MODELING DRUG TRAFFICKING ROUTES USING POTENTIAL SURFACE ANALYSIS FOR THE SIMULATION OF MILITARY TRAINING SCENARIOS

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ABSTRACT

This research paper reports the methodology that adopted Potential Surface Analysis to model drug trafficking routes that led to social problems and public health deterioration in Thailand, the region and most parts of the world. With the final output aimed at creating military training scenarios to be included in a fire-arms training simulator of the Royal Thai Army, real world data from Geographic Information Systems (GIS) were prepared and used as Earth 'Surface' data upon which an Analytic Hierarchy Process (AHP) was performed. Before that process, roundtable discussions among expert of the filed were held to achieve factors and their ratings. Weightings and ratings were based on debate brought to the table from experiences, knowledge, expertise and judgments that ended up with mutual agreement. Physical, drug-aspect and Socio-demographic factors were identified as three main factors and their sub-factors were further separated to respond to drug-trafficking in reality. The factors seem literally diverse so that the Consistency Measure stepped in to ensure the consistency of each weighting and rating significance. Since the calculated Consistency Ratio (CR) was 0.0944, the significance of all the factors became less than 0.10, making the consistency reasonably acceptable. The Potential Surface Analysis (PSA) took form of suitability map that revealed the potential of GIS vector layers that suited drug-trafficking routes. Areas of most suitability were cross-checked to find that they corresponded with recorded drug-trafficking routes. It was securely concluded that the PSA was the proper method adopted to model a drug trafficking route given the studied factors. The project was carried on to simulate the real terrain of real events that passed more realism to military training scenarios in an army simulator.

Keywords: Modeling and Simulation, Drug Trafficking, Potential Surface Analysis, Military Simulation and Training

1. INTRODUCTION

1.1. Drug Situation: The World, The Region, and Thailand

Drug uses still generate social problems and public health deterioration in Thailand, the region and most parts of the world. According to World Drug Report (2015), it was estimated that almost a quarter of a billion people between the ages of 15 and 64 years used an illicit drug in 2013. Although opium poppy is cultivated in South-East Asia, individual drug seizures indicate that neither of the opium cultivating countries in the region, the Lao People's Democratic Republic and Myanmar, appears to be an important heroin trafficking departure hub (United Nations Office on Drugs and Crime, 2015). On the other hand, Windle (2016) found that while Thailand is no longer a major source of any illicit drug, it is an important transit point for drugs originating in other Southeast Asian states. The current trends in drug production, trafficking, and consumption say that Thailand is an important transit point for drugs destined for countries in Southeast Asia, East Asia, and Oceania because the country shares porous, remote, and poorly controlled borders with major drug producers. Therefore, we believe that virtual world simulation of training scenario is one of alternatives so that interception, monitoring and surveillance in drug trafficking can be enhanced.

1.2. AHP and PSA in Suitability Map

Jafari S. and Zaredar (2010) embraced the commonly used spatial AHP method for determining the most suitable areas for rangelands in Taleghan basin. Results indicated that the spatial analytical hierarchy process was a powerful support system resolving different uses of land suitability issues in the region. To deal within consistent judgments for complex decision analysis, Patil et al (2012) adopted AHP on land use suitability in conjunction with five different models and spatial PSA technique regarding highly suitable areas to find the highest potential candidates for residential construction purposes for Pimpri-Chinchwad-Municipal Corporation (PCMC) area, Maharashtra, India. However, debates to bring experiences, knowledge, expertise and judgments for mutual agreement for weightings and ratings were not mentioned.

Esmaelian et al (2015) proposed a Multicriteria Spatial Decision Support System (MC-DSS) to identify shelters and emergency service locations in urban evacuation planning to determine the zones most vulnerable to an earthquake. The final scores obtained were integrated into a mathematical programming model to calculate a GIS platform for the most suitable locations for emergency service stations. They suggested that MC-DSS be able to analyze spatial and space–time data so that the DMs could develop models that best represented reality. Taking a totally different approach, Chiranjeevi and Revathy (2015) provided a deeper understanding and assessment of the predictive accuracy with the assistance of information technology for knowledge discovery. They developed and implemented data mining framework to work with the geospatial plot of crime that helped to improve the productivity of the detectives and other law enforcement officers. The data source was the complete record of drugs such as cannabis, opioid, cocaine or amphetamine-type stimulant group leaving and returning to ports in the Airport region.

