
| 8 | 86.29 | 10.22 | 3.49 |
| 9 | 88.51 | 8.98 | 2.51 |
| 10 | 87.67 | 9.49 | 2.84 |
| 11 | 87.57 | 9.17 | 3.26 |
| 12 | 86.54 | 9.94 | 3.52 |
| 13 | 84.54 | 11.77 | 3.69 |
| 14 | 85.1 | 11.07 | 3.83 |
| 15 | 88.07 | 7.40 | 9.53 |
| 16 | 90.78 | 7.04 | 2.18 |
| 17 | 87.96 | 9.07 | 2.97 |
| 18 | 86.65 | 10.43 | 2.92 |
| 19 | 87.28 | 10.79 | 1.93 |
| 20 | 88.14 | 9.69 | 2.17 |
| 21 | 86.49 | 11.16 | 2.35 |

## ***Dust Model Implementation***

One of the critical problems in making an effective strategy to control fugitive road dust is to estimate the emission factor accurately (Tsai and Chang, 2002). Different models were employed in research studies to estimate dust emissions. Emission factor equations were used to estimate the quantity and distribution of the daily dust emissions from the pre and post transformation exercises. Though Equation (1) was used in the pre and post transformation analyses, two other US EPA dust models were also tested (Equations (2) and (3)) to compare the differences in dust emission estimation values. Accordingly, as presented in the table 5-7, emission factors (lb/VMT) were calculated separately for each of the vehicle types at varying speeds (4.3 m/s, 5 m/s, 5.94 m/s, 6.1 m/s, and 6.54 m/s) and moisture content (low, 0.2% and high 1.1%). They were also employed to understand the differences in the amounts of dust emitted by HMMWV’s, MTV’s, and Strykers during the transformation exercises. The first model (Equations (2) & (3)) included speed factor whereas the second replaced the speed factor with moisture content (Equations (3) & (4)). The third model (Equation (7)) which was designed for light duty vehicles traveling on industrial roads, expressed emission factor in terms of silt content percent and mean vehicle weight in tons.

The analysis showed an increase in the emission factor values for all vehicle types, moving from low speed to high speed, though it was more prominent with Strykers (Table 5-6). Similar trend was observed with the second and third EPA emission factor equations, the former excluded the speed factor but included moisture content while latter had only silt content and mean weight factors. Etyemezian et al (2003) compared emission factors measured at Ft. Bliss and those calculated according to AP-42 guidance document (US EPA, 1999). They stated that by not accounting for vehicle speed, the AP-42 estimates were too high for vehicles traveling at low speed. Measurement of emission factors for unpaved PM10 road dust at Ft. Bliss exhibited a strong dependence on vehicle speed. The emission factor for PM10 road dust provided in the AP-42 (US EPA, 1999) does not include speed dependence. In addition to the neglect of vehicle speed, some of the inconsistencies in the AP-42 emission factors for PM10 dust from unpaved roads came from the ‘lumping’ of the vehicle weights. Emission factors calculated this way were not self consistent (Etyemezian et al, 2003).

A reasonably conservative value of 0.2 percent was selected for the default dry condition moisture content. This moisture value was not the average moisture content of the road surface material but is the minimum moisture content following an extended period without water additions to the road surface (Midwest Research Institute, 1998). Even though the default moisture value may be viewed as conservative, the default should not generally lead to unacceptable emission estimates (Midwest Research Institute, 1998). This is due to the fact that moisture is raised to such a low power (0.3 and 0.4) in the predictive emission factors. As per the AP-42 document, the overall mean moisture content in publicly accessible road data set was found as 1.1 percent (Midwest Research Institute, 1998). Although this value potentially could have provided the default, it was believed that 1.1 percent did not adequately represent the extremes of the data set. The database contained moisture contents approximately 0.1 to 0.3 percent for roads even in what were not considered "dry" parts of the nation (Midwest Research Institute, 1998). This situation was not surprising since the moisture content of the surface material of an unpaved road is very dynamic. The moisture content is affected by a number of meteorological and physical parameters that vary considerably with time and by location (Midwest Research Institute, 1998).

Dornbusch et al. (2008) used US EPA 2006 emission factor equation to estimate the quantity of total suspended particulate matter emission from unpaved road.
For urban roads, rain is the primary meteorological event which supplements moisture to the road surface. The frequency, duration, and quantity of rain are important aspects which determine the moisture content on any day and the long term average moisture content (Midwest Research Institute, 1998). However, default maximum moisture content of 1.1 percent was considered for the study and a minimum was set at 0.2 percent for calculating the emission factor using equation (2) commensurate with the conditions at PTA. The emission factor estimations calculated by the US EPA 1998 dust model (Equation 2) were higher even at low speed (Table 5-7). US EPA 1979 dust model seemed more reasonable and acceptable as it was more representative of the actual dust emissions quantified at PTA. The model was

considered a better one than the rest of the available models. Considering the environmental conditions at PTA and the vehicles involved in the training exercises, more importance was given to factors such as silt percentage, number of wheels, velocity and vehicle weight. Hence US EPA1979 dust equation was well qualified to account for pre and post transformation dust emissions.

*Table 5-7: Emission factor calculations using US EPA 1979, US EPA 1998 and US EPA 2006 dust models for pre and post transformation*

| **VEHICLE TYPE** | **Emission Factor (kg/km)**<br>**US EPA 1979**<br>$E = K\ 5.9\ (s/12)\ (S/30)\ (W/3)^{0.7}\ (w/4)^{0.5}$ | | **Emission Factor (kg/km)**<br>**US EPA 1998**<br>$E = K\ (s/12)^{a}\ (W/3)^{b} / (M/0.2)^{c}$ | | **Emission Factor (kg/km)**<br>**US EPA 2006**<br>$EF = k\ (s/12)^{a}\ (W/3)^{b}$ |
|---|---|---|---|---|---|
| | **Low speed (m/s) (i-5, ii-5, iii-4.3)** | **High speed (m/s) (i-5.94, ii-6.54, iii-6.1)** | **Low moisture (%) (0.2 %)** | **High moisture (%) (1.1 %)** | |
| HMMWV (i) | 0.25 | 0.30 | 2.56 | 1.30 | 1.27 |
| MTV (ii) | 0.40 | 0.50 | 3.00 | 1.56 | 1.50 |
| STRYKER (iii) | 1.00 | 1.42 | 6.00 | 3.00 | 2.75 |

## *Dust generated from different vehicle types*

The amount of dust emitted during transformation exercises varied largely and distinctly depending on the type of the vehicle. During the pre transformation analysis, HMMWV's generated an average of 33 kg of dust per vehicle day with a standard deviation of 5.36 kg (Table 5-8), whereas MTV's emitted an average of 36.7 kg of dust per vehicle day with a high standard deviation of 30 kg (Table 5-9). During the post transformation, Strykers generated an average of 53.5 kg of dust per vehicle day with a standard deviation of 34.6 kg (Table 5-10).

*Table 5-8: Estimated amount of dust generated per vehicle day by HMMWV during the pre transformation exercise*

| **HMMWV** | **Total Dust (Kg)** | **Days (#)** | **Dust per vehicle day (Kg/day)** |
|---|---|---|---|
| A-6 | 328 | 9.70 | 34 |
| B-7 | 283 | 10.15 | 28 |
| A-7 | 348 | 9.02 | 39 |
| Average | | | 33.38 |
| Standard Deviation | | | 5.36 |

*Table 5-9: Estimated amount of dust generated per vehicle day by MTV during the pre transformation exercise*

| MTV | Total Dust (Kg) | Days (#) | Dust per vehicle day (Kg/day) |
|---|---|---|---|
| B-60 | 787.36 | 10.00 | 78.73 |
| B-7 | 246.91 | 8.54 | 28.91 |
| A-2 | 201.44 | 10.18 | 19.78 |
| B-1 | 213.78 | 10.33 | 20.69 |
| C-2 | 938.95 | 10.32 | 90.98 |
| C-3 | 200.39 | 10.33 | 19.39 |
| HHC-64 | 168.44 | 8.94 | 18.84 |
| HHC-63 | 156.90 | 9.58 | 16.37 |
| Average | | | 36.72 |
| Standard Deviation | | | 30.11 |

*Table 5-10: Estimated amount of dust generated per vehicle day by Strykers during the post transformation exercise.*

| **Stryker** | **Total Dust (Kg)** | **Days (#)** | **Dust per vehicle day (Kg/day)** |
|---|---|---|---|
| C-66 | 327 | 8.98 | 36 |
| C-11 | 258 | 9.84 | 26 |
| C-12 | 246 | 8.30 | 20 |
| C-14 | 245 | 9.43 | 27 |
| C-21 | 959 | 9.97 | 96 |
| A-12 | 50 | 10.07 | 5 |
| A-14 | 1104 | 9.40 | 117 |
| A-21 | 353 | 9.39 | 38 |
| A-31 | 906 | 9.46 | 96 |
| B-32 | 702 | 9.03 | 78 |
| HHC-71 | 1217 | 10.68 | 114 |
| HHC-74 | 362 | 8.89 | 41 |
| HHC-73 | 373 | 9.48 | 39 |
| HHC-72 | 392 | 10.05 | 39 |
| B-12 | 391 | 9.82 | 40 |
| B-14 | 328 | 9.19 | 36 |
| Average | | | 53.53 |
| Standard Deviation | | | 34.63 |

Dust produced from the post transformation involving only Strykers was much higher than that produced from HMMWV's and MTV's individually, in the pre transformation study (Figure 5-2). Although distance travelled by Strykers was lower, dust emissions were higher due to high weight and more wheels. Statistical analysis of the data showed a significant effect of vehicle type on average dust produced, at a 0.05 level of significance, using Student t-test. Statistical hypotheses were stated as,

Null Hypothesis $H_o$: As a result of the transformation, there was no significant difference in dust emissions at PTA and,

Alternate Hypothesis, $H_1$: As a result of transformation, there was a significant variation in dust emissions at PTA.

The average amount of dust generated from HMMWV's and MTV's was significantly different when compared to that generated from Strykers. Conversely, there was not a significant variation in the amount of dust produced between HMMWV's and MTV's.

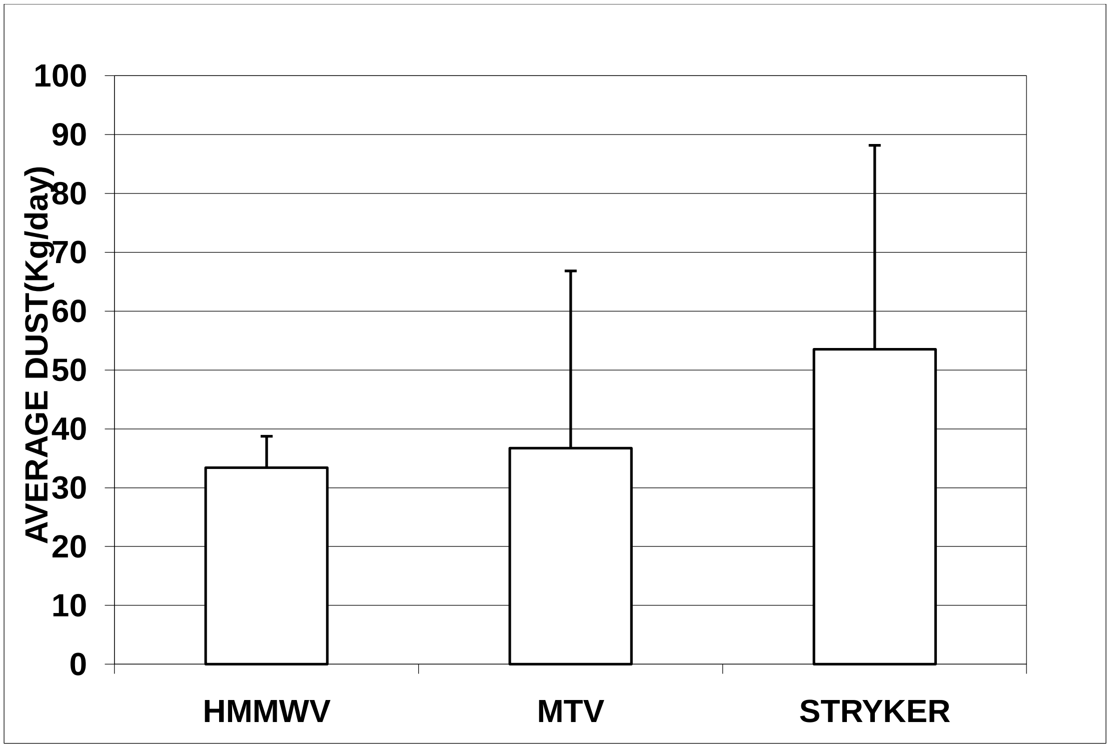


*Figure 5-2: Average dust generated per vehicle day during pre and post transformation*

## Spatial Representation

### *Critical road segment identification*

Identification of critical road segments was conducted separately for pre and post transformation. The emission factor values for each GPS data point were saved in a .txt file. The individual .txt files thus obtained were combined separately for each vehicle type in ESRI's ArcGIS using the merge tool. Shapefiles were created for all the vehicles. PTA roads shapefile, background map, soils and ranges shapefiles were provided by the Integrated Training Area Management (ITAM), Hawaii. PTA road segments including all road attributes were joined to each GPS data point using the spatial join function in ArcGIS. The road segment column was summarized by selecting the appropriate parameter for analysis. The output obtained was again joined to the road segments, which resulted in a new column with dust emission values in the PTA roads shapefile. Thematic maps were produced showing the dust emission distribution at each point along different road segments of PTA separately for each vehicle type (Figures 5-3, 5-4, 5-5).

The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic. Dust emissions also depend on source parameters that characterize the condition of a particular road and the associated vehicle traffic. Each moving point was assumed to be on unimproved road as no off-road traffic was allowed. Most of the roads at PTA were unimproved.

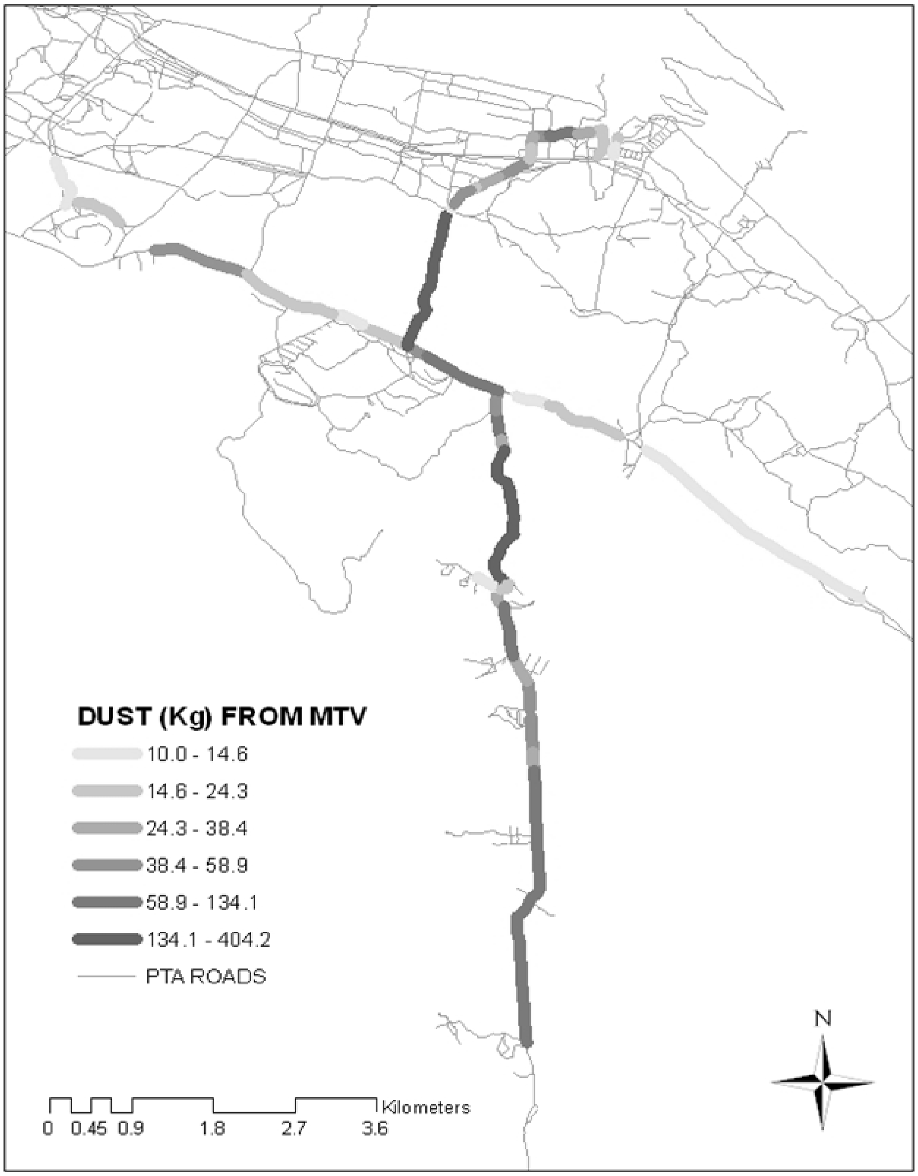


*Figure 5-3: Spatial representation of dust emissions from MTV's during pre transformation at PTA*

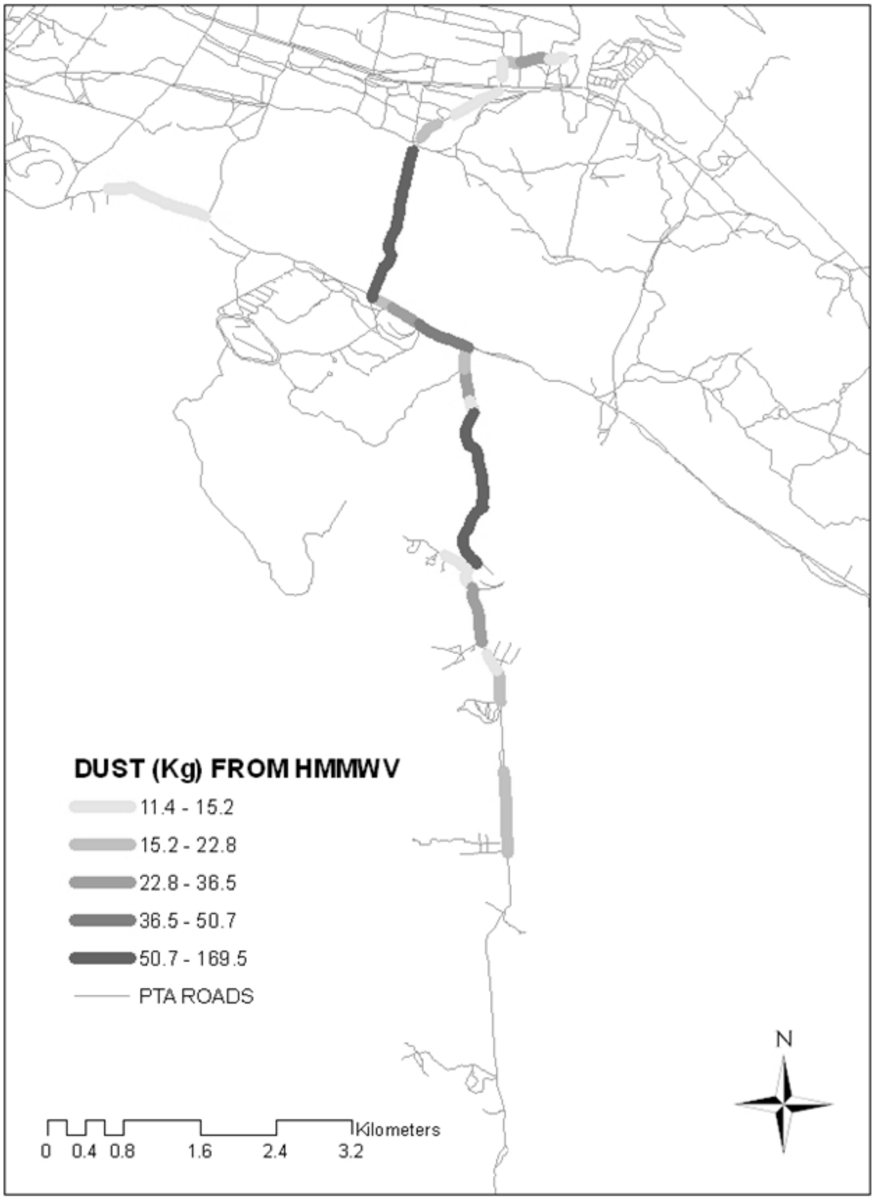


*Figure 5-4: Spatial representation of dust emissions from HMMWV's during pre transformation at PTA*

