# TERRAIN ANALYSIS FOR PATH FINDING OF COMBAT CROSS-COUNTRY MOVEMENT

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**A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Geoinformatics**

**Suranaree University of Technology**

**Academic Year 2012**

# การวิเคราะห์ภูมิประเทศเพื่อค้นหาเส้นทางการเคลื่อนที่ของหน่วยรบ

**พันโทหญิงวัชราภรณ์  พิมพา**



**วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต**

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# TERRAIN ANALYSIS FOR PATH FINDING OF COMBAT CROSS-COUNTRY MOVEMENT

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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วัชราภรณ์ พิมพา : การวิเคราะห์ภูมิประเทศเพื่อค้นหาเส้นทางการเคลื่อนที่ของหน่วยรบ (TERRAIN ANALYSIS FOR PATH FINDING OF COMBAT CROSS-COUNTRY MOVEMENT) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร.ทรงกต ทศานนท์, 218 หน้า.

วัตถุประสงค์หลักของงานวิจัยชิ้นนี้คือ การพัฒนาระบบ การกำหนดเส้นทางแบบอัตโนมัติ (Cross-Country Movement for Combat Mobility: CCM4CM) ซึ่งได้ทำการสร้างแผนที่ CCM สำหรับการเคลื่อนที่ของหน่วยรบจากวิธีการของกองทัพบกสหรัฐอเมริกา และการประยุกต์กระบวนการค้นหาเส้นทางที่เลือกมา 2 แบบ ( BFS และ A-Star) ในการกำหนดเส้นทางที่สั้นที่สุดและที่ใช้เวลาเดินทางน้อยที่สุด ซึ่งเป็นประโยชน์สำหรับการวางแผนการปฏิบัติการทางทหาร พื้นที่ศึกษาคือ อ.แม่สอด จ.ตาก ซึ่งอยู่ทางทิศตะวันตกของประเทศไทย โดยการสร้างแผนที่ CCM จะเป็นไปตามเงื่อนไขที่แยกกันระหว่างฤดูแล้งและฤดูฝน ยานพาหนะที่เลือกมาศึกษาของแต่ละหน่วยรบคือ ทหารราบมาตรฐาน (กองทหารเดินเท้า) ทหารราบยานเกราะ (M113) ทหารราบยานยนต์ (M35 truck) ทหารม้ารถถัง (Stingray tank) ทหารม้ายานเกราะ (M113) ทหารม้าลาดตระเวน (Scorpion tank)

ในวัตถุประสงค์แรก แผนที่ CCM ของแต่ละหน่วยรบสร้างขึ้นจากปัจจัยหลัก 5 ปัจจัย ประกอบด้วย (1) ปัจจัยความเร็วต่อความชันของพื้นที่ ( Speed/slope factor) (2) ปัจจัยการเปลี่ยนแปลงของอาการลาด (Slope-intercept-frequency: SIF factor) (3) ปัจจัยพืชพรรณไม้ปกคลุมดิน (Vegetation factor) (4) ปัจจัยความสามารถในการรับน้ำหนักของดิน (Soil factor) และ (5) ปัจจัยความขรุขระของพื้นผิว (Surface roughness factor) ผลลัพธ์ของแผนที่ CCM บ่งชี้ว่าทหารราบมาตรฐานสามารถเคลื่อนที่ผ่านภูมิประเทศในทุกลักษณะได้เป็นอย่างดี ยกเว้นในเขตพื้นที่ผ่านไม่ได้ที่กำหนด (แหล่งน้ำผิวดิน) ส่วนยานพาหนะทุกชนิดที่เลือกมาศึกษา จะมีพื้นที่ผ่านได้กระจุกตัวอยู่ทางฝั่งตะวันตกของพื้นที่เป็นส่วนใหญ่ เนื่องจากเป็นเขตที่มีพื้นที่ค่อนข้างจะราบเรียบ ทำให้เหมาะสมต่อการเคลื่อนที่ในลักษณะของ CCM มากกว่าทางตอนกลางและฝั่งตะวันออก ซึ่งเป็นพื้นที่ภูเขามีความลาดชันสูง ทำให้เสี่ยงต่อการเกิดแผ่นดินถล่มมาก ดังนั้นจึงถูกจัดเป็นเขตผ่านไม่ได้ของทุกยานพาหนะที่กำหนด สำหรับเขตผ่านได้ช้าจะพบกระจายตัวอยู่ทั่วไประหว่างเขตผ่านได้และเขตผ่านไม่ได้ โดยทั่วไปพื้นที่เขตผ่านได้ของทุกยานพาหนะจะลดลงเป็นอย่างมากในช่วงฤดูฝนเมื่อเปรียบเทียบกับฤดูแล้ง โดยมักเปลี่ยนไปเป็นเขตผ่านได้ช้าแทน สำหรับยานพาหนะที่มีอัตราเร็วสูงสุดในที่นี้ คือรถถัง Scorpion (หากพิจารณาจาก ปัจจัยความเร็วต่อความชันของพื้นที่ที่มีค่าสูงสุด) ที่ 54.29 กม./ชม. รองลงไปคือรถถัง Stingray ที่ 46.0 กม./ชม. ทั้งนี้หากพิจารณาเฉพาะปริมาณของพื้นที่ผ่านได้ พบว่าในฤดูแล้งรถถัง Scorpion และ Stingray จะมี