By thus far, AHP and PSA have been rarely applied to modeling drug trafficking routes. The closest study was when Dell (2011) examined how drug traffickers' economic objectives influenced the direct and spillover effects of Mexican policy towards the drug trade. The study predicted the diversion of drug traffic following close the Mexico's conservative National Action Party (PAN) victories by estimating a model of equilibrium routes for trafficking drugs across the Mexican road network to the U.S. When drug traffic was diverted to other municipalities, drug trade-related violence in these municipalities increased. Taken into account the room for AHP and PSA to play in drug trafficking route prediction, we identified physical, drug-aspect and socio-demographic factors and their respective sub-factors to respond to drug-trafficking in Thailand's northern borderline. PSA method resulted in suitability maps to reveal the potential of GIS vector layers calculated for drug-trafficking routes. The PSA-based real terrain was passed on to military training scenarios for incorporating into the army simulator.

1.3. The Royal Thai Army Fire-arms Training Simulator

The Royal Thai Army cooperates with Thai Government Agencies in Chiang Mai to intercept drug trafficking from entering the country and to suppress internal drug cartels. Nine fire-arms simulators worth of more than 2 million US dollars were installed in the army units across the country and one of them in Chiang Mai for task force and special force trainings. Officials from drug suppression and interception state agencies are welcome to recall their fire-arms aiming, shooting and frequently shoot-not-shoot decision skills. The Army Training Command needs to upgrade the simulators by incorporating a mission-based training scenario into the systems. Geo-specific and user-centered training scenarios were initiated by the authors to respond to the trained missions and drug-trafficking scenarios were realized to simulate real world mission of drug suppression and interception.

2. DATA AND METHODOLOGY

2.1. GIS Data Collection

The GIS data collection incorporated a combination of vector and raster GIS. One-meter resolution satellite image was used for GIS layer generation as shown on the Figure 1 right inset. Numerous and different work plans were carried out to cover the entire 20 km^2 study area. Urban survey was conducted and concluded to be the most time-consuming of the field survey tasks. The survey of land uses and plantation in agricultural areas was completed by the integration of remote sensing image processing and GIS heads-up digitization method. A forest inventory was divided into several plots to collect tree or shrub types and heights for later use in virtual world creation. Terrain contour lines were interpolated from GPS height point collection for terrain generation. The validation of spatial data accuracy was randomly ground-checked and reported to be insignificant for the terrain heights which were later cover-planted by three dimensional vegetation models.

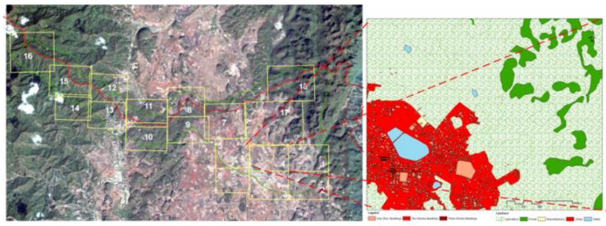

Figure 1: The studied areas and GIS data layers of an urban part

2.2. Methodology

Figure 2 illustrates the conceptual framework of the current study. The methods of this investigation are fourfold; (2.2.1) Defining factors and sub-factors related drug trafficking, (2.2.2) Analytic Hierarchy Process (2.2.3), Modeling drug trafficking routes using PSA, and (2.2.4) Virtual world creation, the details of which are as follows;

2.2.1. Defining factors and sub-factors related drug trafficking

Prior to applying Potential Surface Analysis to model drug trafficking routes, roundtable discussions were proceeded in order to retrieve which factors and sub-factors had comparatively more impact on drug trafficking. The group discussions were carried out among several military and police sectors that are involved with interception, monitoring and surveillance of drug trafficking. Particularly, homogeneity within those decision makers was necessary to impose. Since the factors and sub-factors were debated and defined (as seen in Table 6 and 7), the same group of decision makers needed to evaluate the significance of each criterion using AHP (Malczewski, 1999) as one of weighting and rating techniques to be described later in section 2.2.2. This methodology of multiple decision making executing variables related to drug trafficking demonstrates a substantially unique work compared to the results when Medel, Lu, and Chow (2014) merely defined variables of drug trafficking cost based on common knowledge.