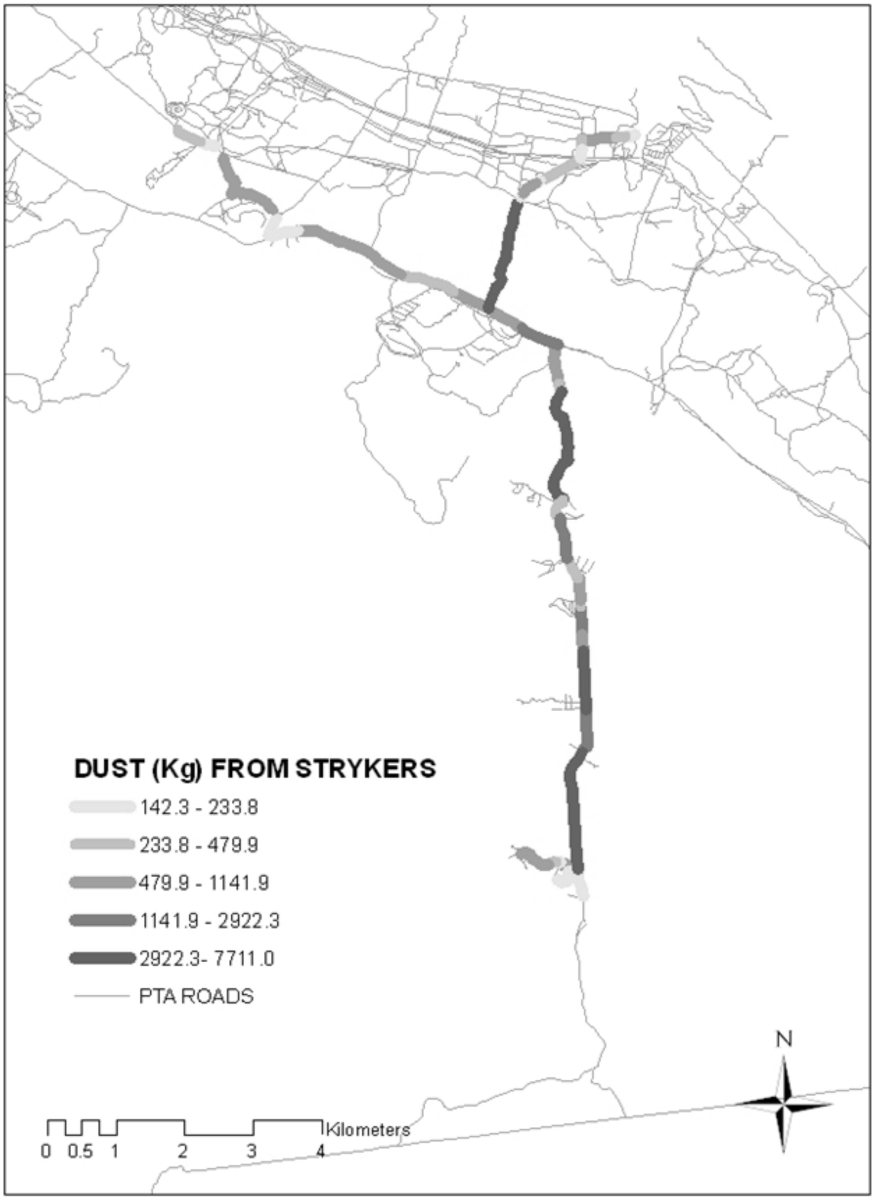


*Figure 5-5: Spatial representation of dust emissions from Strykers during post transformation at PTA*

From the GIS analysis, critical roads requiring appropriate road treatment were identified based on the amount of dust generated from the roads for pre and post transformation maneuvers (Figure 5-6). These critical roads were recognized by the specific ID for each road segment. Depending on the road length and the amount of dust emitted, dust generated per road segment (kg/km) was calculated. These calculated dust values were sorted and ranked producing the top most dust producing road segments. In the pre transformation analysis (Table 5-11), the total amount of dust distributed ranged from 8 kg/km/vehicle day to 28 kg/km/vehicle day, whereas for the post transformation analysis (Table 5-12), the value ranged from 57 kg/km/vehicle-day to 98 kg/km/vehicle-day. It was noticed that some of the most traveled road segments (Road segment ID's, 1871, 2134, 1246, 1990, 1991, 1133, and 2377) were identified most critical, indicating high vehicular traffic on the roads at PTA. There are about 2,585 road segments at PTA with a total length of 541.5 km. Of these most critical roads constituted about 2 % (13 km) of all the roads at PTA and contributed about 42% (5,118 kg) of total dust (about 12,085 kg) generated pre and post transformation exercises.

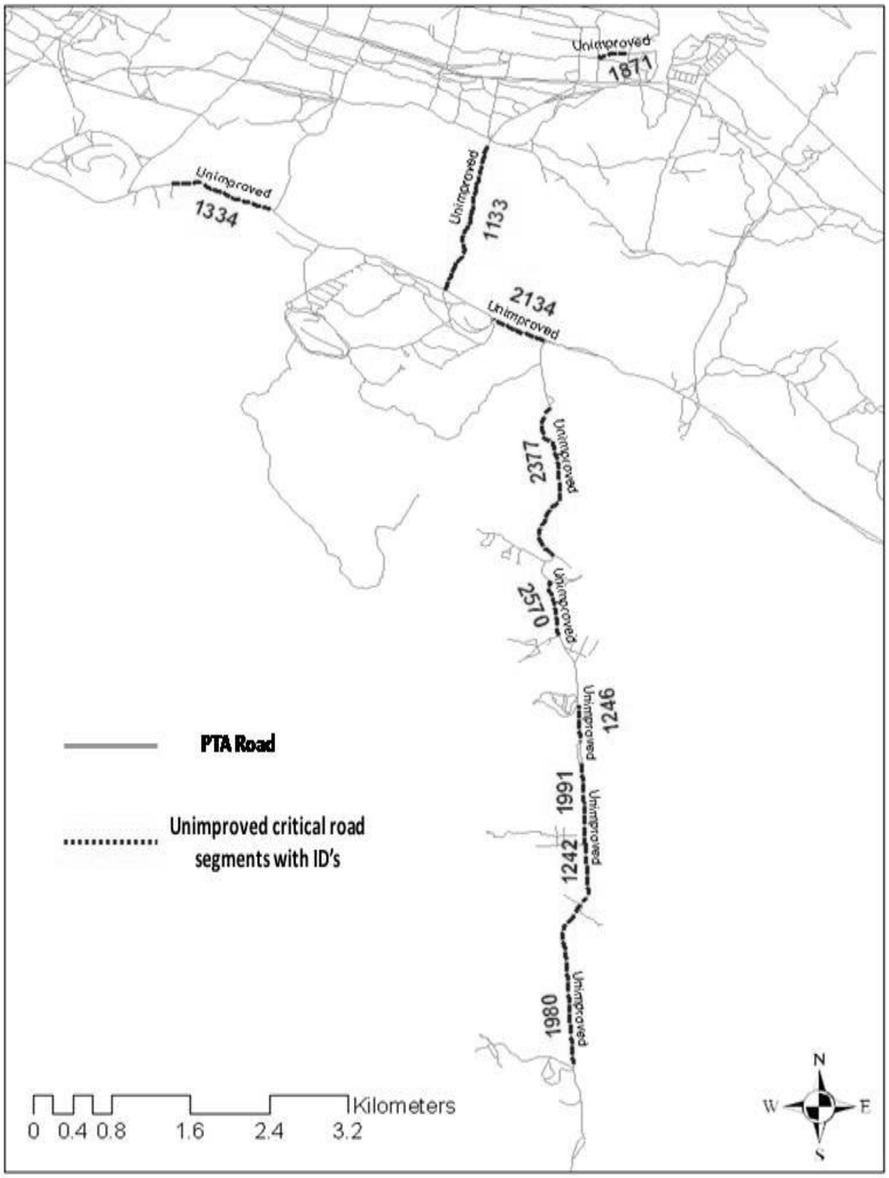


*Figure 5-6: Critical road segments identified during pre and post transformation*

*Table 5-11: Dust generated along the critical road segments by the MTV's and HMMWV's travel combined, during the pre transformation exercise at PTA.*

| RANK | ROAD ID | ROAD LENGTH (km) | DUST (kg) | DUST (kg/km/day) | TOTAL BATTALION DUST (kg/km/day) |
|---|---|---|---|---|---|
| 1 | 1871 | 0.3 | 85 | 28 | 341 |
| 2 | 2134 | 0.6 | 134 | 25 | 297 |
| 3 | 2377 | 1.8 | 403 | 23 | 281 |
| 4 | 1133 | 1.6 | 377 | 24 | 285 |
| 5 | 2570 | 0.6 | 110 | 19 | 233 |
| 6 | 1242 | 0.6 | 82 | 14 | 163 |
| 7 | 1991 | 0.8 | 110 | 13 | 160 |
| 8 | 1118 | 0.3 | 29 | 10 | 120 |
| 9 | 898 | 0.2 | 18 | 9 | 110 |
| 10 | 1025 | 0.2 | 17 | 8 | 102 |

*Table 5-12: Dust generated along the critical road segments by the Stryker's travel, during the post transformation exercise at PTA*

| RANK | ROAD ID | ROAD LENGTH (km) | DUST (kg) | DUST (kg/km/day) | TOTAL BATTALION DUST (kg/km/day) |
|---|---|---|---|---|---|
| 1 | 1246 | 0.4 | 370 | 98 | 3544 |
| 2 | 1990 | 0.2 | 205 | 95 | 3438 |
| 3 | 1991 | 0.8 | 622 | 77 | 2773 |
| 4 | 1871 | 0.3 | 186 | 62 | 2235 |
| 5 | 1872 | 0.1 | 77 | 61 | 2185 |
| 6 | 847 | 0.3 | 184 | 60 | 2143 |
| 7 | 2377 | 1.8 | 990 | 59 | 2110 |
| 8 | 898 | 0.2 | 111 | 58 | 2105 |
| 9 | 1209 | 0.2 | 123 | 58 | 2072 |
| 10 | 1133 | 1.6 | 886 | 57 | 2049 |

## ***Total Battalion Maneuver Impact***

The total vehicle average dust emissions from second brigade 25th infantry light division Battalion were predicted. Each Battalion had three active companies (Alpha, Bravo, and Charlie). During the pre transformation, each company contained 4 HMMWV’s and 4 MTV’s in each of the 3 platoons. Hence they were 12 HMMWV’s and 12 MTV’s in a Battalion. The amount of dust generated for the whole Battalion (Alpha, Bravo, and Charlie companies) was projected from the calculated dust emissions HMMWV’s and MTV’s together were targeted to generate 2,090 kg dust per km for a Battalion day, on the critical road segments at PTA (Table 5-10). During the post transformation, they were 3 platoons, each containing 4 Strykers. Therefore, 36 Strykers were present in a Battalion, and a total of 24,654 kg dust per km was emitted per Battalion day on the most critical road segments at PTA (Table 5-11).

# Sensitivity analysis

Many factors affect dust emission predictions which are temporally and spatially variable. Emission factor changes with changes in the variable. Knowledge of the variability of the individual factors associated with physical properties of the unpaved road and their role on particulate matter emissions is critical to develop accurate air quality standards and models (Dornbusch et al., 2008). Sensitivity analysis was performed with US EPA 1979 emission factor equation to depict how sensitive the emission factor was to changes in the parameters, (1) Silt content and (2) average velocity.

Dust emissions from unpaved roads were found to vary directly with the fraction of silt (particles smaller than 75 μm in physical diameter) in the road surface materials. As the silt content of a rural dirt road was found to be changing with geographic location, it was measured for use in projecting emissions. For a conservative approximation, the silt content of the parent soil was often used. Road silt content was determined normally lower than in the surrounding parent soil, because the fines were continually removed by the vehicle traffic, leaving a higher percentage of coarse particles (Mansell, 2006). From soil samples analysis, an average silt value of 9.73 % was taken in to consideration. HMMWV’s generated 0.6 kg/km of dust for silt % of 9.73 at an average velocity of 5.35 m/s. MTV’s traveling at 5.96 m/s generated an average of 1kg/km and Strykers with an average velocity of 5.45 m/s emitted 2.8

kg/km of dust. Increase in silt % increased dust linearly (Figure 5-7). Analysis of amount of dust generated or the measure of emission factor with changing average velocity was also investigated. The average velocities of the three vehicle types were similar although the amount of dust estimated differed. During the pre transformation, HMMWV's, which traveled at an average velocity of 22.5 kph, generated an average of 0.65 kg/km of dust per day. MTV's which moved at an average velocity of 20.1 kph, generated an average of 1.6 kg/km.

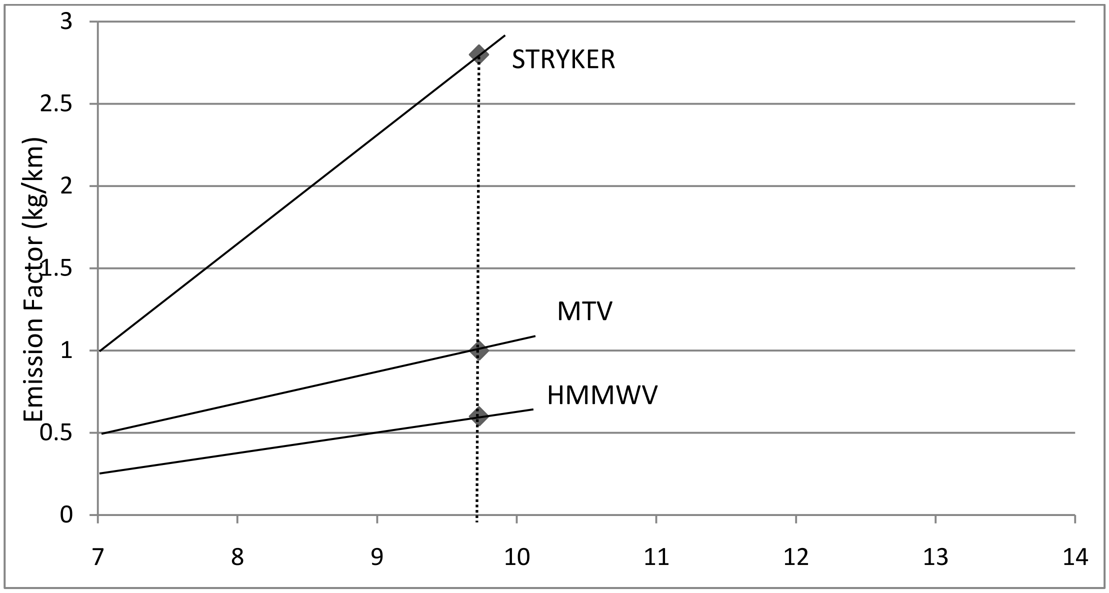


*Figure 5-7: Change in emission factor with the silt percentage during the pre and post transformation.*

During the post transformation, Strykers traveled with an average velocity of 19.3 kph at which they emitted an average of 2.9 kg/km of dust. It was observed that the sensitivity of the dust emissions to average velocity was more pronounced in Strykers and MTV's when compared to HMMWV's (Figure 5-8).

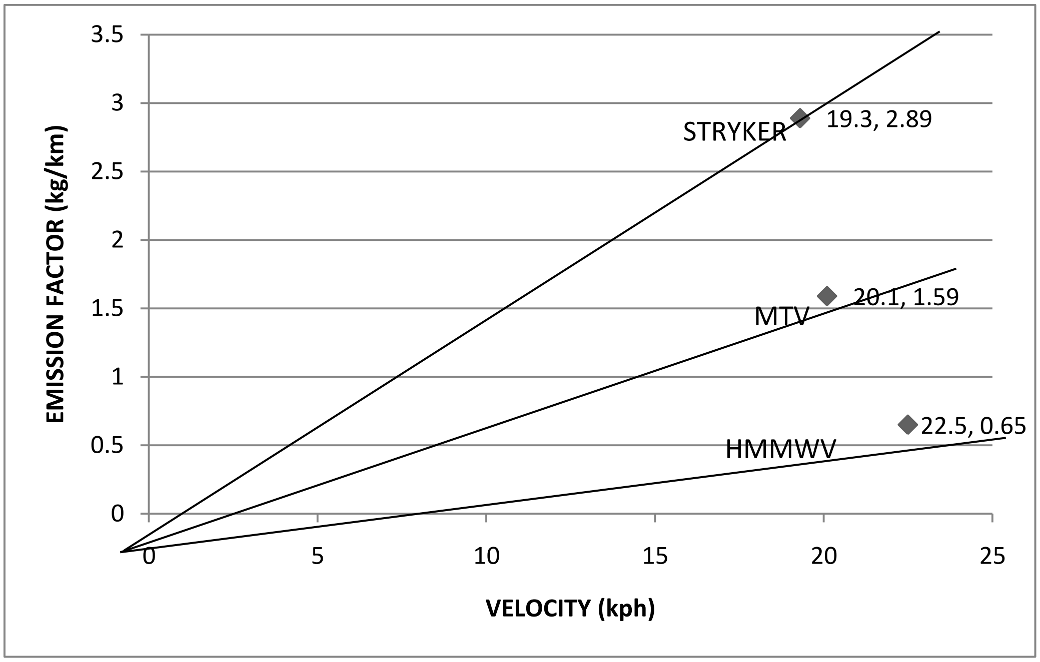


*Figure.5-8: Change in emission Factor with average velocity during the pre and post Transformation*

# Chapter 6: Conclusions

## Summary

Stryker Brigade Combat Team (SBCT) maneuver training typically covers a larger area, potentially extending training into areas that have not been used as frequently. Increased movement of Stryker vehicles, a heavy-duty class vehicle, on unpaved areas would result in particulate emissions (US Army Environmental Command, 2008). Dust constitutes nearly two-thirds of the primary PM10 emissions according to the US National Emissions Trends inventory for 1997 (US EPA, 1998). Particles suspended by vehicular movement on paved and unpaved roads are a major contributor to dust emissions. Yet, traditional methods for quantifying road dust emissions have been a subject of controversy in recent years (Kuhns et al., 2001).

Dust emissions are difficult to measure directly because they can be very diffuse, intermittent, and variable. For this reason the published emission factors had a high degree of uncertainty, and the predicted emission rates should be treated with scepticism (Ministry for the Environment, 2001). In addition, many of the emission factors are for particles smaller than 30 µm, which only covers a fraction of the particles that can be emitted as nuisance dust. Where emission factors are applied to dust emissions, it is important that the underlying assumptions are clearly stated. Vehicle –generated dust from unpaved roads and from off-highway activity can be both a local nuisance and a significant contributor to regional air quality (Ministry for the Environment, 2001).

The Army identified in the EIS a potential significant impact from dust. PM10 emissions are most important because they are easily airborne and are small enough to be inhaled deep into the lungs creating potential adverse health effects (Tetra tech, Inc. 2004). The Army conducted additional modeling which provided a better understanding of the conditions and potential adverse impacts from dust. The Army developed additional mitigation programs that are known to be effective for controlling dust, reducing the severity of the potential impacts. We believe that implementation of these measures will avoid exceeding the PM10 standards to avoid unacceptable impacts to human health and visual resources (Tetra tech, Inc. 2004).