ประสิทธิภาพในการเคลื่อนที่มากกว่ายานพาหนะแบบอื่นมาก แต่ในฤดูฝนรถถัง Scorpion จะทำได้ดีที่สุด ตามมาด้วยรถลำเลียงพลหุ้มเกราะ M113 นอกจากนั้นพบว่ารถบรรทุก M35 จะทำงานได้แย่ที่สุดในทั้งสองฤดูกาล

ในวัตถุประสงค์ที่สอง ระบบการกำหนดเส้นทางแบบอัตโนมัติ ได้รับการพัฒนาจากแผนที่ CCM ที่เกี่ยวข้องซึ่งได้จากวัตถุประสงค์ที่ 1 โดยเลือกวิธีการที่ทำงานได้ดีกว่าในการค้นหาเส้นทางระหว่างแบบจำลอง BFS และ A-Star ซึ่งผลการเปรียบเทียบระหว่าง 4 ดัชนีบ่งชี้ความสามารถคือ (1) ผลการค้นหาเส้นทาง (Completeness) (2) หน่วยความจำที่ใช้ในการประมวลผล (Space complexity) (3) เวลาที่ใช้ในการประมวลผล (Time complexity) และ (4) ความเหมาะสมของเส้นทางที่ได้จากการประมวลผล (Optimality) พบว่าระบบ A-Star และ BFS ต่างสามารถพบคำตอบตามหลักการทำงานของตนได้ อย่างไรก็ตาม A-Star สามารถทำงานได้ดีกว่า BFS ค่อนข้างมากในเรื่องของเวลาที่ใช้ในการประมวลผล และความถูกต้องของคำตอบในทุกกรณีที่เลือกมาศึกษา ในเรื่องของหน่วยความจำที่ใช้ในการทำงานยังไม่สามารถชี้ชัดได้ว่าระบบใดทำงานได้ดีกว่ากัน ดังนั้นจากการเปรียบเทียบผลลัพธ์ที่ได้ทั้งหมด ระบบ A-Star จึงถูกเลือกมาใช้ในการพัฒนาระบบการกำหนดเส้นทางแบบอัตโนมัติสำหรับใช้ประโยชน์ในกิจกรรมทางทหารต่อไป



สาขาวิชาการรับรู้จากระยะไกล ลายมือชื่อนักศึกษา ________________________

ปีการศึกษา 2555 ลายมือชื่ออาจารย์ที่ปรึกษา ____________________

ลายมือชื่ออาจารย์ที่ปรึกษาร่วม__________________

WATCHARAPORN PIMPA : TERRAIN ANALYSIS OF PATH FINDING OF COMBAT CROSS-COUNTRY MOVEMENT. THESIS ADVISOR : ASST. PROF. SONGKOT DASANANDA, Ph.D. 218 PP.

GIS/TERRAIN ANALYSIS/CROSS-COUNTRY MOVEMENT/A STAR SEARCH/ BREADTH FIRST SEARCH

The main objectives of this research are to develop the automatic path finding (Cross-Country Movement for Combat Mobility: CCM4CM) system operating on the CCM maps for combat mobility. The maps are derived based on the method of the US Army. The system applies the selected path finding algorithms (BFS and A-Star) to find the shortest and fastest paths that are useful for military operations planning. The whole area of Maesot District, Tak Province, in western Thailand was selected as the study area. The CCM maps were set separately between dry and wet seasons for all six concerned combat units, which are Standard Infantry (Foot troops), Armored Infantry (M113), Mechanized Infantry (M35 truck), Tank Cavalry (Stingray tank), Armored Cavalry (M113), Reconnaissance Cavalry (Scorpion tank).