Figure 2: Conceptual framework of study

2.2.2. Analytic Hierarchy Process

AHP is one important multi criteria decision analysis (MCDA) that researchers frequently used to explain the significance intensity of criteria quantitatively. So as to acquire the significance value of each factor, roundtable discussions were performed among the same group of officers (described in section 2.1). The pairwise comparison method developed by Saaty (1980) was applied to obtain relative weights for the output. The scale of pairwise comparison contains intensity of significance from 1 to 9. The method could be best described by an example of intensity scale of significance among physical and drug factors displayed in Table 1. Experts when considering that the type of road network to have more intensity of significance to drug trafficking would have a scale of 3 compared to that of the landuse. On the contrary, landuse would have the intensity of significance to drug trafficking of 0.33 compared to the type of road network. Pair by pair, all factors and sub-factors were scaled from a group of experts. Eventually, the single intensity of significance among factors was agreed at the end of each roundtable discussion so that the pair wise comparison method could be calculated as seen an example in Table 2. The pairwise comparison accomplished this way ensured the estimation of factors and sub-factors weights (Malczewski, 2015) to be further analyzed in PSA. Next step was to compute factor weights using normalized pairwise matrix (Malczewski, 1999). It comprised three steps including; (a) summing in each column of pairwise comparison matrix (Table 2); (b) dividing each component in the matrix by sum values acquired from step (a) bringing up normalized pair wise comparison matrix (Table 3); and (c) computing the average of components in each row of the normalized matrix. These averages gave the estimation of relative weights of criteria associated (Table 4).

Table 1: An Example of intensity scale of significance

Intensity of Significance	
Landuse	RD[a]
9 8 7 6 5 4 3 2 1	2 **3** 4 5 6 7 8 9
Landuse	TS[b]
9 8 7 6 5 4 3 2 1	2 3 **4** 5 6 7 8 9
Landuse	SM[c]
9 8 7 6 5 4 3 2 1	2 3 4 **5** 6 7 8 9
RD	TS
9 8 7 6 5 4 3 2 1	2 **3** 4 5 6 7 8 9
RD	SM
9 8 7 6 5 4 3 2 **1**	2 3 4 5 6 7 8 9
TS	SM
9 8 7 6 5 4 3 2 **1**	2 3 4 5 6 7 8 9

[a]*Type of road network*, , [b]*Transit site*, [c]*Trafficking method*

Table 2: An example of pairwise comparison

Pairwise comparison			
Criteria	RD	TS	SM
Landuse	0.33	0.25	0.20
RD	1.00	0.33	1.00
TS	3.00	1.00	1.00
SM	1.00	1.00	1.00
Sum	5.33	2.58	3.2

Table 3: An example of normalized pairwise comparison matrix

Criteria	RD	TS	SM
Landuse	0.06	0.10	0.06
RD	0.19	0.13	0.31
TS	0.56	0.39	0.31
SM	0.19	0.39	0.31

Table 4: An estimation of the relative weights

Criteria	TS	Weight
Landuse	(0.06+0.10+0.06)/3	0.07
RD	(0.19+0.13+0.31)/3	0.21
TS	(0.56+0.39+0.31)/3	0.42
SM	(0.19+0.39+0.31)/3	0.30

In our study, we implemented above mentioned steps (from Table 1 to 4) so as to retrieve the estimation of relative weights of factors and sub-factors defined by group of officers. The results are shown in section 3.2. To verify reasonably acceptable relative weights, Consistency Ratio (CR) was employed. If the CR was <1.0, the overall relative weights of factors and sub-factors were reasonable, otherwise, the intensity of significance among factors was reconsidered.

2.2.3. Modeling Drug Trafficking Routes using PSA

To the best of our knowledge, none research on drug trafficking in Thailand has been focused on geographical relations. Moreover, it has been confirmed that using the combination of AHP and PSA can enhance the understanding of decision making problems involving spatially referenced aspects (Pawattana, and Tripath 2008, Dell 2011; Alexakis, Hadjimitsis, and Agapio 2015, Mishra and Deep 2015). Prior to applying PSA, twelve GIS layers were extracted from orthophotos associated with field survey to create a defense geo-database. Those factors and sub-factors related to drug trafficking, which were imposed by a group of decision makers, were manipulated and transformed into a spatially referenced format even though a few of them was non-spatial including the number of information received per month, and trafficker's network (Table 6). PSA, based on equation 1, was applied to model drug trafficking routes. The relative weights of each criterion acquired from section 2.2.2 (An example as seen in Table 4) were included in this equation (W_i and X_i).