The Army acknowledged and has considered the public's concern that annoying dust will be intermittently produced by training and convoy activities at Pohakuloa Training Area (PTA). The Army also recognized that the potential magnitude of dust impacts is sensitive to the amount of vegetation cover that can be maintained on the area. There is significant uncertainty about the extent to which vegetation cover will be reduced by vehicle maneuver activity (Tetra Tech, Inc. 2004).

The vehicle tracking study at PTA was useful in estimating the daily dust emissions from the pre and post transformation military maneuvers. HMMWV's (2,358 kg, 4 wheeled) and MTV’s (8,889 kg, 6 wheeled) were involved in the pre transformation. They traveled an average distance of 221.5 km for a period of 10 days with an average velocity of 5.79 m/s, where HMMWV’s moved an average distance of 42.41 km per vehicle day with an average velocity of 5.35 m/s and MTV’s moved 19.81 km per vehicle day with an average velocity of 5.96 m/s. Post transformation exercise involved Strykers (16,128 kg, 8 wheeled), which traveled an average distance of 128 km for a period of 10 days and 13.4 km per vehicle day with an average velocity of 5.45 m/s.

Daily dust emissions pre and post transformation were estimated. 8 – 28 kg/km/vehicle day was observed during pre transformation analysis where HMMWV’s and MTV’s, emitted 33 kg dust per vehicle day and 36.7 kg dust per vehicle day respectively.  57- 98 kg/km/vehicle day was estimated during post transformation where Strykers generated 53.5 kg dust per vehicle day. A sensitivity analysis was conducted using US EPA (1979) emission factor equation, which underscored how the changes in parameters, silt content and average velocity affected emission factor. At a silt percentage of 9.73, HMMWV’s, MTV’s, and Strykers emitted 0.6 kg/km, 1.0 kg/km and 2.8 kg/km respectively. A linear trend was observed. Similarly, emission factor also changed linearly with average velocity. Average velocities of all the three vehicle types showed a minor variation. But emissions varied drastically between vehicle types with Strykers dominating at 2.89

kg/km for 19.3 kph average velocity, followed by MTV's with 1.59 kg/km at 20.1 kph and HMMWV's producing 0.65 kg/km at an average velocity of 22.5 kph.

There are about 2,585 road segments at PTA with a total length of 541.5 km. Of these most critical roads constituted about 2 % (13 km) of all the roads at PTA and contributed about 42% (5,118 kg) of total dust (about 12,085 kg) generated pre and post transformation exercises. Daily dust emissions for Battalions were also predicted pre and post transformation. 2,090 kg/km dust per Battalion day was assumed to have produced from pre transformation and an amount of 24,654 kg/km dust per Battalion day from post transformation on critical road segments (Road ID's – 1871, 2134, 1246, 1990, 1991, 1133, and 2377 from ArcGIS analysis).

## Effects of Dust at PTA

Dust emissions from military training would result in short- and long-term impacts on listed species and their designated critical habitat within the PTA ROI as a result of changes in military training. Within the ROI, one wildlife species, the Palila (Loxoiides bailleui), has critical habitat (Figure 6-1 depicts the proximity of PTA to critical bird habitats). Proposed activities border on the Palila designated critical habitat in the ROI. There are 2,569 acres of Palila critical habitat within the ROI. The Army is responsible for maintaining this habitat in a condition suitable for the Palila and, by doing so contribute to the recovery of the species. Increased training would have adverse impacts on the habitat, deterring the recovery of the species (Tetra Tech Inc., 2004).

Mitigation measures would minimize impacts to threatened and endangered species and their habitats (Figure 6-2 shows the Threatened and Endangered plant species concentration near and around PTA), but not to a less than significant level. Surveys of PTA have reported at least 383 archaeological sites, including 96 at the Keamuku Parcel. Surveys along proposed trails have identified nine sites along the PTA trail (Tetra Tech Inc., 2004).

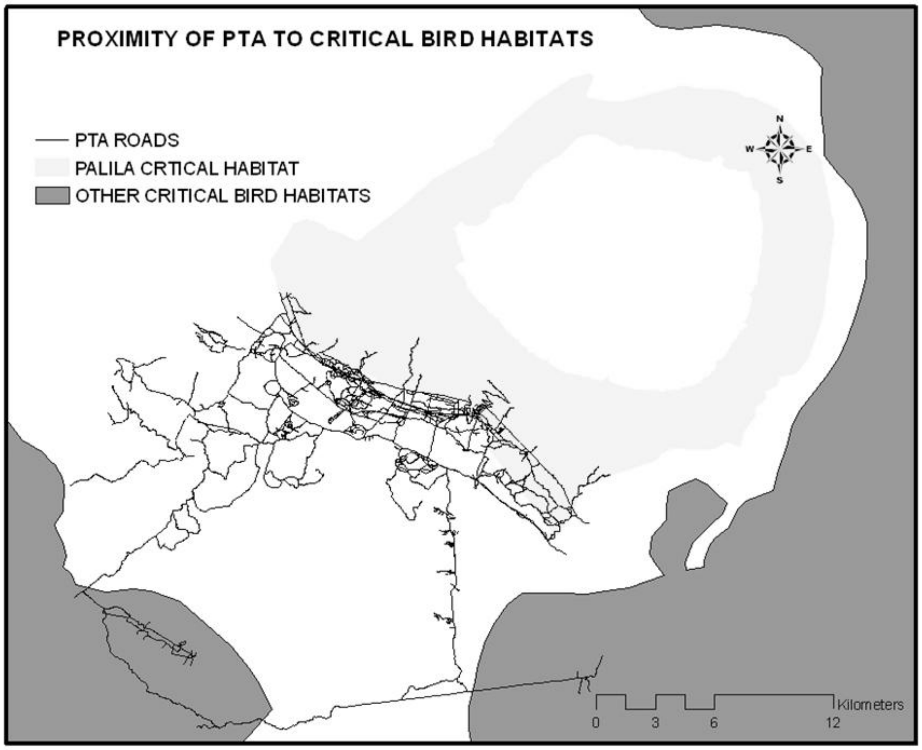


*Figure 6-1: Proximity of PTA to Critical Bird Habitats (Source: State of Hawaii, 2002)*

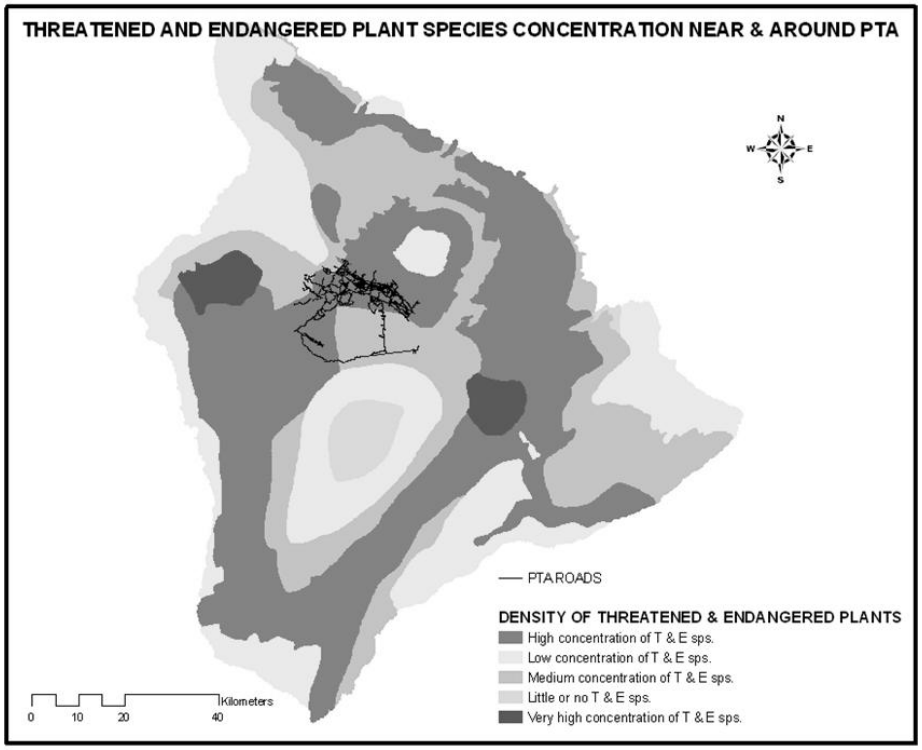


*Figure 6-2: Threatened and Endangered Plant Species Concentration near and around PTA (Source: State of Hawaii, 2002)*

Data from the January 2006 through June 2007 air-quality monitoring for particulate matter at PTA suggest maneuver training itself is unlikely to result in significant impacts. The data indicate that even during maneuver training, concentrations of TSP and PM10 along the PTA's boundary are well below federal and state 24-hour and annual average standards. Consequently, generation of dust during maneuver training is of less concern than dust generated from wind erosion. PM10 emissions would be approximately 1,463 tons per year, an increase of about 618 tons per year.

Approximately 32 percent of the net increase in PM10 emissions would be associated with vehicle travel on unpaved roads while the remaining 68 percent represents potential emissions from off-road vehicle maneuver activity. These emissions could be significant if not mitigated. The amount of impacts to vegetation from SBCT would increase with the need for larger training areas; however, the intensity of the impacts would decrease through their more frequent use of existing roads. The impacts from maneuver training could range from less than significant to significant depending on environmental conditions and spatial extent of damage (US Army Environmental Command, 2008).

## Intervention Needs

PTA should be required to have a dust control plan, and paving or gravel surfacing of dirt roads in order to reduce dust. Materials and construction methodologies should be made available for sensitively preparing unpaved roads, including appropriate landscaping along roadsides that prevent dust from reaching adjacent areas. Dust from unpaved roads should be addressed to achieve air quality goals. Vegetative buffer zones should be established to reduce the impact of dust pollution (East Mountain area plan, 2005). Buffer zones minimize adverse impacts of pollutants on a specific area by reduction of human exposure to the pollution source.

Recently, a study was conducted that evaluated the effectiveness of processed installation solid waste (ISW) for dust suppression and road stabilization on unpaved roads (Svendsen et al., 2007). Dust control is a never ending problem as a permanent solution to dust control on unpaved roads does not exist. The available commercial off-the-shelf products utilizing salt-based, lignin/resin-based, petroleum based and polymer-based materials are temporary solutions, generally lasting about six months or less in high-traffic situations (Svendsen et al., 2007).

The use of dust suppression technology on unpaved installation road networks is expensive and time consuming and is not economically feasible except on the most frequently traveled roads. Dust control products on unpaved roads have been extensively used on military installations for a number of years (Svendsen et al., 2007). In general these products are sufficient to last from three to six months if road traffic is predominantly wheeled. According to Gebhart et al. (1999), tracked vehicles reduce dust suppression effectiveness 50 to 75 percent. To reduce maintenance expenditures and extend dust suppression effectiveness, an alternative to standard dust suppression technologies was investigated.

Dust emissions from vehicular movement on unpaved roads are a major source of respirable emissions in urban areas. Blackwood and Drehmel (1981) analyzed forces that produce emissions from unpaved roads, showing that if fine material can be reduced or moisture increased, emissions will be reduced. A wide variety of options exist to control emissions from unpaved roads (US EPA, 2006). Dust emissions can be controlled using wet suppression, chemical stabilization, re-vegetation of exposed surfaces, surface improvements, and speed controls.

*Vehicle restrictions* that limit the speed, weight or number of vehicles on the road,

*Surface improvement*, by measures such as a) paving or b) adding gravel or slag to a dirt road; and

*Surface treatment*, such as watering or treatment with chemical dust suppressants.

Other surface improvement methods cover the road surface with another material that has lower silt content (US EPA, 2006).

Dust emissions from unpaved surfaces are caused by the same factors as for paved surfaces, but the potential emissions are usually much greater. Unpaved surfaces can be a significant cause of dust problems on adjacent paved surfaces (e.g. roads) if there is no control over carry-out of mud and dirt. This can be controlled by the use of wheel wash facilities. Wet suppression of unpaved areas can achieve dust emission reductions of about 70% or more, and this can sometimes be increased by up to 95% through the use of chemical stabilization. Revegetation and paving can achieve up to 100% control efficiencies, but have only limited application (Ministry for the Environment, 2001).

## Recommendations for future work

Brigade- and battalion-level training would primarily occur at PTA, and the frequency of maneuver training at PTA is expected to increase slightly above existing levels. The Army’s integrated training area management (ITAM) program would substantially mitigate potential wind erosion problems by providing management tools that would help limit damage to vegetation from vehicle maneuver activity. Fugitive particulate emission from deployment over paved roads would be relatively minor and produce no impact over the large number of road km traveled during a deployment (US Army Environmental Command, 2008). Impacts to threatened, endangered, or sensitive species could occur from continued use of Army lands. The U.S. Army is required by the Endangered Species Act to conserve populations of federally listed Threatened and Endangered species that occur on its installations (Orth and Warren, 2006). Conservation plans and mitigation measures would reduce the impacts to less than significant (US Army Environmental Command, 2008).

Increases in training exercises have the potential to result in effects to air quality because of additional troop movements that result in dust emissions. Increases in criteria pollutants have the potential to decrease visibility and violate the NAAQS. The only potential effect to air quality from additional training activities would result from increased traffic on dirt roads and trails. Long-term adverse effects have the potential to result from mobile sources and increased training exercises. Mobile sources have the potential to result in effects to air quality from increased emissions of dust (PM) and vehicle exhaust. Increases in training exercises have the potential to result in effects to air quality because of additional troop movements that result in dust emissions (US Army Environmental Command, 2008).

Increases in criteria pollutants have the potential to decrease visibility and violate the NAAQS. SBCT-related contributions to dust are not expected to cause violation of attainment criteria. Mitigation measures will reduce air quality impacts to less than significant. Military training, particularly maneuver training, is a recurring activity contributing to dust. With implementation of the mitigation program, impacts would reduce air quality impacts, however, given the resulting increase in overall PM10 levels, the uncertainties associated with any estimate of potential wind erosion conditions, and public perceptions of the potential magnitude of this impact, the Army considers wind erosion to be a significant air quality impact. Combined with other projects, the cumulative air quality effects from primary air pollutants, such as PM10, could be significant (US Army Environmental Command, 2008).

# Bibliography

Albertson, P.E. 2001. Sustainability of military lands: Historic erosion trends at Fort Leonard Wood, Missouri. The Environmental Legacy of Military Operations. Geological Society of America. *Reviews in Engineering Geology*, 14, pp. 151-161.

Ayers, P.D., M. Vance, L. Haugen, and A.B. Anderson. 2000. An evaluation of GPS based continuously operating vehicle monitoring systems to determine site specific event severity factors. U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, Illinois, ERDC/CERL Technical Report TR-00-43.

Ayers, P.D., A. B. Anderson, and C. Wu. 2004. GIS and neural network method for potential road location for military land management. ASAE Paper 041148. ASAE annual meeting. St.Joseph, MI.

Ayers, P. D., A B. Anderson, and C. Wu. 2005. Analysis of vehicle use patterns during field training exercises to identify potential roads. Assessing the Impacts of Military Vehicular Traffic on Natural Areas. *Journal of Terramechanics*, 42(4): 321-338.

Beavers, M. A. 2000. Analysis of fire history and management concerns at Pohakuloa Training Area. Center for Environmental Management of Military Lands, Colorado State University, Fort Collins, Colorado.

Becker, D. L., and E. S. Tackle. 1979. Particulate deposition from dry unpaved roadways. Atmospheric Environment, 13, 661-668.

Blackwood, R. T., and D. C. Drehmel. 1981. New concepts for control of fugitive particle emissions from unpaved roads. Environment International, 6, pp. 333-336.

Campbell, S., and Shimp, D.R. 1998. Spatial and seasonal distribution of PM10 and PM2.5 emissions in central Kern County, California. *Proceedings*, *PM2.5: A Fine Particle Standard*, Chow, J.C. and Koutrakis, P., Eds. Air & Waste Management Association, Pittsburgh, PA, pp. 475-486.

Canadian Chemical Producer’s Association. 2001. Source characterization guidelines: Primary particulate matter and particulate precursor emission estimation methodologies for chemical production facilities. Available at: http://www.ccpa.ca/files/Library/Documents/Environment/NERM_Resources/Source_Characterization_Guidelines_for_Particulate_Matter.pdf (accessed August 20, 2008)

Cole, W. 2002. Big Island Residents Worry about Army Expansion. Report from Honolulu Advertiser: 9 July 2002. Honolulu, HI. Available at www.honoluluadvertiser.com (accessed November 4, 2006)

Commonwealth of Australia. 2001. National Pollutant Inventory. Emission estimation technique manual for mining. Version 2.3. Available at: http://www.npi.gov.au/handbooks/approved_handbooks/pubs/mining.pdf (accessed July 8, 2008)

Cowherd, C., P. Englehart, G. E. Muleski, J. S. Kinsey, and K. D. Rosbury. 1990. Control of fugitive and hazardous dusts. Noyes Data Corp, Park Ridge, NJ.

Cionco, R., and D. Hoock. 2002. Dust generation modeling - Source terms and microscale transport from military installations. U.S. Army Research Laboratory, AMSRL-CI-EB, White Sands Missile Range, New Mexico 88002-5501

Dale, D., and S. Warren. 2004. Session 8: Encroachment and range sustainability. Military training enhances biodiversity. Available at: www.dtic.mil/ndia/2004enviro/sessions/session8/dale.ppt (accessed August 4, 2008)

Dornbusch, K. W., J. N. Strange, and A. D. Rooke Jr. 1988. Prediction of Dust Propensity for Military Operations in Desert Areas. Science and Technology Corp, Hampton, VA.

Dyck, R. I. J., and J. J. Stukel. 1976. Dust emissions from trucks on unpaved roads. *Journal of Science and Technology,* 10, pp. 1046-1048.

East Mountain Area Plan, Bernalillo County, New Mexico. 2005. Natural Environment. Available at: http://www.bernco.gov/upload/images/zoning_building_planning/east_area_2005/natural_environment4.pdf (accessed September 25, 2008)

Eaton, R. A., and Beaucham, R. E. 1992. Unsurfaced road maintenance management. U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. Special Report, 92(26), p. 61.

Ehlen, J., and R. S. Harmon. 2001. The Environmental Legacy of Military Operations; Boulder, Colorado. Geological Society of America. Reviews in Engineering Geology, 5(14), pp. 151-161.

Etyemezian, V., S. Ahonen**,** D. Nikolic, J. Gillies, H. Kuhns, D. Gillette, and J. Veranth. 2004. Deposition and removal of dust in the arid southwestern United States: measurements and model results. *Journal of Air and Waste Management Association*, 54(9), pp. 1099-111.

Etyemezian, V., H. Kuhns, J. Gillies, M. Green, M. Pitchford, and J. Watson. 2003a. Vehicle-based road dust emission measurement: I—methods and calibration. *Atmospheric Environment*, 37(32), pp. 4559-4571.

Etyemezian, V., H. Kuhns, J. Gillies, J. Chow, K. Hendrickson, M. McGown, and M. Pitchford. 2003b. Vehicle-based road dust emission measurement (III): effect of speed, traffic volume, location, and season on $PM_{10}$ road dust emissions in the Treasure Valley, ID. *Atmospheric Environment*, 37(32), pp. 4583-4593.

Federation of American Scientists (FAS). 1998. Military Analysis Network. MTV http://www.fas.org/man/dod-101/sys/land/m1083.htm

Gebhart, D. L., M. L. Denight and R. H. Grau. 1999. Dust control guidance and technology selection key. AEC Report #SFIM-AEC-EQ-CR-99002/CERL Report #99/21, Construction Engineering Research Laboratory, Champaign, Illinois.

Gillies, J. A.,V. Etyemezian, H. Kuhns, H. Moosmueller, J. Engelbrecht, J. King, S. Uppapalli, G. Nikolich, J. D. McAlpine, D. A. Gillette, K. J. Allwine. 2007. Particulate matter emissions from for dust from unique military activities. Report Number: A305874, prepared for Desert Research Institute, Reno, NV.