In the first objective, the CCM maps for each relevant combat unit were derived as a product of five main factors F1 - F5 that represent key terrain and environmental characteristics of the study area: (1) F1, speed/slope factor; (2) F2, slope-intercept-frequency (SIF) factor; (3) F3, vegetation factor; (4) F4, soil factor; and (5) F5, surface roughness factor. The resulting CCM maps indicated that the standard infantry (foot troops) could move over most considered terrains well in both dry and wet seasons except over few specified No Go areas (water body). For all considered vehicles, their Go areas were mainly found on the western side of the district due to the rather flat terrain of the area that is suitable for the concerned CCM movement. On the other hand, the No Go areas notably situated in mountainous regions in the middle and eastern parts of the district due to the high surface slopes and the proneness to landsliding of the areas. In addition, the Slow Go areas were found distributed around and in-between the Go and No Go areas for most interested vehicles. The Go areas of all vehicles decreased dramatically from dry season to wet season and mostly turn into Slow Go areas. Among the four considered vehicles, the Scorpion tank could attain the highest moving speed (regarding the maximum F1 values) at about 54.29 km/hr, followed by the Stingray at 46.0 km/hr. Regarding the amount of the Go areas, in dry season, the Scorpion and Stingray tanks were far more effective on CCM activity than the other studied vehicles. But in the wet season, the Scorpion tank did best, followed by the M113. In addition, the M35 truck performs worst in both wet and dry seasons.

In the second objective, CCM4CM was created based on the associated CCM maps obtained from the first objective and the superior path finding algorithm between two candidates, the BFS and A-Star. Four specific details of their performances, or quality indices, were compared which are: (1) completeness; (2) space complexity; (3) time complexity; and (4) optimality. The obtained results indicate that both algorithms can find the solutions under their own procedures; however, the A-Star did much better than the BFS in terms of processing time and correctness of the solutions found in all cases under consideration, But in term while it is still uncertain of the used memory, which of the two is superior in terms of memory case. As a consequence, the A-Star was chosen to build the automatic path finding system for further use in the military services.

School of Remote Sensing Student's Signature______________________

Academic Year 2012 Advisor's Signature______________________

Co-advisor's Signature____________________

# ACKNOWLEDGEMENTS

First of all, I wish to express my sincere gratitude to my major advisor, Asst. Prof. Dr. Songkot Dasananda, and my co-advisor, Asst. Prof. Dr. Sunya Sarapirome, for their support, guidance, and valuable suggestions throughout this study. I would also like to thank Asst. Prof. Dr. Suwit Ongsomwang, a committee member, for his many useful comments on my work. And I wish to extend my special thanks to the other committee members, Assoc. Prof. Dr. Nittaya Kerdprasop, Dr. Dusdi Chanlikit and Col. Ravee Rojanawongse for their contributions to my study.

I would also like to thank the Royal Thai Survey Department and the 3rd army area for supporting the data needed for the research. Constant help and advice given by General Saprang Kallayanamittra, Col. Piyachart Soonyakanit, Col. Somsak Techasueb, Col. Chatree Sanguantham, Col. Attawoot Kiatiwat, Dr. Janjira Payakpate and Mr. Phonrob Sawasdee from the very early stage of this research till the end are also very much appreciated.

I would also like to thank the School of Remote Sensing, Institute of Science, Suranaree University of Technology, for giving me the opportunity to pursue a Ph.D. program in geoinformatics and to learn more about geoinformatics techniques which are useful for my work and duty in the future.

To complete the thesis, my thanks are also due to Dr. Apiradee Saravisutra, Mrs. Sirilak Tanang, Mr. Chat Phayungwiwatthanakoon, Mr. Prasit Mekarun, Mr. Satith

Sangpradid, Mr. Tinn Thirakultomorn and all friends at School of Remote Sensing, for their help and being good friends for long time.

Finally, my appreciation is devoted to my mother for giving me inspiration and her continuous love, care and support.

Watcharaporn Pimpa

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# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| A* | = | A-Star Search |
| AFV | = | Armored Fighting Vehicles |
| APC | = | Armored Personnel Carriers |
| BFS | = | Breadth First Search |
| CCM | = | Cross-Country Movement |
| CCM4CM | = | Cross-Country Movement for Combat Mobility |
| CFO | = | Complex Factor Overlay |
| CI | = | Cone Index |
| COO | = | Combined Obstacle Overlay |
| CU | = | Chulalongkorn University |
| DEM | = | Digital Elevation Model |
| DBH | = | Diameter at Breast Height |
| DFS | = | Depth First Search |
| DOH | = | Department of Highways |
| EAC | = | Echelons Above Corps |
| FM | = | Field Manual |
| GIS | = | Geographic Information Systems |
| IFV | = | Infantry Fighting Vehicles |
| IPB | = | Intelligence Preparation of the Battlefield |
| LULC | = | Land Use and Land Cover |