Potential drug trafficking routes = $\sum_{i=1}^{n} WiXi$ (1)

Where

W_i is relative weight of factor$_i$ related drug trafficking
X_i is relative weight of sub-factor of factor$_i$ related drug trafficking

The potential areas of drug trafficking were spatially analyzed using equation 1 and categorized into less, moderate and high potential. Most importantly, the validation of modeled drug trafficking routes was carried out using lessons learnt from the operational military units and the Thai Government Agencies in Chiang Mai. The results of model validation were further explained.

2.2.4. Virtual World Creation

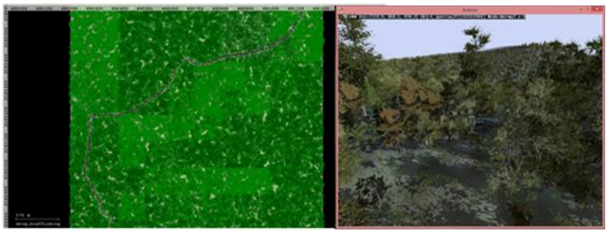

Figure 3: Terrain data prepared in Landbuilder® and the virtual world rendered by Buldozer®

3D virtual world creation started with selecting a region from GIS data in Section 2.1 that covered the result of the modeled drug-trafficking routes in Subsection 2.2.3. The necessary and prepared GIS data included interpolated heights, satellite images, GIS attributes data that defined position and boundary of natural and manmade objects, photos from the selected site for 3D model selection and 3D models to represent objects found on the selected site. Visitor4® terrain development tool that was part of Virtual Battle Space version 3 (VBS3®) was used to create the virtual world. The process encompassed inputting the .tif terrain height data, satellite images and GIS shapefile vector layers. Landbuilder® (Figure3 left) was used to plot 3D vegetation models bounded by a forest ESRI® shapefile. The virtual world was rendered by Buldozer® (Figure3 right). The processed virtual world was further used (Figure 4 left) for mission training scenarios (Figure 4 right) in VBS3®.

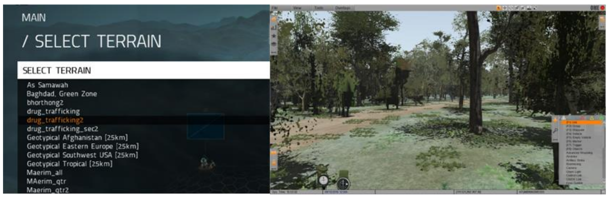

Figure 4: Terrain data prepared in Landbuilder® and the virtual world rendered by Buldozer®

2.2.5. Drug Trafficking Training Scenario

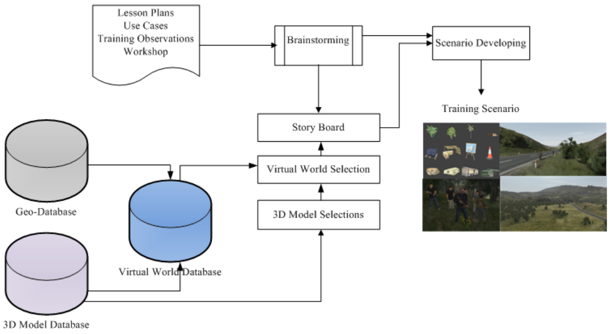

Figure 5: Steps of training scenario creation

Training Scenario requirements were gathered via activities in Figure 5. Such diparate data was from lesson plan, standard operating procedures, trainings or genuine field experience, and training observation. Workshops on Range3000® Video Branching at the

Chulachomklao Royal Military Academy during 9 - 10 July 2015 (Figure 6 upper left) and Workshop of Weighting and Rating Factors and Sub factors-related drug trafficking at one of the Army units in Chiang Mai on 14 May 1015 (Figure 6 upper right) were also incorporated into the VBS3® Engine scenario where appropriate weapons, backpack, avatar and vehicle (Figure 6 lower left) were selected and placed on the selected virtual world of (Figure 6 lower right).