Gleason, M. S., D. T. Faucette, M. M. Toyofuku, C. A. Torres, and C. F. Bagley. 2007. Assessing and Mitigating the Effects of Windblown Soil on Rare and Common Vegetation. *Environmental Management*, 40(6), pp. 1016-1024.

Global Security Organization. 2008. Pohakuloa Training Area. Available at: http://www.globalsecurity.org/military/facility/pohakuloa.htm (accessed February 2007).

Hall, F. 1981. Visibility reductions from soil dust in the western U.S. *Atmospheric Environment*, 15, pp. 1929-1933.

Haugen, L., P.D. Ayers, M. Vance, and A. Anderson. 2000. Using GPS for vehicle tracking and dynamic property monitoring. Presented at the 2000 ASAE Annual International Meeting, Paper No. 001071. ASAE, 2950 Niles Road, St. Joseph, MI 49085-9659 USA.

Haugen, L. B. 2002. Design and testing of a vehicle tracking system for monitoring environmental impact at U.S. army training installations. M.S. Thesis. Colorado State University. Fort Collins, Colorado.

Kirkham, R. R., M. A. Chamness, C. J. Driver, B. C. 2005. Barfuss Air Quality and Road Emission Results for Fort Stewart, Georgia. Pacific Northwest National Laboratory, Richland, Washington 99352.

Kuhns, H., V. Etyemezian, D. Landwehr, C. MacDougall, M. Pitchford and M. Green. 2001 Testing re-entrained aerosol kinetic emissions from roads (TRAKER): a new approach to infer silt loading on roadways. *Atmospheric Environment*, 35, pp. 2815–2825.

Kuhns, H., J. Gillies, V. Etyemezian, D. Dubois, S. Ahonen, D. Nikolic, and C. Durham. 2005. Spatial variability of unpaved road dust PM10 emission factors near El Paso, Texas. *Journal of Air and Waste Management Association*, 55(1), pp. 3-12.

Kunze, M. D., and D. S. Jones. 2004. Unpaved roads conditions assessment protocol. Center for Environmental Management of Military Lands (CEMML), Colorado State University, Fort Collins, Colorado 80523-1490.

Li, Q., P.D. Ayers, A.B. Anderson, and C. Wu. 2003. Soil and vegetation disturbance of tracked and wheeled off-road vehicles. ASAE Paper 031055. St. Joseph, MI.: ASAE.

Loope, L. L. and P. G. Scowcroft. 1985. Vegetation response within exclosures in Hawaii: A review. IN: C. P. Stone and J. M. Scott (eds.). Hawaii's Terrestrial Ecosystems: preservation and management. University of Hawaii Press, Honolulu, HI.

Mansell, G. 2006. Summary of the WRAP Dust Emissions Inventories Technical Memorandum prepared for the Western Governors Association by ENVIRON International Corporation, Novato, CA. Available at: http://www.fas.org/man/dod-101/sys/land/m998.htm (accessed December 2007)

McDonald. T.P. and J.P. Fulton 2005. Automated time study of skidders using global positioning system data. *Computers and Electronics in Agriculture*, 48(1), pp. 19-37.

McElroy, H. R. 2006. Pohakuloa Training Area celebrates 50 years of service to the military. Available at: http://www.wood.army.mil/engrmag//McElroy.pdf (accessed July 6, 2008)

Ministry for the Environment. 2001. Good practice guide for assessing and managing the environmental effects of dust emissions. Ministry of the Environment, Wellington, New Zealand.

Midwest Research Institute. 1998. Emission factor documentation for AP-42 Section 13.2.2, unpaved roads. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Washington, D.C.

Midwest Research Institute. 2001. Revisions to AP-42 Section 13.2.2 ‘‘Unpaved Roads’’. Technical Memorandum Prepared for the US EPA, Research Triangle Park, NC, Midwest Research Institute, Kansas City, MO.

Nicholson, K.W., J. R. Branson, P. Geiss, and R. J. Cannel. 1989. The effects of vehicle activity on particle resuspension. *Journal of Aerosol Science*, 20, pp. 1425–1428.

Ontario Ministry of Environment. 2007. Step by step guideline for emission calculation, record keeping and reporting for airborne contaminant discharge. Government of Ontario, Canada.

Orth, P. B., and Steven D. Warren. 2006. Disturbance dependency of threatened and endangered species found on US Army lands. Center for Environmental Mangement of Military Lands Colorado State University, Fort Collins, Colorado.

Padgett, E. P., D. Meadows, E. Eubanks, and W. E. Ryan. 2007. Monitoring dust emissions from off-highway vehicles traveling on unpaved roads and trails using passive samplers. *Environmental Monitoring and Assessment*, 144(3), pp. 93-103.

Pahrump Regional Planning District. 2004. Draft: PM10 emissions inventory, area sources. Available at: http://ndep.nv.gov/baqp/planmodeling/file/pahrump_ei-2001.pdf (accessed August 2008)

Pinnick, R. G., G. Fernandez, B. D. Hinds, C. W. Bruce, R. W. Schaefer, and J. D. Pendleton. 1985. Dust Generated by Vehicular Traffic on Unpaved Roadways: Sizes and Infrared Extinction Characteristics. *Aerosol Science and Technology,* 4(1), pp. 99-121.

Sato, H. H., W. Ikeda, R. Paeth, R. Smyth and M. Takehiro. 1973. Soil survey of the island of Hawaii. USDA Soil Conservation Service in cooperation with the University of Hawaii.

Shaw, R. B., and M. J. Castillo. 1997. Plant communities of Pohakuloa Training Area. Center for Ecological Management of Military Lands, Fort Collins, Colorado, USA.

State of Hawaii. 2002. Office of Planning. Hawaii Statewide GIS Program [Web page]. Located at http://www.state.hi.us/dbedt/gis/. Accessed: August-October 2008.

Svendsen, N., R. R. Busby, D. L. Gebhart, R. Hegarty, G. Muleski, C. Cowherd, and D. Gray. 2007. An ASABE Meeting Presentation Paper Number: 072116 Unpaved Road Dust Control and Road Stabilization using Processed Installation Solid Waste. ASABE Annual Meeting, Minneapolis.

Tetra Tech, Inc. 2004. Final Environmental Impact Statement. Transformation of the 2nd Brigade, 25th Infantry Division (L) to a Stryker Brigade Combat Team in Hawaii. Volume I. Tetra tech, Inc., Honolulu, Hawaii. Prepared for Department of Army, Office of the Secretary of the Army, Washington, DC, and US Army Corps of Engineers, Honolulu Engineer District, Fort Shafter, Hawaii.

Tsai, C. J. and C. T. Chang. 2002. An investigation of dust emissions from unpaved surfaces in Taiwan. Separation and Purification Technology 29(8), pp. 181-188.

U.S. Army Garrison, Hawaii, and U.S. Army Corps of Engineers, 1997. Final Endangered Species Management Plan Report for the Pohakuloa Training Area, October.

U.S. Army Garrison, Hawaii, and U.S. Army Corps of Engineers, 1998. Final Ecosystem Management Plan Report, Pohakuloa Training Area, March.

US Army. 2008. U.S. Army Factfiles. Available at: http://www.army.mil/factfiles/equipment/wheeled/hmmwv.html (accessed June 22, 2008)

US Army Environmental Command. 2008. Final Environmental Impact Assessment Permanent Stationing of the 2/25TH Stryker Brigade Combat Team Prepared for Headquarters, Department of the Army, Washington, DC. Prepared by U.S Army Environmental Command, Aberdeen Proving Ground, Maryland.

US EPA. 1974. U.S. Environmental Protection Agency Development of Emission Factor for Dust Sources, EPA450/3-74-037, U.S. Environmental Protection Agency, Research Triangle Park, NC.

US EPA. 1994. PART 5 Information Sheet # 1: Fleet Average Dust; Dust Emission Factors; Particle Size Cutoff Limitations.

US EPA. 1995. Compilation of Air Pollutant Emission Factors. Report No. AP-42. Prepared by US Environmental Protection Agency.

U.S. EPA. 1996. Compilation of Air Pollutant Emission Factors, Vol.1, Stationary Point and Area Sources. US EPA Office of Air and Radiation, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

US EPA. 1998. National Air Pollutant Emission Trends, Procedures Document, 1900-1996. Report No. EPA-454/R-98-008. Prepared by U.S. EPA.

US EPA. 1999. Compilation of air pollutant emission factors – Vol. I, Stationary point and area sources. Report No. AP-42, 5TH ed. Prepared by US Environmental Protection Agency, Research Triangle Park, NC.

US EPA. 2001. CMB8 User's Manual. EPA-454/R-01-XXX, Office of Air Quality, Planning and Standards, Research Triangle Park, NC 27711.

US EPA, 2003. AP-42, fifth ed., vol.1, Miscellaneous Sources, US Environmental Protection Agency, Research Triangle Park, NC; (Chapter 13) (http://www.epa.gov/ttn/chief/ap42/ch13/final/c13s0202.pdf).

US EPA. 2006. AP-42, fifth ed, vol.1, Miscellaneous Sources, US Environmental Protection Agency, Research Triangle Park, NC; (Chapter 13). (http://www.epa.gov/ttn/chief/ap42/ch13/final/c13s0202.pdf).

U.S. Pacific Command, 1995. Final Hawaii Military Land Use Master Plan, July.

Watson, J. G., and J. C. Chow. 2000. Reconciling Urban Dust Emissions Inventory and Ambient Source Contribution Estimates: Summary of Current Knowledge and Needed Research- DRI Document No. 6110.4 F. Prepared for Desert Research Institute, Reno, NV.

Weather Underground, Inc. 2008. Weather graph of PTA. Available at: https://www.wunderground.com/weatherstation (accessed December 10, 2008)

Williams, S. D., M. K. Shukla, and J. Ross. 2008. Particle Matter Emission by a Vehicle Running on Unpaved Road. *Atmospheric Environment,* 42(16), pp. 3899-3905.

Wilson, E.O. 1992. The Diversity of Life. Harvard University Press, Cambridge, Massachusetts.

World Meteorological Organization. 2009. World Weather Information Services – Honolulu, Hawaii. Climatological information. Available at: http://www.worldweather.org/093/c00849.htm#climate (accessed January 10, 2009)

Wu, C. 2005. Analysis of vehicle use patterns during military field exercises to identify potential roads. Ph.D. Dissertation. University of Tennessee, Knoxville, TN.

Wu, C., P. D. Ayers and A.B. Anderson. 2007. Validating a GIS-based multi-criteria method for potential road identification. *Journal of Terramechanics,* 44(3), pp. 255-263.