Figure 6: Drug trafficking scenario creation on VBS3 Game Engine

3. RESULTS AND DISCUSSION

The GIS layers were prepared from the ortho-rectification of satellite image of high resolution and topographic map for field survey. Consequently, twelve GIS layers were compiled in the geo-database to support the PSA for drug trafficking routes and training scenarios. The literature review of related research was conducted to emphasize the application of PSA for drug trafficking routes by integrating geospatial technology. It was found that the results of this project provided new findings, which employed the PSA principle and theory to analyze potential areas for drug trafficking routes coupled with the MCDA. Additionally, using AHP to configure the weighting and rating of factors, could incorporate tactics into intercepting and suppressing the drug trafficking. The extended sub-factors, including the significance and level of factors related to the interception and suppression of drug trafficking routes, were achieved through the meetings and discussions between researchers and representatives from relevant sectors of the Thai Government Agencies. Accordingly, the results from the PSA were divided into three parts: (i) factors and level of factors involved in drug trafficking routes, (ii) the score of significance and level of factors involved in drug trafficking routes, and (iii) the potential of drug trafficking area.

3.1. Geo-database Creation

Satellite images were processed for relief displacement and the resultant ortho-rectified images showed significant accuracy where random point generation means was applied to obtain forest stands at the spatial accuracy of approximately 72%. Attribute of the forest stand was populated further by plotting for forest inventory data. An expert group was consulted before, during, and after the forest survey of the study to validate while surveying the area for a safety reason of the survey team (see Figure7). The forest inventory was carried out on the high potential area of drug trafficking resulted from subsection 2.2.3. A 20m x 20m plot was for tree, shrub and forest in general. A 20m x 10m plot was for forest profile and density. A 5m x 5m plot was for trees at sapling stage and ground cover. And a 2m x 2m plot was for seedling to sapling. The forest inventory of the studied areas as shown on the Figure 7 lower inset was conferred to the forest department in Chiang Mai province.

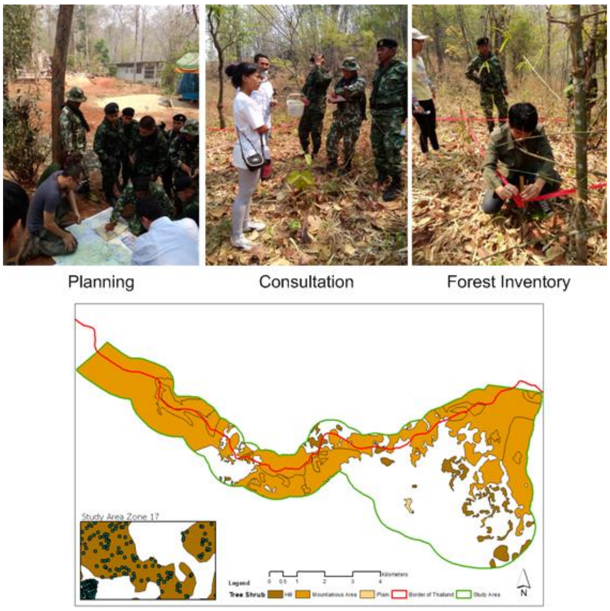

Figure 7: Planning, consultation and plotting for forest inventory data

3.2. Factors and sub-factors related drug trafficking

Fifteen experienced decision makers were designated both in command and field operation levels assigned from the Thai Government Agencies in Chiang Mai. There was an attentive issue found during the group discussions. Rank discrepancies among army officers suspected to have caused mute discussions were eliminated by allowing chances of writing documents to express relevant, straightforward and meaningful ideas. The factors and sub-factors categorized from the group discussion are shown in Table 6 and 7. Afterwards, the significance of each criterion and sub-criterion (scale of 1-9) was agreed from the decision makers mentioned above and pairwise comparison method was applied in order to acquire the relative weights of factors and sub-factors as seen in Table 6 and 7.