# Appendices

# Appendix A

## *Vehicle Movements during Pre transformation*

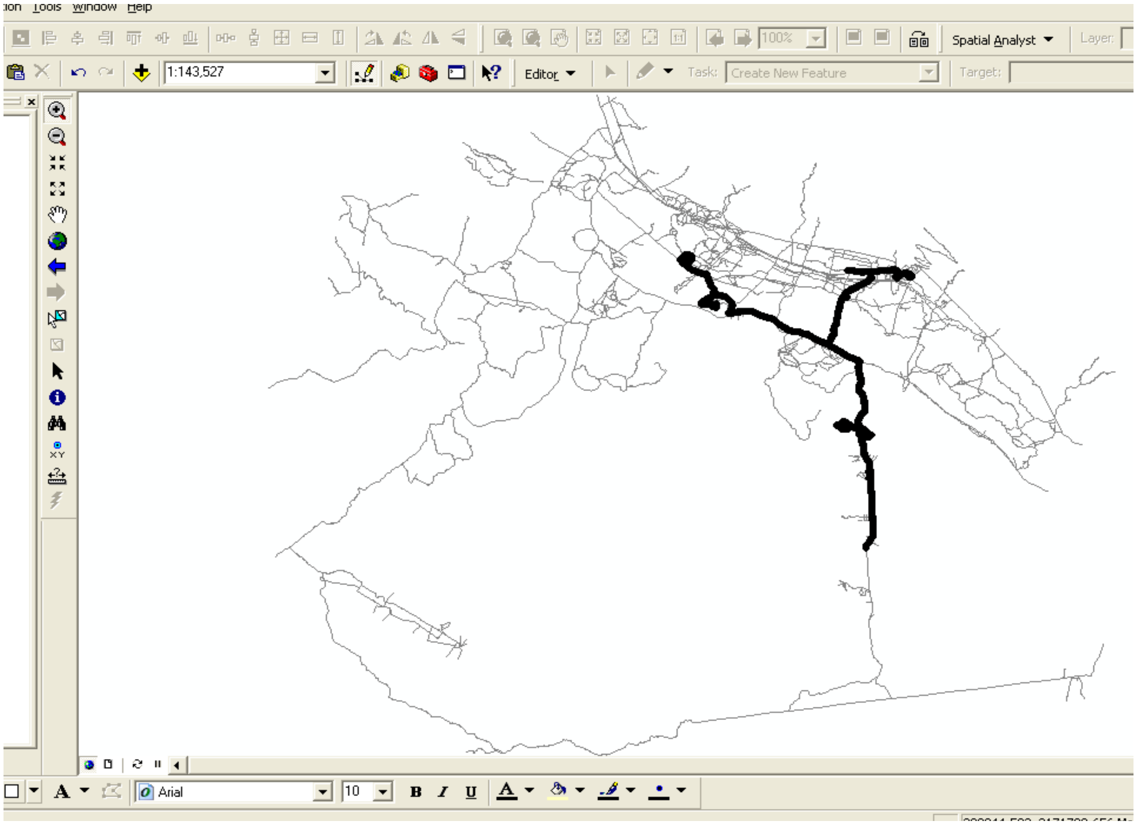


*Figure A-1: ArcGIS plot of MTV B-60 during pre transformation*

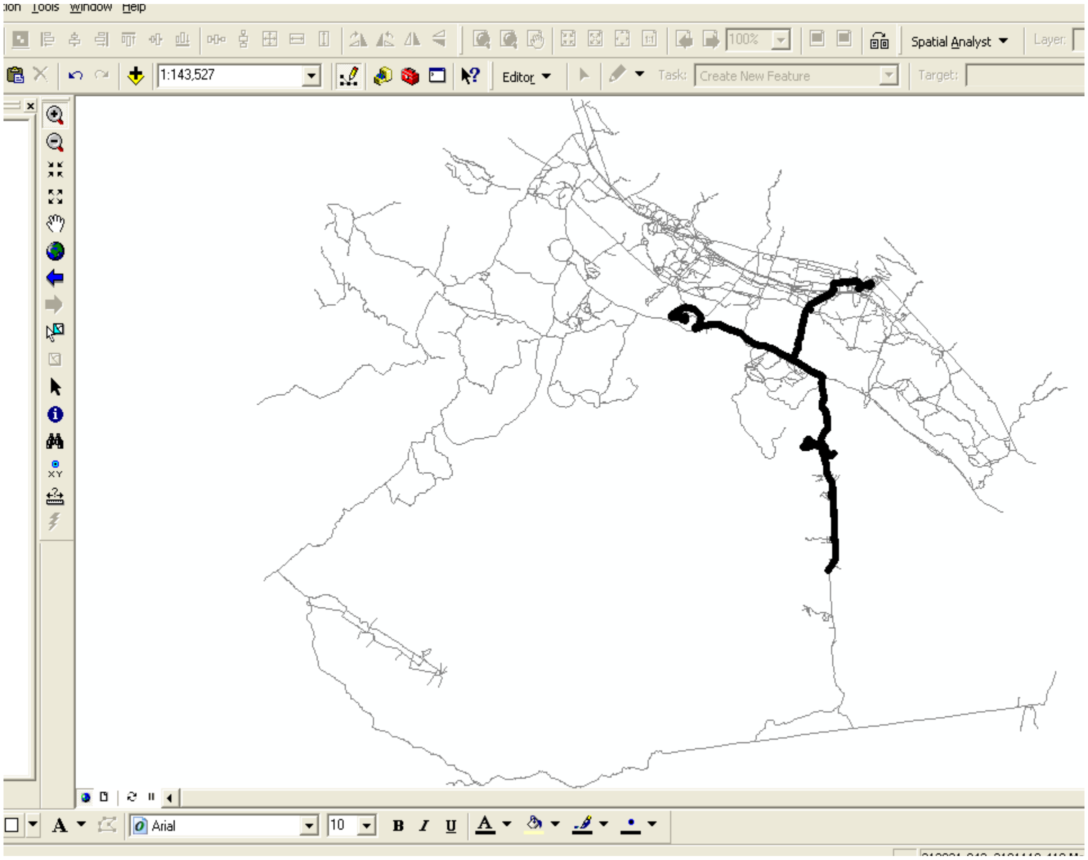


*Figure A-2: ArcGIS plot of MTV B-7 during pre transformation*

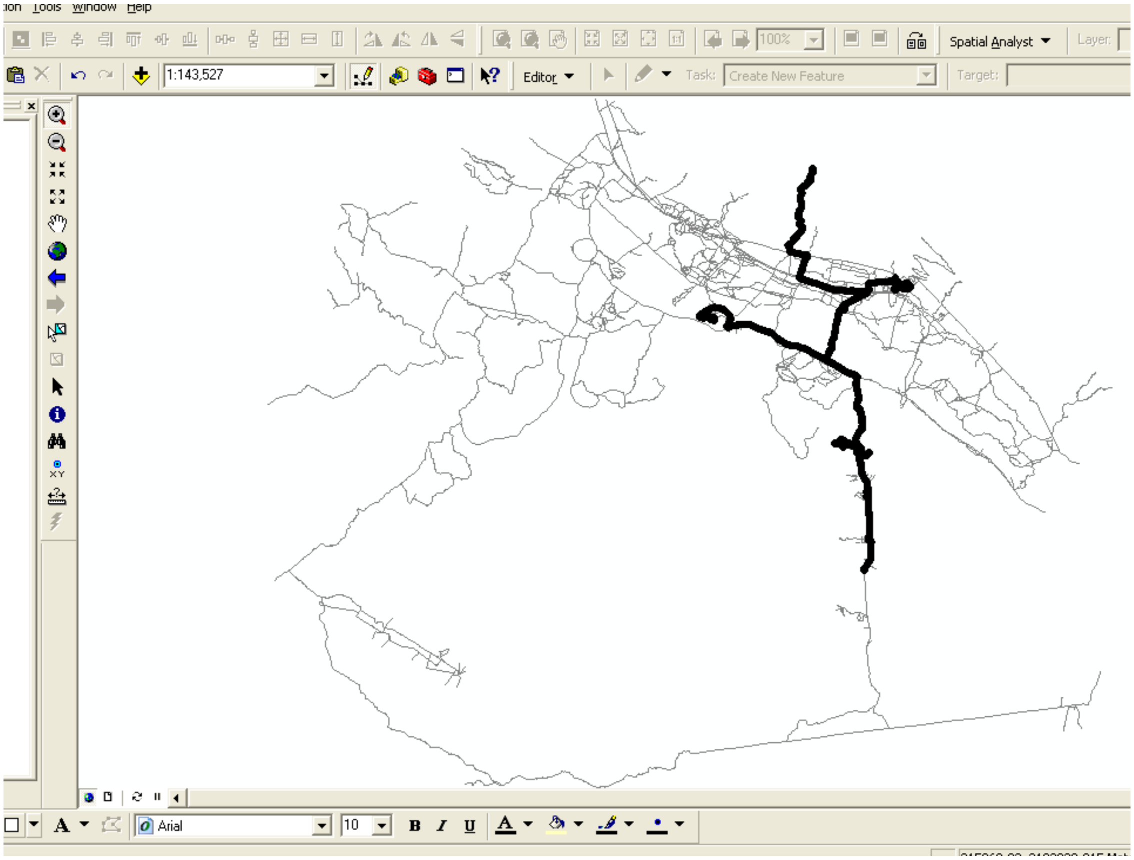


*Figure A-3: ArcGIS plot of HMMWV A-6 during pre transformation*

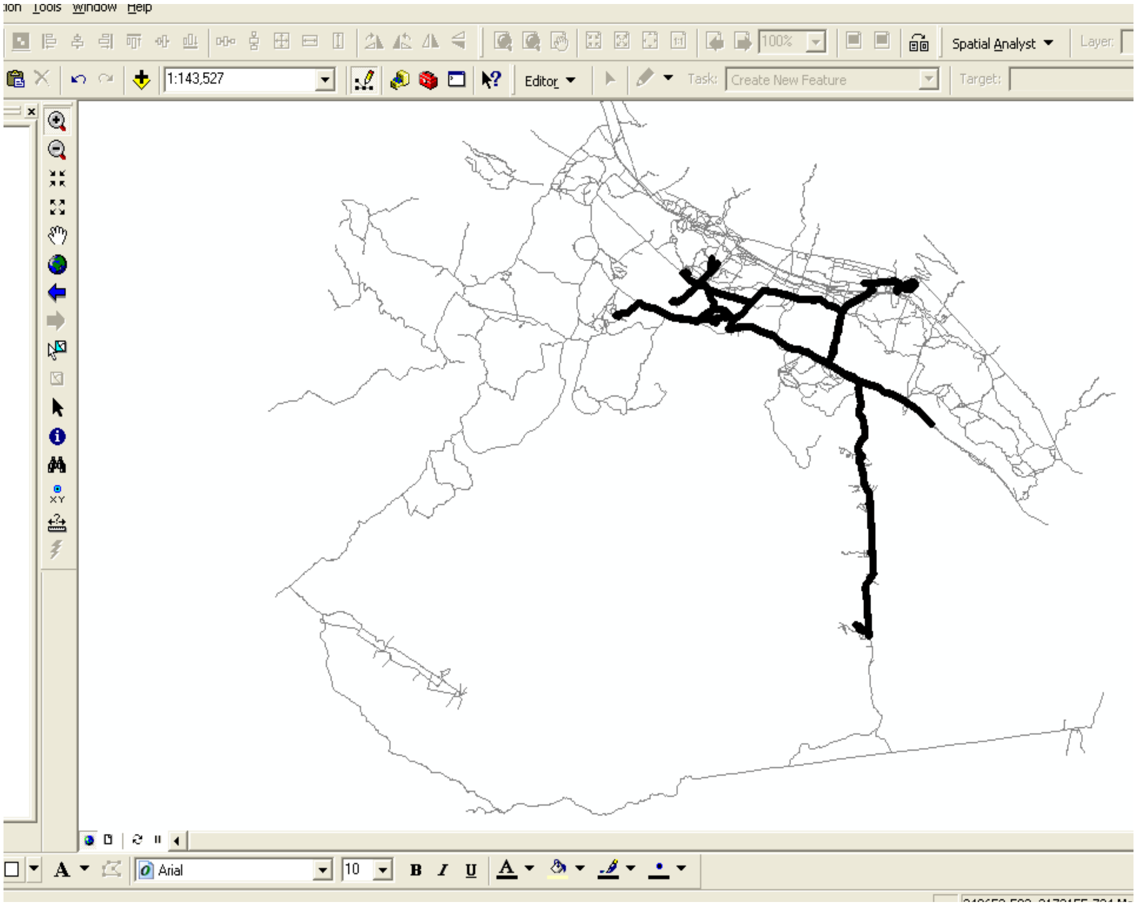


*Figure A-4: ArcGIS plot of MTV A-2 during pre transformation*

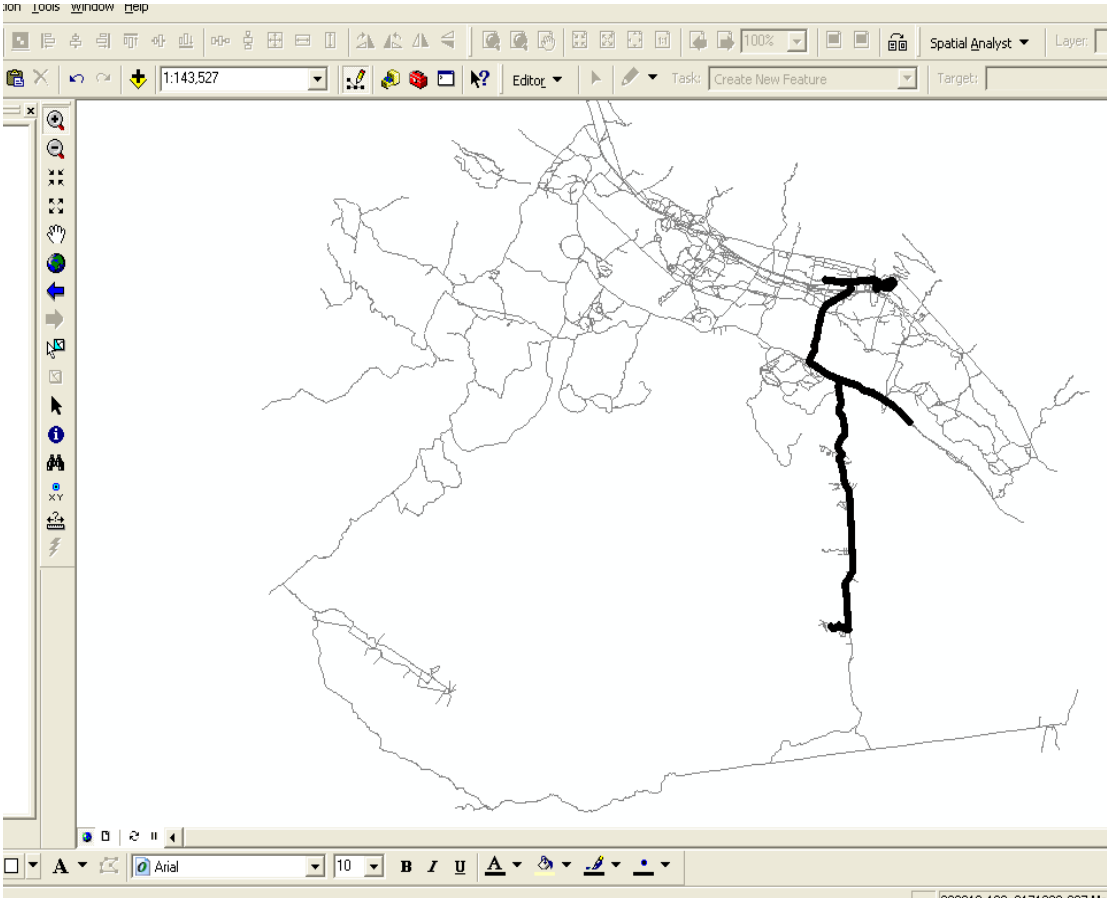


*Figure A-5: ArcGIS plot of MTV B-1 during pre transformation*

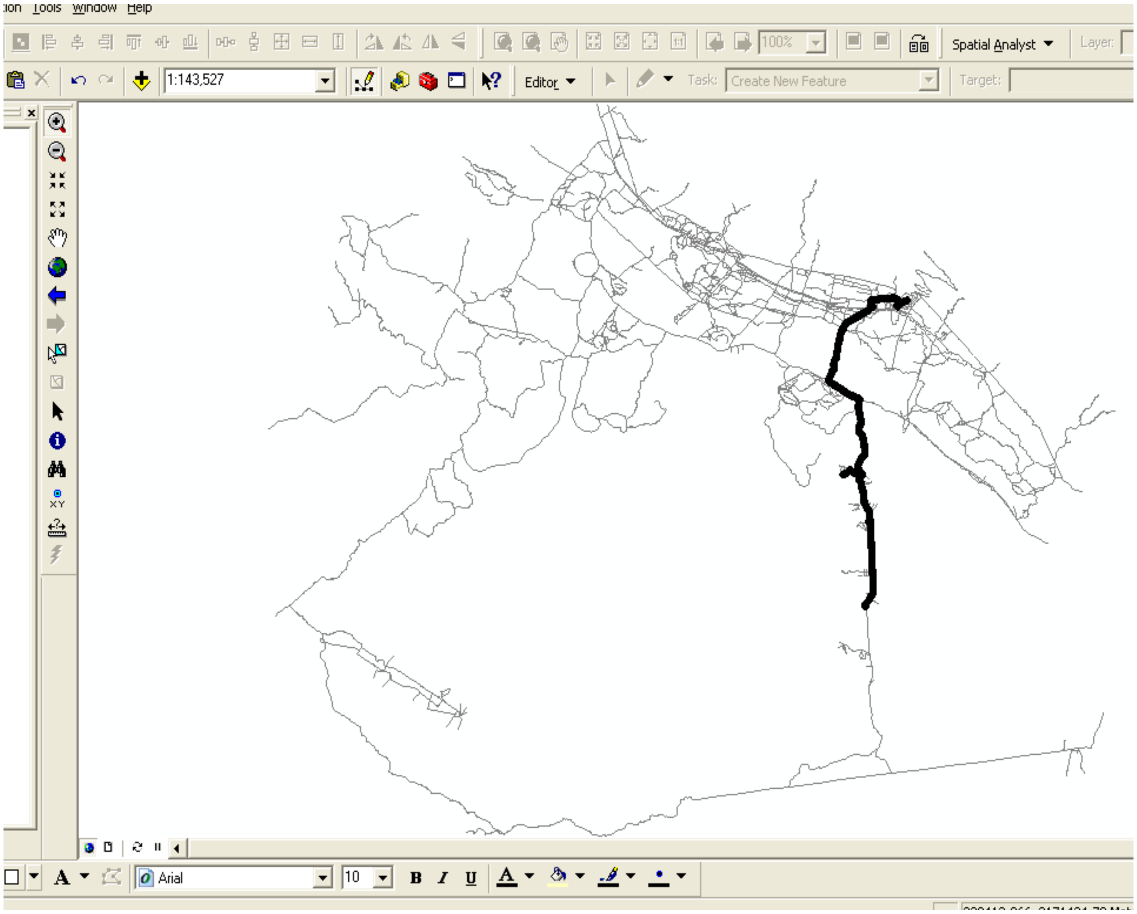


*Figure A-6: ArcGIS plot of HMMWV B-7 during pre transformation*

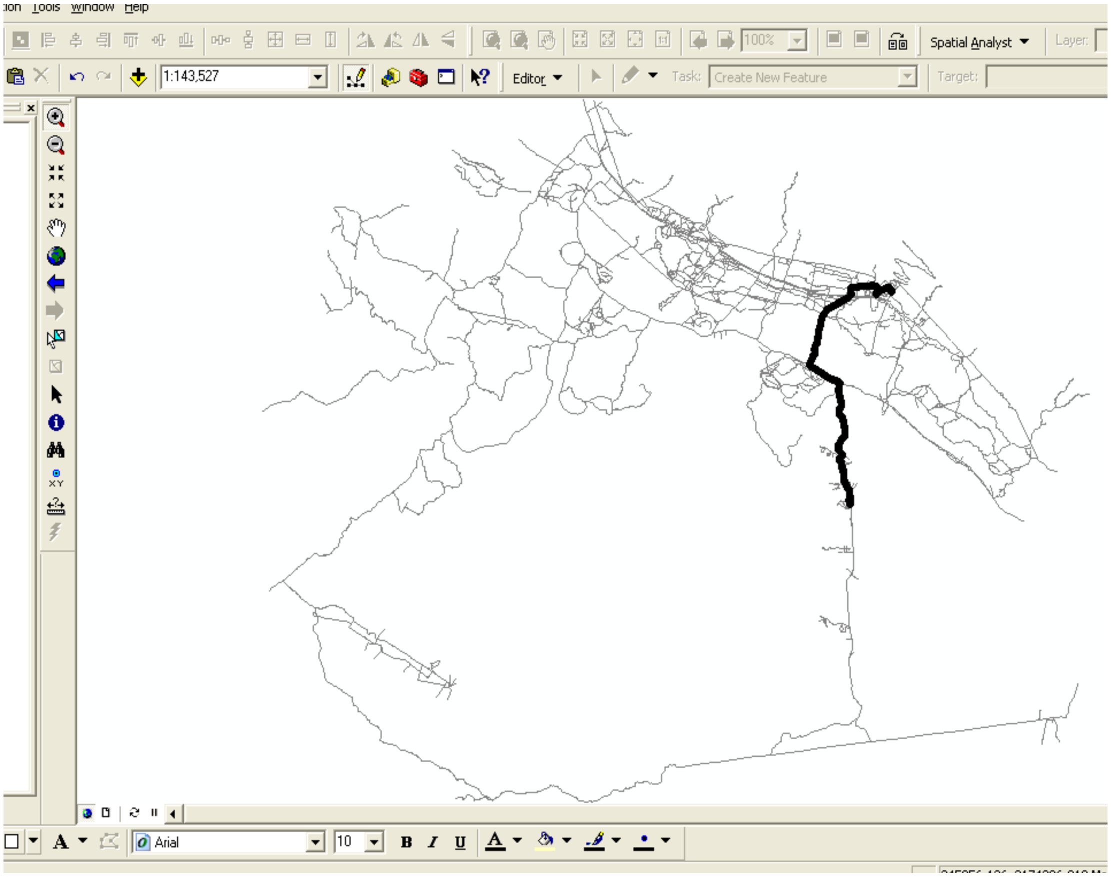
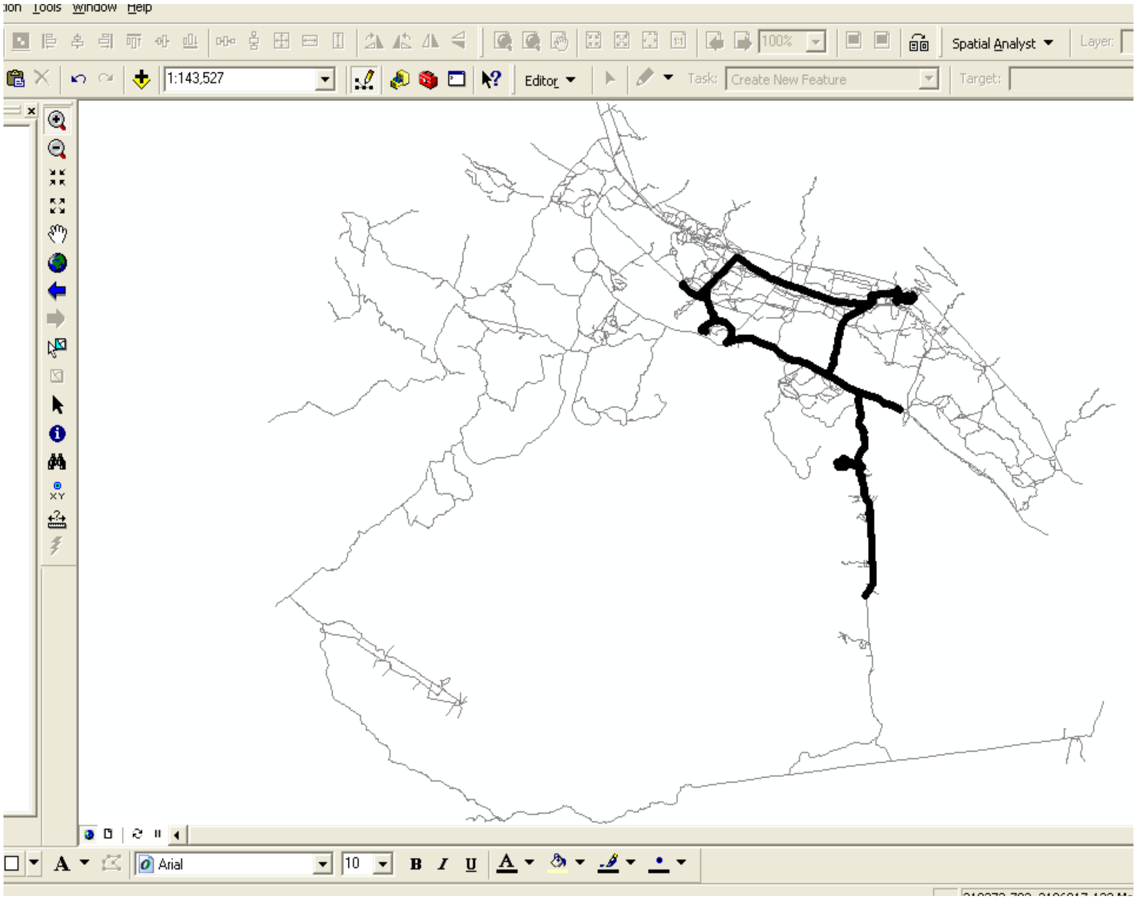


*Figure A-7: ArcGIS plot of MTV C-2 during pre transformation*



Task: Create New Feature

*Figure A-8: ArcGIS plot of MTV C-3 during pre transformation*

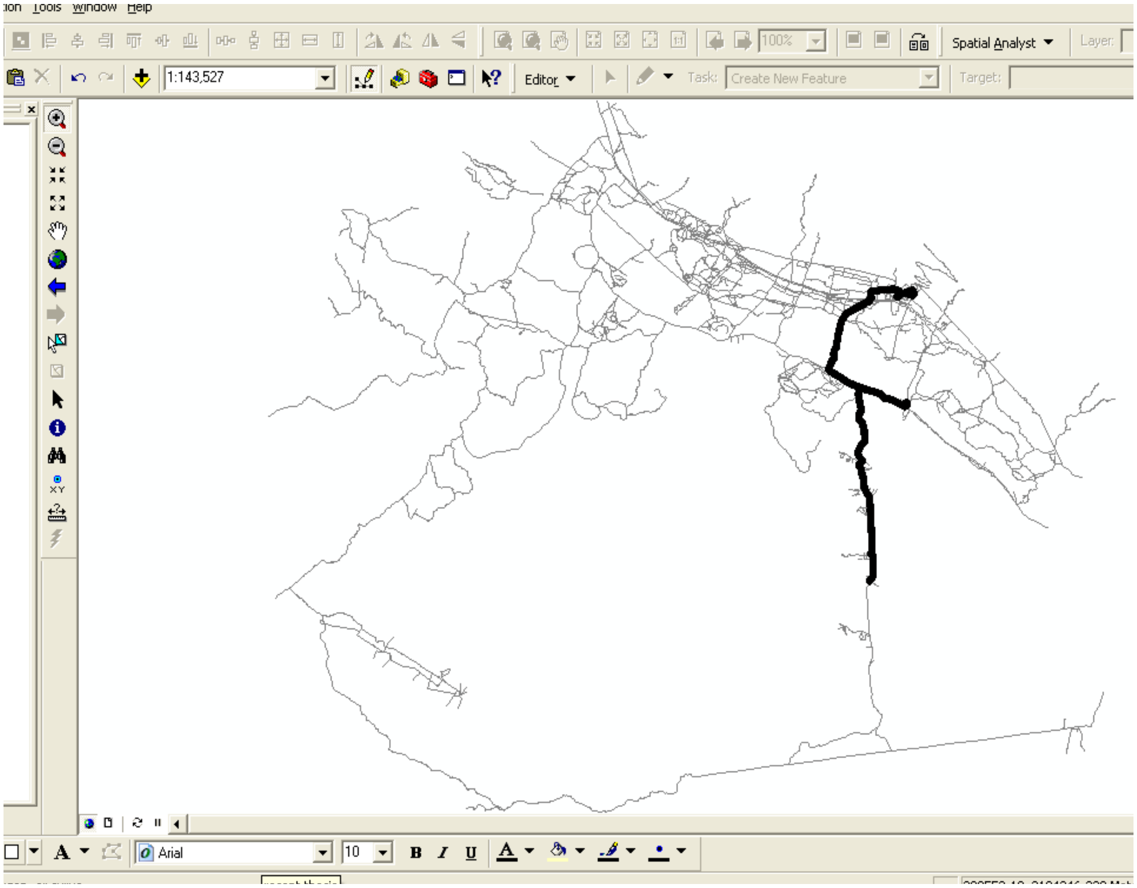


*Figure A-9: ArcGIS plot of HMMWV A-7 during pre transformation*

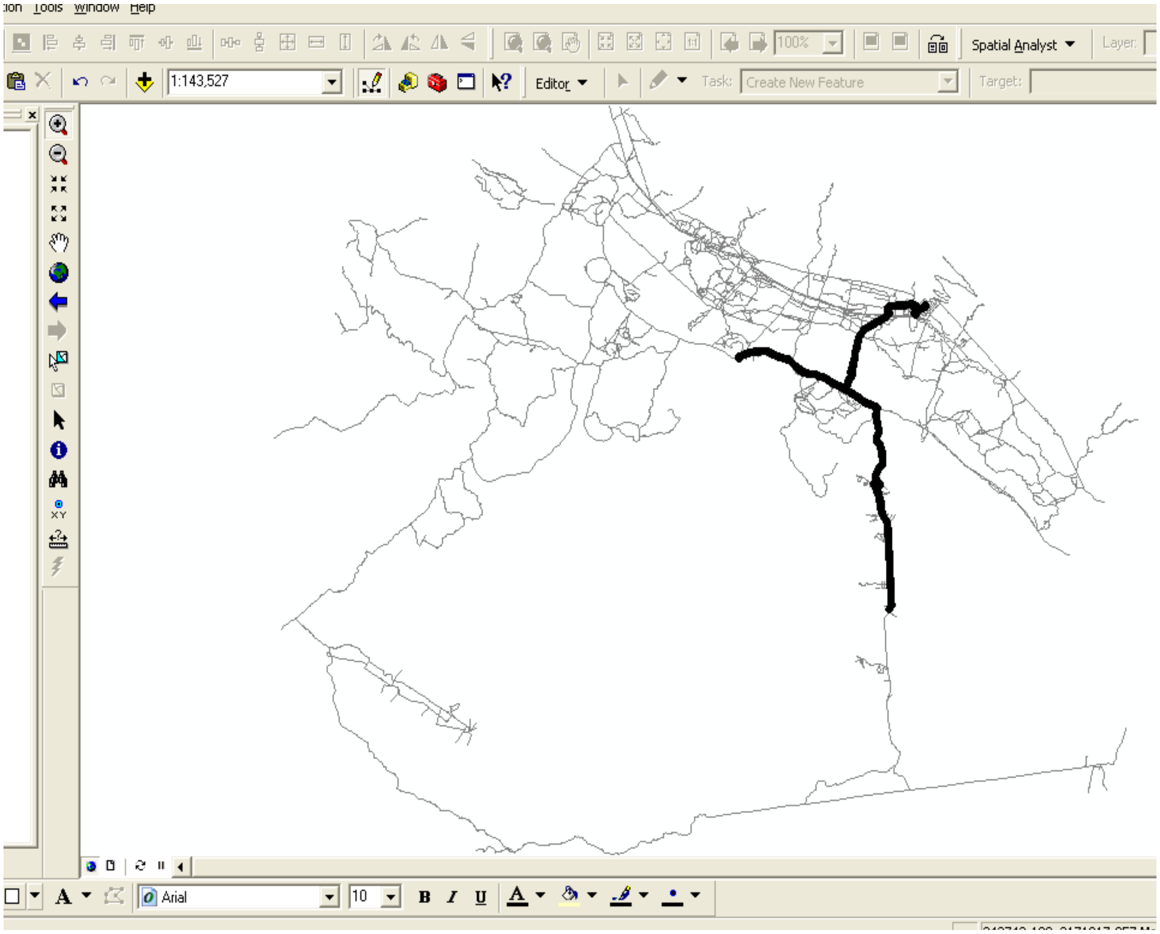


*Figure A-10: ArcGIS plot of MTV HHC-63 during pre transformation*

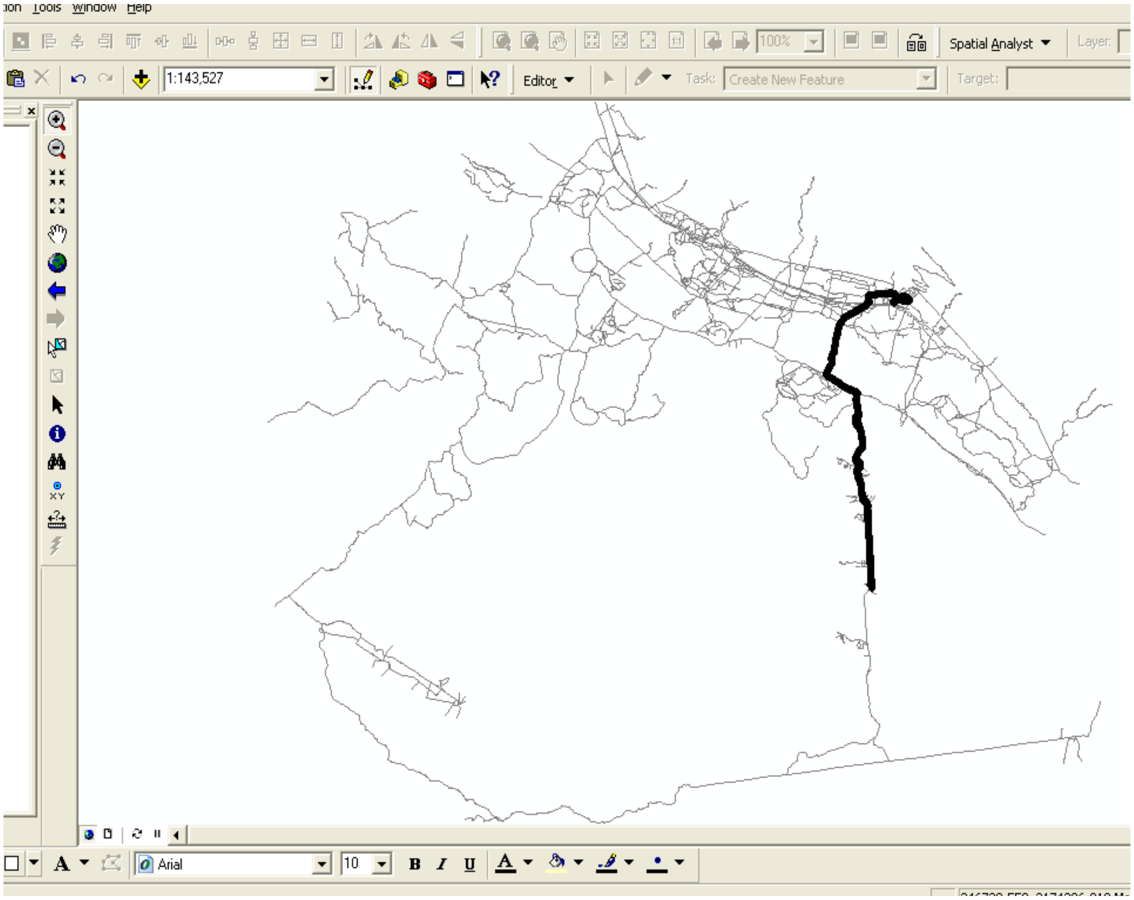


*Figure A-11: ArcGIS plot of MTV HHC-63 during pre transformation*

# Appendix B

## *Vehicle Movements during Post transformation*

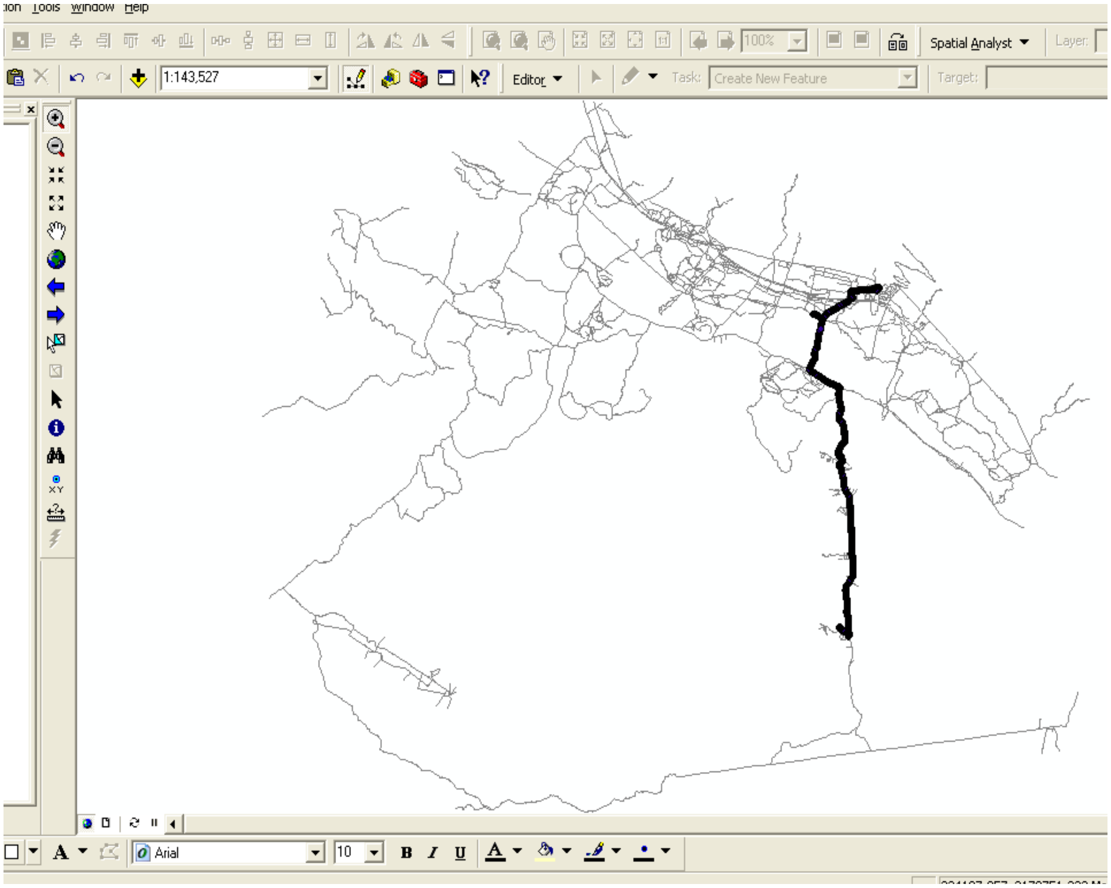


*Figure B-12: ArcGIS plot of Stryker C-66 during post transformation*

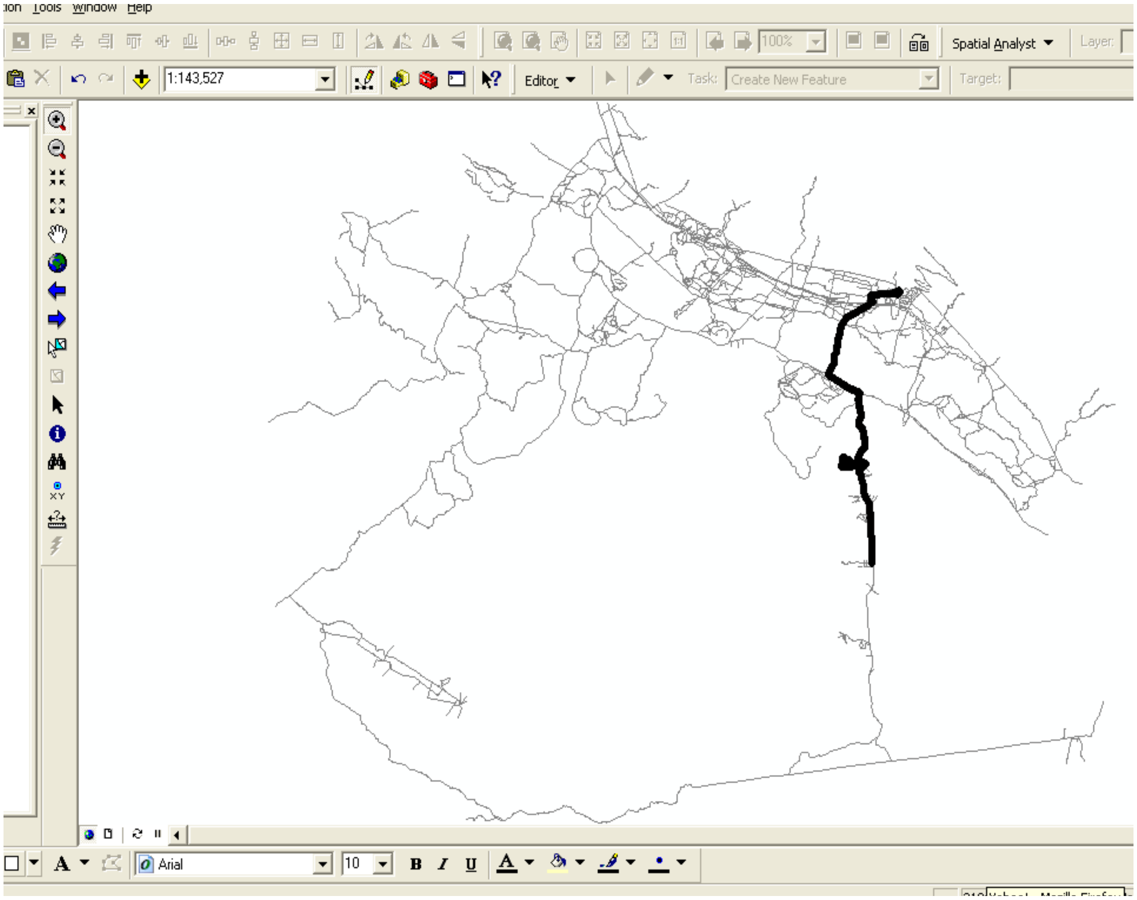