Table 6: Weights of factors related drug trafficking

Group of factor	Factor	Weight
1. Physical	Land use	2.37
	Road network	4.15
	Residential area	1.90
	Confidential	7.13
2. Drug	Drug production site[a]	4.72
	Transit site	6.63
	Drug SM	8.50
	Drug SR[b]	5.79
	Activities of MO[c]	10.86
	A number of information[d]	18.61
3.Socio-demographic	Trafficker's network	16.71
	Ethic group	12.62

[a]inneighboring country [b]Trafficking route [c]Military officers [d]received per month

Table 7: Weights of Sub-factors related drug trafficking

1. Physical Factors	Description	Weight
Land use	Field crop area	0.1521
	Horticultural crop area	0.2138
	Forest area	0.3641
	Urban area	0.1416
	Water area	0.0581
	Miscellaneous area	0.0703
Road network	Highway	0.1098
	Sub-pathway	0.3179
	Topographic pathway	0.5724
Residential area	Distance from urban area < 300 m	0.1667
	Distance from urban area > 300 m	0.8333
Confidential	Distance< 500 m from confidential	0.1667
	Distance > 500 m from confidential	0.8333
2. Drug Factors		
Drug production site[a]	Distance from drug production site <1 km	0.7500
	Distance from drug production site >1 km	0.2500
TS	Distance from transit site<1 km	0.8300
	Distance from transit site> 1km	0.1700
Drug SM	Motorbike	0.5500
	Pedestrian	0.3100
	Vehicle	0.1400
Drug SR	Outward border	0.1991
	Along border	0.6012
	Inward topographic pathway	0.1997

Table 7 (Cont'd)

Activities MO[c]	Reconnaissance	0.184
	Waylay	0.3327
	Check point	0.3938
	Blockade	0.0890
A number of information[d]	None	0.0355
	Less	0.0715
	Moderate	0.1367
	High	0.2425
	Very high	0.5138
3.Socio-demographic		
Trafficker's network	Distance	0.0807
	Nationality	0.2923
	Mutual interest	0.6270
Ethic group	Lahu	0.2475
	Lisu	0.1538
	Thai Yai (Shan)	0.1013
	Akha	0.0560
	Wa	0.2379
	Chin Haw	0.0684
	Kachin	0.0325
	Local Thai	0.0297
	Mixed group	0.0729

[a]in neighboring country [b]from border [c]from residential area [d]received per month

The relative weights of criteria and sub-criteria were confirmed reasonably as the CR value was lesser than 0.1.

3.3. PSA Modeling Drug Trafficking Routes

Drug trafficking routes were modeled and the results were explained regarding the physical and socio-demographic correlation of drug. In Figure 8, the high potential of drug trafficking routes was discovered on the eastern and central parts of the study area, referred to as route A and route B, respectively. The physical relation could be elaborated in that prior to crossing Thailand border, drug traffickers with distance from drug production site more than 1 km chose to use a pedestrian means to smuggle drug along a topographic pathway. Afterwards they smuggle drug toward and through Thailand border either by pedestrian or by motorbike along sub-pathway and the topographic pathway. These trafficking trips occurred at forest, field crop (rice and corn fields) and horticultural crop areas (mango, lychee, longan and rubber plantations) before transferring to designated transit sites with distance lesser than a kilometer. Furthermore, ethnic groups among trafficker's networks described socio-demographic aspects related to drug trafficking. Further explanation was that trafficker's network nationality outside Thailand of route A and B had no difference; on the other hand trafficker's network nationalities within the country were in two different ethnic groups. The distance of trafficker's network found in route A was shorter than in route B because in route A the distance

from production site outside Thailand to its ethnic group populated at transit site was short. In addition, the number of information that officers received per month showed insignificant impact on trafficking routes.
The predicted drug trafficking routes were validated using actual data of trafficking routes recorded in year 2015 by Thai Government Agencies in Chiang Mai. It was discovered that the study's predicted drug trafficking routes A and B were completely precise when trafficking routes were validated using actual data of trafficking routes. The high potential drug trafficking routes mentioned above were extracted from the GIS database and transferred into virtual world creation so as to create training scenarios of drug trafficking as explained in section 3.4.

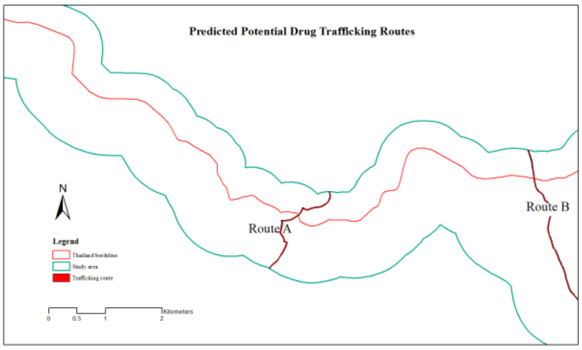

Figure 8: Potential Drug Trafficking Routes

3.4. Virtual World Creation

Figure 9: A visual comparison between a computer-generated image (left) and real photo (right)

Since the virtual world was created from GIS database used for modeling the terrain reality to the database with landscape features described in data attribute such as tree types and tree heights for 3D vegetation model selection, a comparable visualization on the computer-generated scene and photo taken from the landscape was visually validated in Figure 9. Slightly different viewpoints were selected for a comparison. Further studies and topics were discovered upon this comparison. Positional accuracy was achieved upon the placement of 3D models but attribute data representing the nature was difficult to resemble by a generic modeling tool. The study on specific modeling tool for tropical zone was urgently needed to fulfill the photorealistic weakness of the study.

3.5. Drug Trafficking Training Scenario

Figure 10: Workshop for VBS3-Milorange interface

Milorange® was the army simulator that played for test and host of the created drug trafficking training scenarios. A few workshops shown in Figure 10 were held to get the researchers accustomed to the interface whereby the basic shooting scenario was implemented and tested for technical validation when drug trafficking training scenarios were added on.

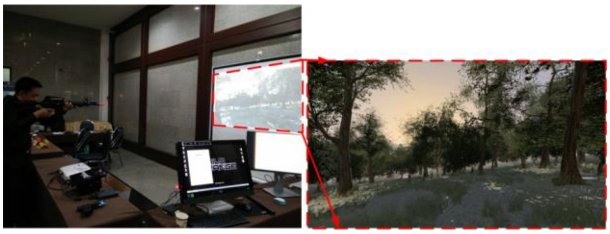

Figure 11: Technology demonstration for conceptual validation

One of the drug trafficking training scenarios was conceptually validated by the army officers in the annual Royal Thai Army Warrior indignity (see Figure 11). Several occasions were seen to have the research output demonstrated and high ranking commanders of the army were satisfied with the output. Various comments were received and promised to be present on further studies.

4. CONCLUSION AND FURTHER STUDIES

This article reports the original work of modeling drug trafficking using PSA to analyze the suitability map from the surveyed and collected GIS data layers. For GIS data collection, field survey was applied for the validation of the GIS layers digitized from the ortho-rectified image. AHP was the tool to calculate weights of factors and sub-factors related to the drug trafficking in order to rate the significance of the factors to one another. The Consistency Ratio (CR) of 0.0944 was achieved to confirm their acceptable consistency. Then, the GIS data layers were used to play host for PSA to find potential areas for the drug trafficking routes. The routes were adopted with relevant GIS data layers for creating the virtual world where the training scenario from direct experience was created for incorporating into the army simulator. It was concluded that the PSA was the right and profound method that was adopted to model the drug trafficking routes given the studied factors and sub-factors. Different steps either technical or conceptual validation were carried out in several formal events that comments were collected and input to the adopted methodology. The generated training scenarios for the purpose of incorporating into the existing simulator were widely and thoroughly accepted by the army. The project was such a success that it was further financially granted for its continuation.

By the time of this article's publication, the authors started to carry on with the project titled geo-database for military and security applications. With the widely accepted concept for GIS terrain modeling, unmanned aerial vehicles were embraced to help collect terrain data for the geo-database creation. Large scale geo-database was expected to help task force units in the northern part of Thailand on terrain analysis prior to mission execution. Training scenarios were extended to the Army Center of Aviation where photorealistic modeling of forested terrain was requested for its own version of helicopter simulator. Game Engine with extensive access to game builder community is currently under investigation to explore for a more open technology that the army can afford to employ and the research and development sectors can attain to the requirements.

ACKNOWLEDGMENTS

This research was funded by the Office of the Higher Education Commission, Thailand and Army Research Development Office, Royal Thai Army. The Authors would like to extend our appreciation to those military and police officers for their valuable and constructive suggestions. The Defence Technology Institute (Public Organization) is acknowledged for the co-researchers and the training scenario output from VBS3® Game Engine that was used to prove successful in incorporating Thailand's geo-specific training scenarios into the army simulator.

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