*Figure B-13: ArcGIS plot of Stryker C-11 during post transformation*

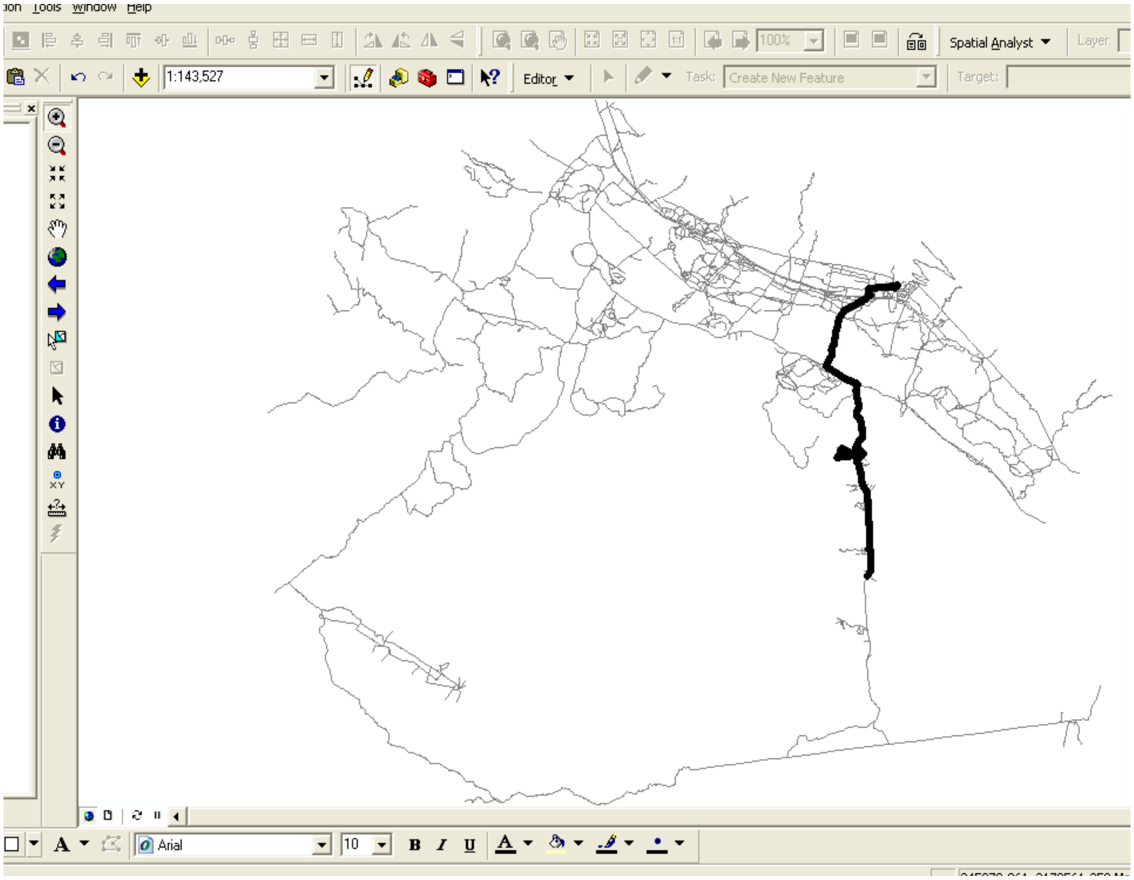


*Figure B-14: ArcGIS plot of Stryker C-12 during post transformation*

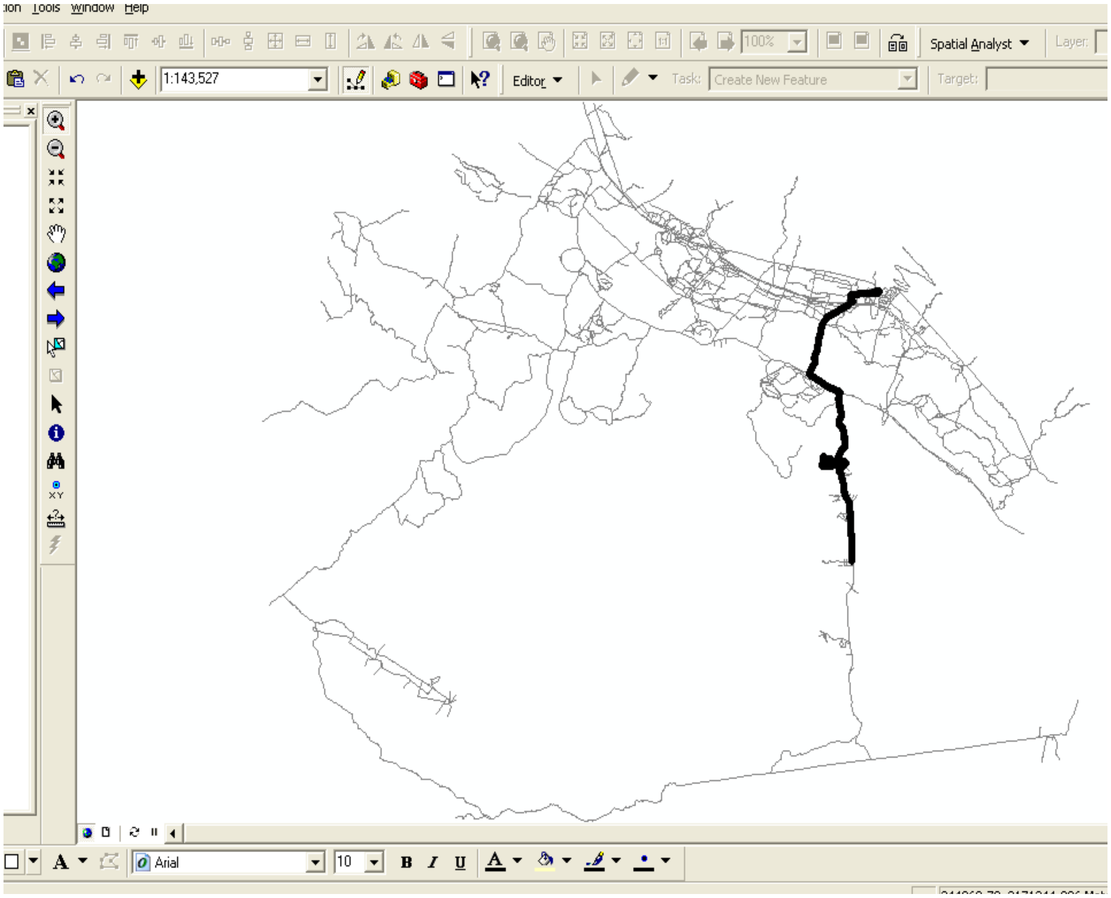


Figure B-15: *ArcGIS plot of Stryker C-14 during post transformation*

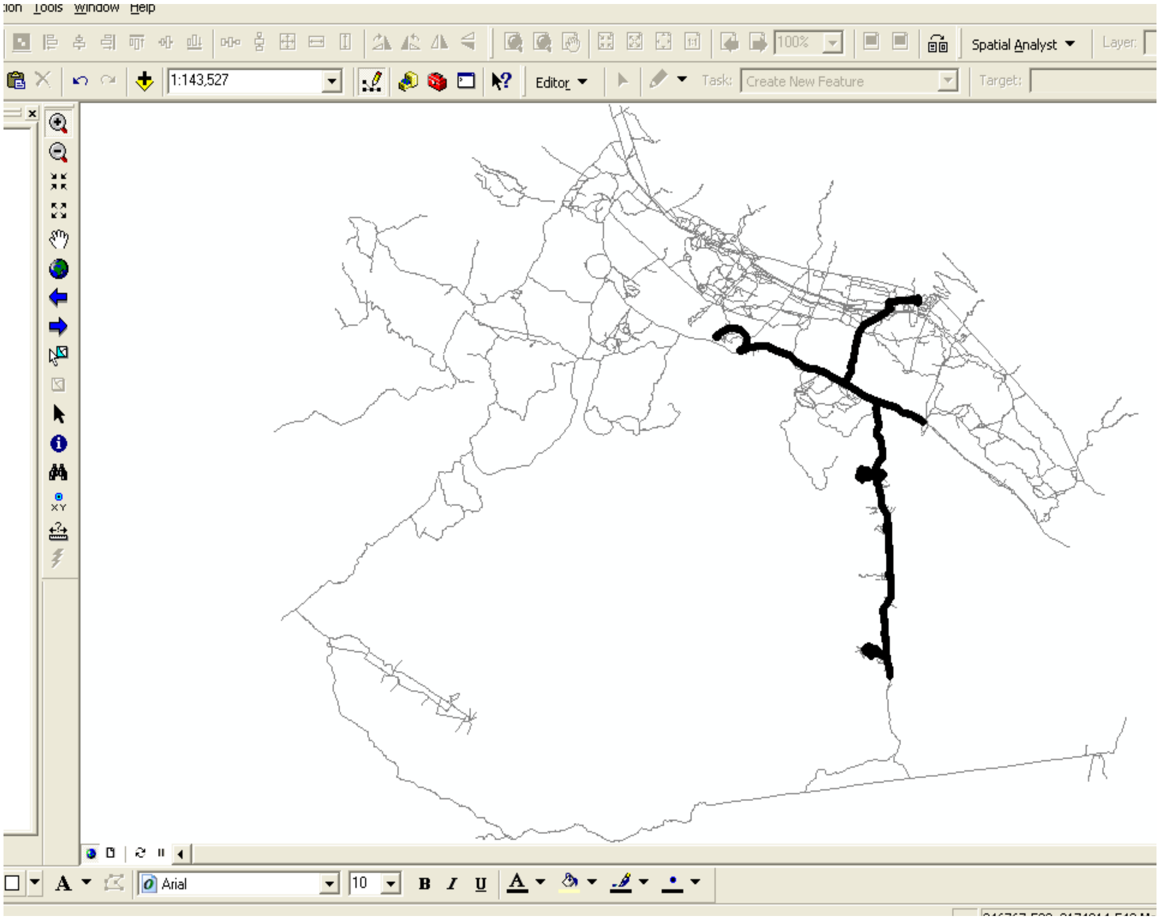


*Figure B-16: ArcGIS plot of Stryker C-21 during post transformation*

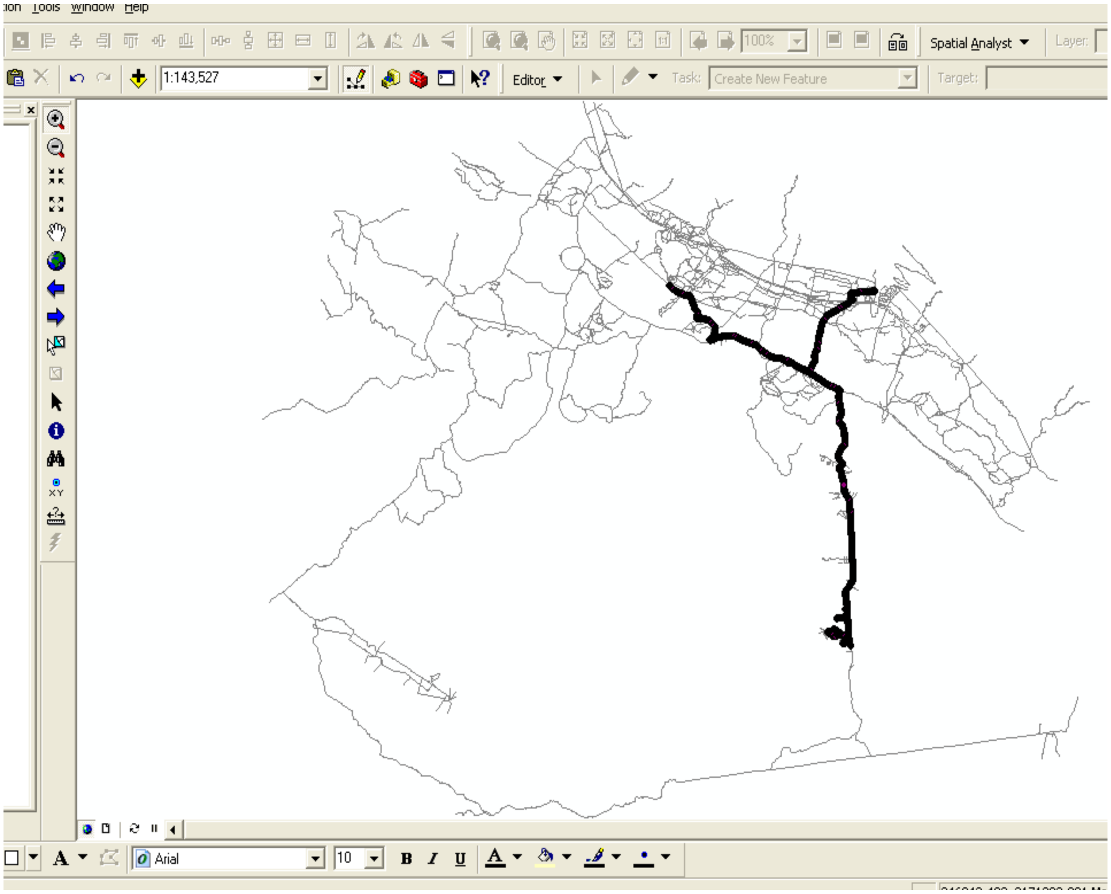


*Figure B-17: ArcGIS plot of Stryker A-12 during post transformation*

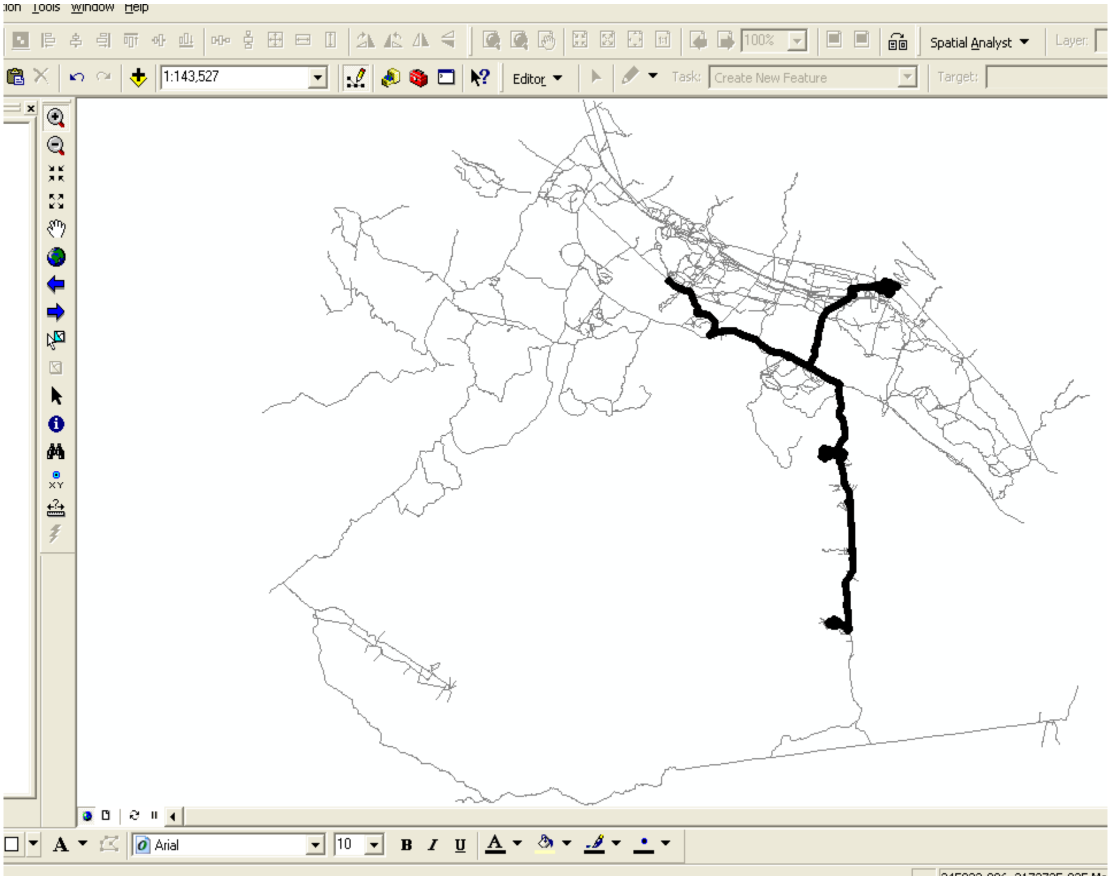


*Figure B-18: ArcGIS plot of Stryker A-14 during post transformation*

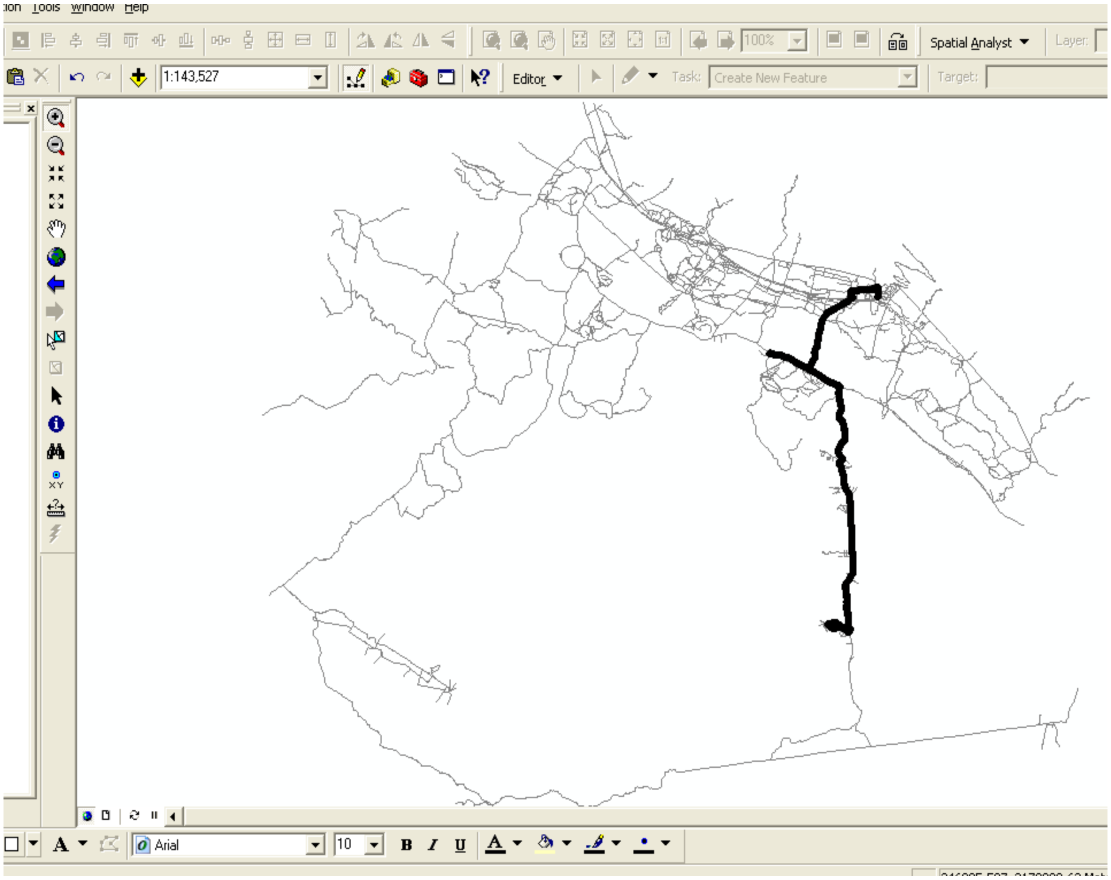
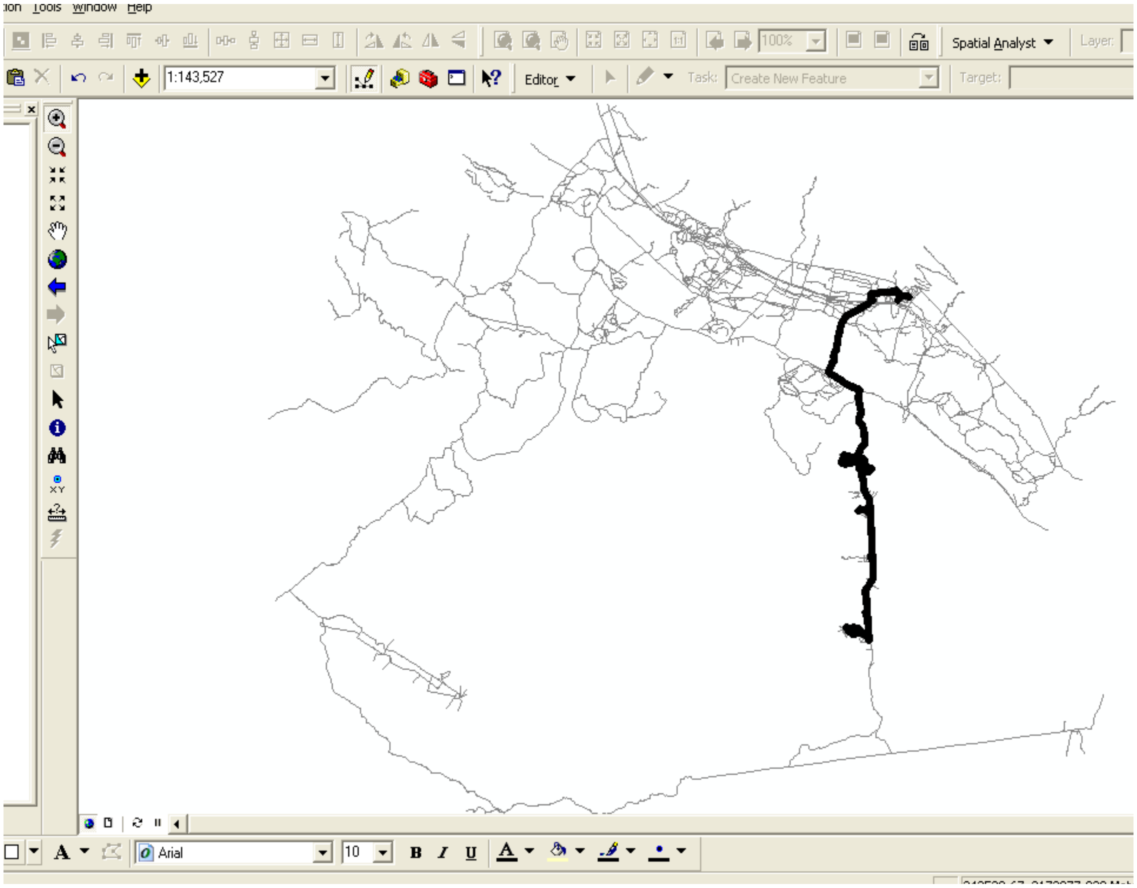


*Figure B-19: ArcGIS plot of Stryker A-21 during post transformation*



1:143,527

Task: Create New Feature

Arial

10

*Figure B-20: ArcGIS plot of Stryker A-31 during post transformation*

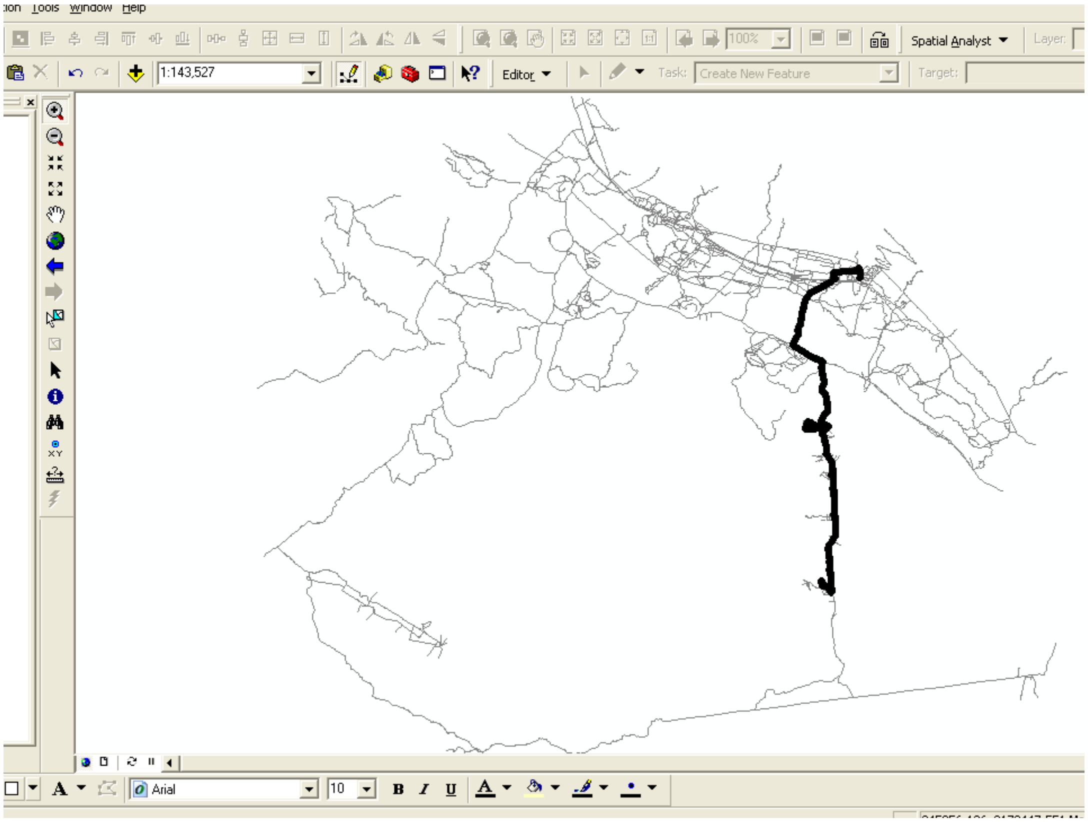


*Figure B-21: ArcGIS plot of Stryker B-32 during post transformation*

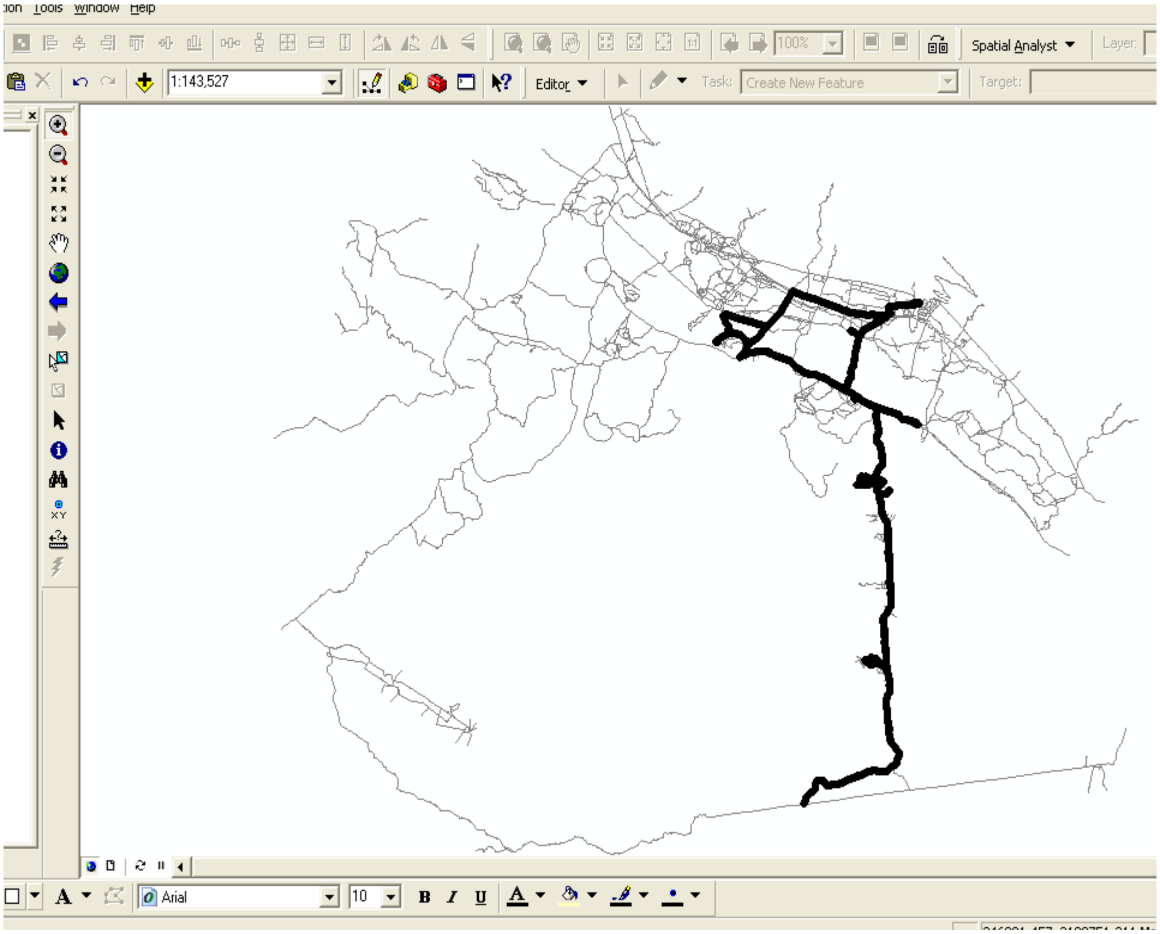


*Figure B-22: ArcGIS plot of Stryker HHC-75 during post transformation*

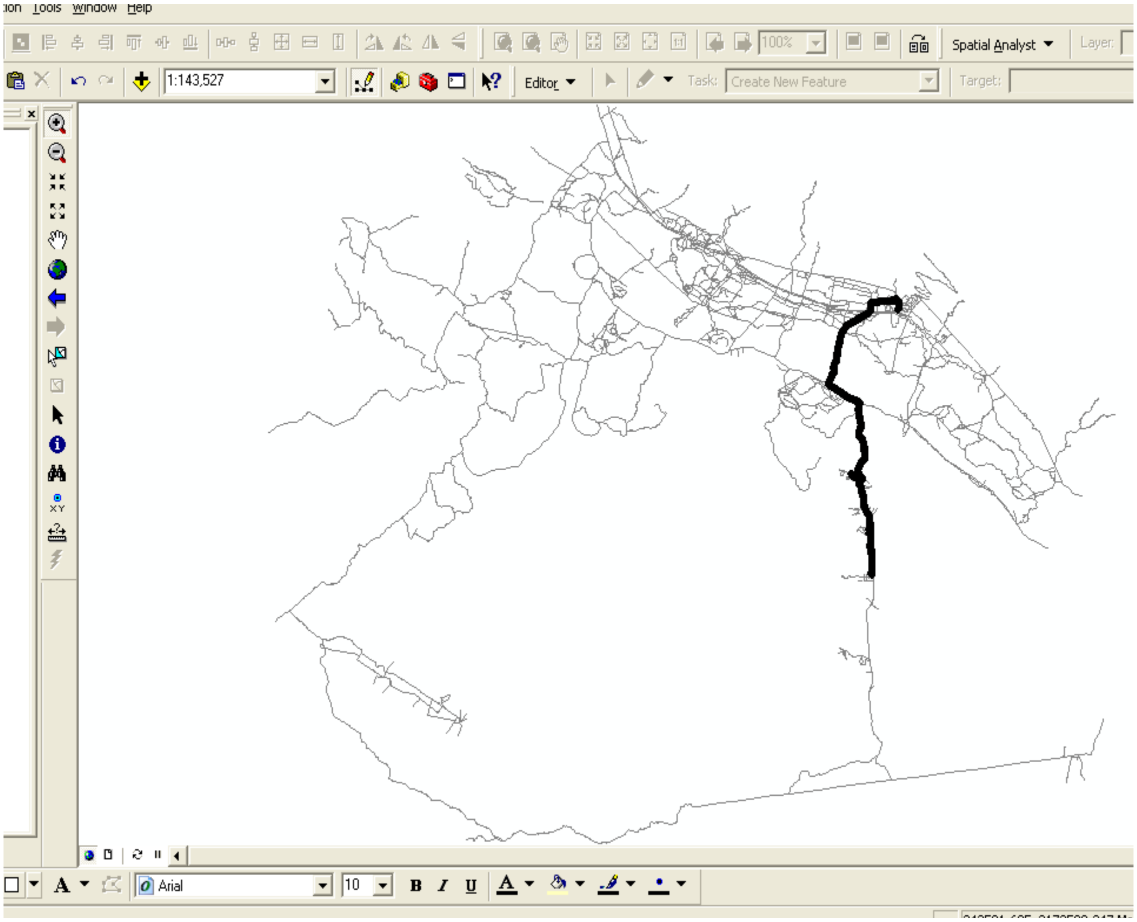


*Figure B-23: ArcGIS plot of Stryker HHC-74 during post transformation*

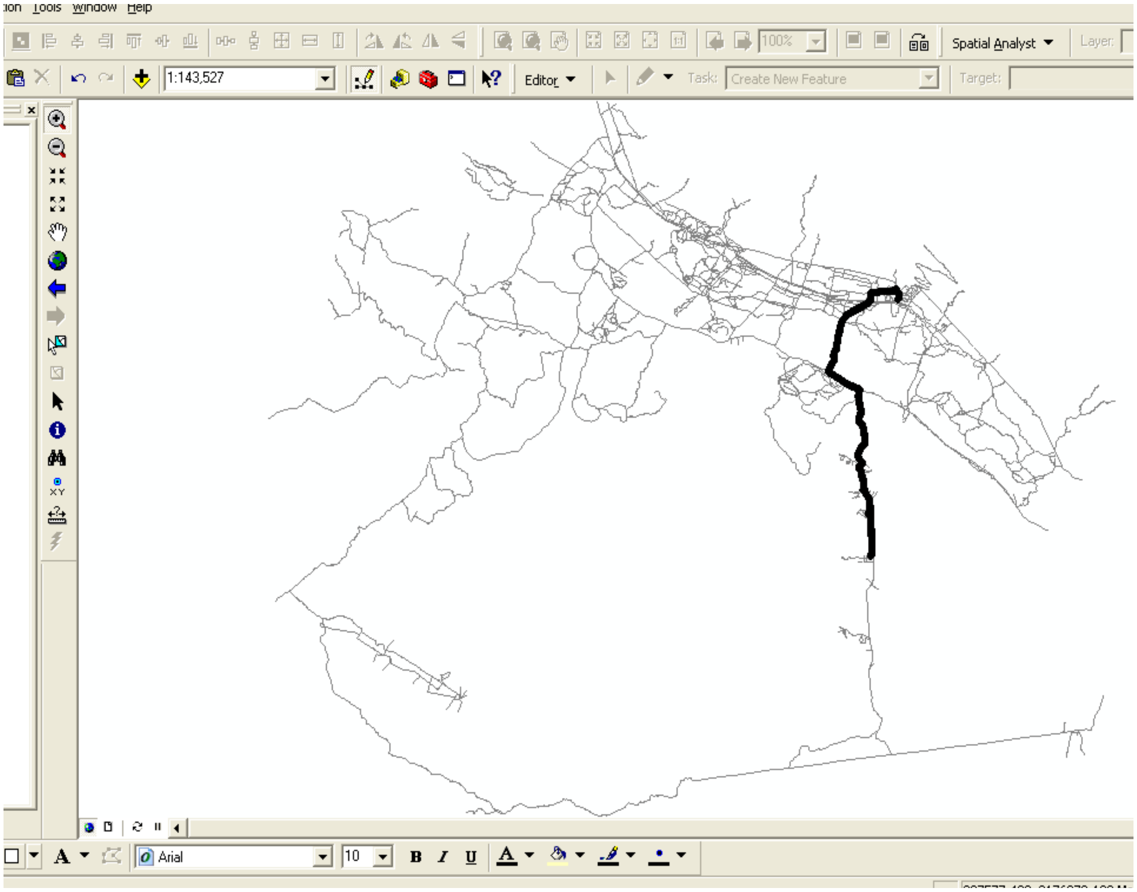


Figure B-24: ArcGIS plot of Stryker HHC-73 during post transformation

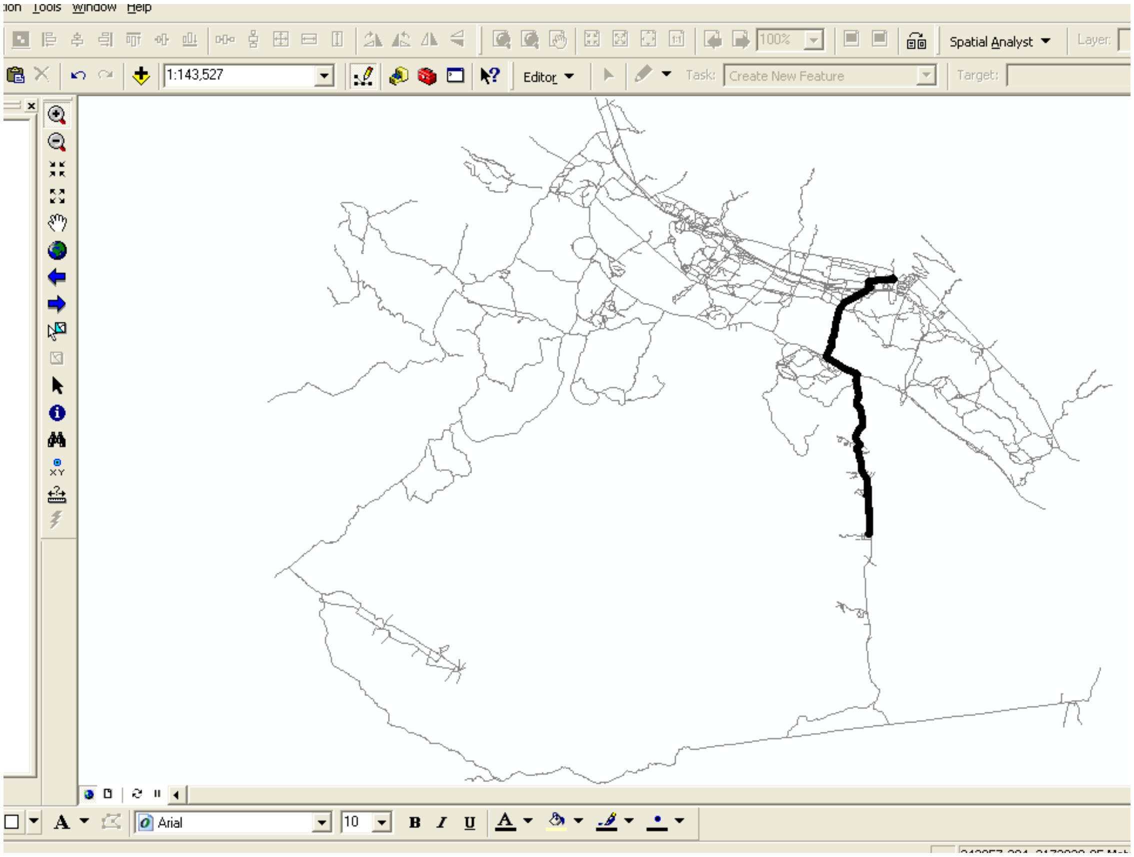


*Figure B-25: ArcGIS plot of Stryker HHC-72 during post transformation*

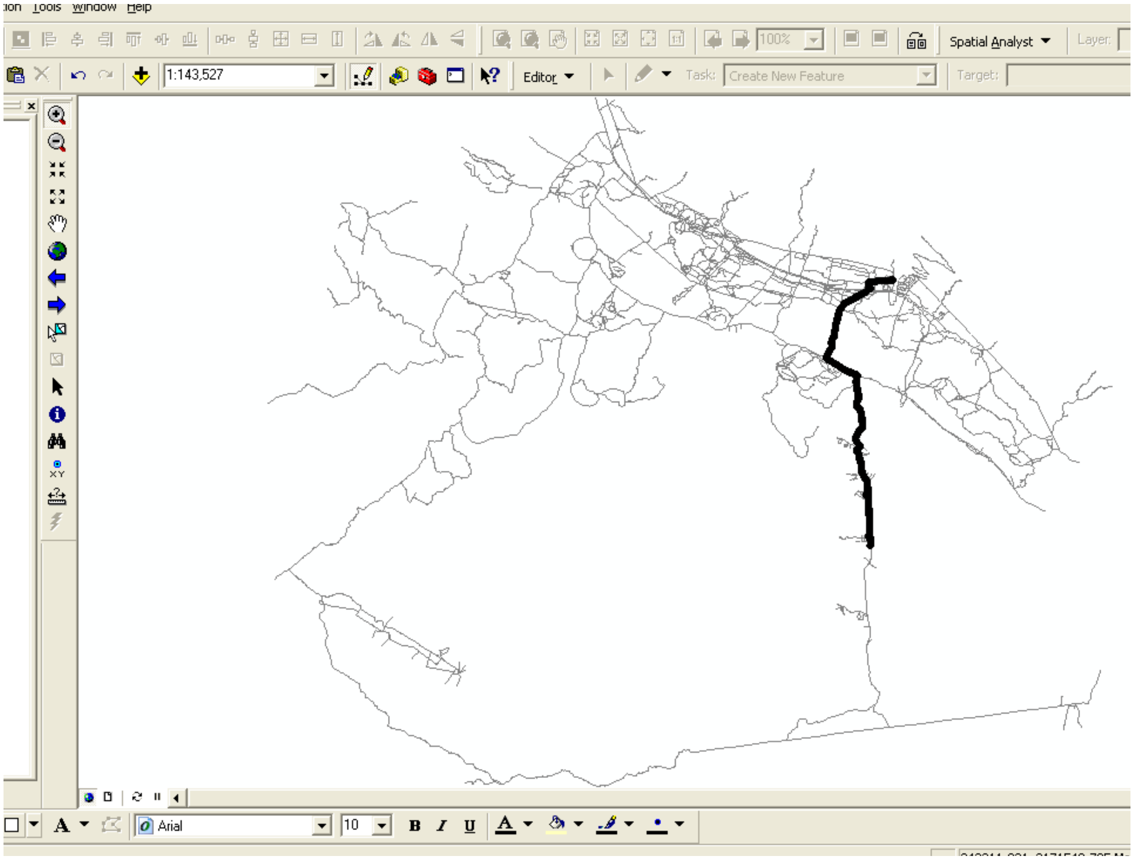


*Figure B-26: ArcGIS plot of Stryker B-12 during post transformation*

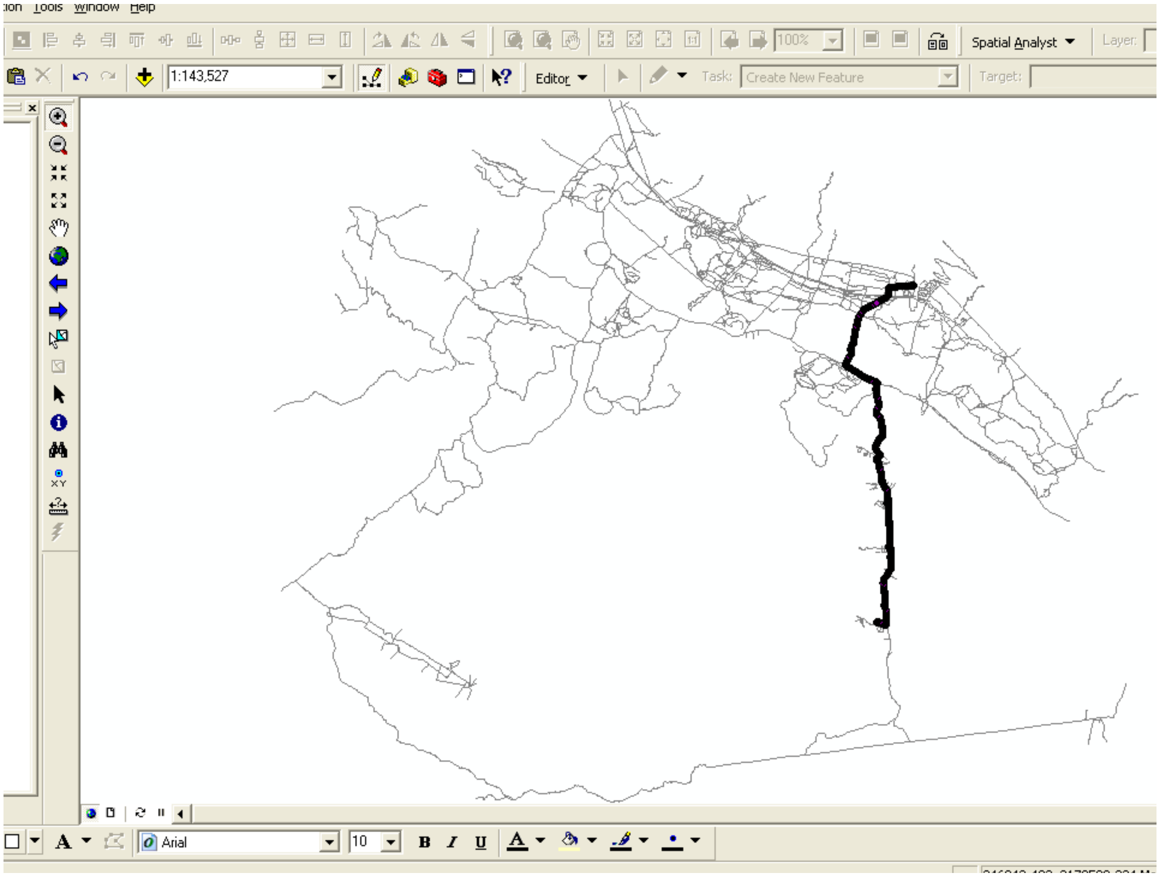


*Figure B-27: ArcGIS plot of Stryker B-14 during post transformation*

# Vita

Naga Swapna Potteti was born in Hyderabad, India on August 11, 1984. She attended elementary school, middle school, and high school in Hyderabad, Andhra Pradesh, India. She graduated from Nagarjuna junior college in June of 2001and began attending Osmania University, Hyderabad, India the following August. In June of 2004, she graduated with a Bachelor of Science in Genetics and Biotechnology. In August of 2004, she continued with her graduate study at the same University and she graduated with a Master of Science in Environmental Science in June 2006. In August of 2006, she began attending The University of Tennessee, Knoxville, pursuing a Master of Science in Biosystems Engineering Technology. The master's degree was awarded in May of 2009.