# LIST OF ABBREVIATIONS (Continued)

| | | |
|---|---|---|
| METT-T | = | Mission, Enemy, Terrain and weather, Troops and resources available, and Time and space restrictions |
| MNRE | = | Ministry of Natural Resources and Environment |
| MOA* | = | Multiple Objective A* algorithm |
| NATO | = | North Atlantic Treaty Organization |
| NIMA | = | National Imagery and Mapping Agency |
| NRMM | = | NATO Reference Mobility Model |
| OCOKA | = | Observation and fields of fire, Concealment and cover, Obstacles, Key terrain, Avenues of approach |
| RCI | = | Rating Cone Index |
| RI | = | Remolding Index |
| RTA | = | Royal Thai Army |
| RTSD | = | Royal Thai Survey Department |
| SD | = | Stem Diameter |
| SIF | = | Slope Intercept Frequency |
| SS | = | Stem Spacing |
| USCS | = | Unified Soil Classification System |
| USGS | = | United States Geological Survey |
| VCI | = | Vehicle Cone Index |

# CHAPTER I

# INTRODUCTION

## 1.1 Problem background

In the battle operation, one of the most important things that needs to be approved by the military leaders before making any strategic decisions is the terrain analysis of the battle field (usually known as the planning of war and military terrain analysis). This task is an integral part of the intelligence preparation of the battlefield (IPB) process which is a key role in any military operation planning. This is because terrain analyses can provide important information to assist intelligence operations, tactical decisions, and tactical operations of the preferred military campaigns.

One of the crucial tasks related to the terrain analysis is to find proper routes for the off-road movement of military personals and vehicles, called the "Cross-Country Movement" (CCM), based on the derived CCM map of the area. The CCM map is sometimes referred to as an avenue of approach map because it provides the best routes by which the vehicles can get to an objective when they cannot use prepared roads. It also shows parts of the terrain that these vehicles cannot cross which are important for the planning of military operations, especially, in the offensive strategy.

Typically, the entire process of finding suitable paths for the combat mobility (from source to destination) was done by military experts based on prior knowledge of the key terrain and environmental characteristics of the operating area. The crucial ones are soil properties, types of dominant vegetation cover, surface configuration, and surface roughness (US Army, 1990). However, this is usually a rather time consuming process as most working steps have to be done manually. Therefore, it is normally a very exhausting working process when being applied to vast and complex topography. In those circumstances, some analyzing tools to assist this kind of work are critically needed. At present, such tools can be produced very effectively by using the computer-based geographic information system (GIS) as a core component. Examples of their developments and fruitful applications to the CCM mapping and path finding analysis for the assumed military operations are shown in this thesis. In the path finding part, two popular searching algorithms, Breadth First Search (BFS) and A-Star (A*) Search were considered in details.

In this work, the GIS-based models have been constructed and implemented to generate the preferred CCM maps and evaluate proper CCM paths for some specified army vehicles (under given requirements) in Maesot District, Tak Province. This area is situated close to the Myanmar border and is considered as an important strategic location under supervision of the 3rd Army Area due to the unresolved territory conflicts with Myanmar and the military operations of some ethnic minorities residing within the Myanmar border. The highly complex and difficult landscape of the area can lead to an exhausted terrain analysis carried out by the responsible agency. As a result, the proposed models in this study might be a valuable tool to assist its work in the future.

## 1.2 Research objectives

1.2.1 To create CCM maps for combat mobility using reclassified GIS data.

1.2.2 To develop application of suitable path finding to combat mobility in the military operations based on shortest and fastest paths.

## 1.3 Scope and limitations

1.3.1 Relevant cost of the movements (e.g. safety, fuel usage, expenditure) along the preferred shortest and fastest paths is not included in path finding analysis (to determine suitable paths).

1.3.2 Only main vehicles of each specified combat unit (infantry and cavalry) are considered.

## 1.4 Benefit of the study

1.4.1 Essential GIS dataset for CCM-based military terrain analysis.

1.4.2 Effective CCM maps for combat mobility in the study area.

1.4.3 Effective path finding analysis model (under given criteria) for the use in the study area.

## 1.5 Study area

The chosen study area is Maesot District in Tak Province, western Thailand (Figures 1.1 and 1.2). Maesot is a well-known area located close to Myanmar border which is notable as being a trade hub and for its substantial population of Burmese migrants and refugees. And as a main gateway between Thailand and Myanmar, it has gained notorious reputation for being center of the black market services such as labor and drug trafficking which cause a new kind of threaten problem to the country.

The district comprises of 10 tambon (or sub-districts): Maesot, Maeku, Phawo, Maetao, Maekasa, Thasailuat, Phrathatphadaeng, Danmaelamao, Mahawan, and Maepa, covering area of about 1,986.12 km$^2$ with total population of about 118,721 in 2009 (Tak Province, 2012). The climate is monsoonal where a heavy rainfall normally occurs during monsoon season (May - October) and the rest of year is relatively dry. The highest amounts of measured rainfall in average are 353.5 mm in August and 305.2 mm in July (for 1961 - 1990 period). During summer (March - April), daytime maximum temperatures can reach 35 - 36$^{o}$C in average but during winter (December-February) the minimum temperatures might drop to be about 15 - 16$^{o}$C in average over the same 30-year period (Thai Meteorological Department, 2012).

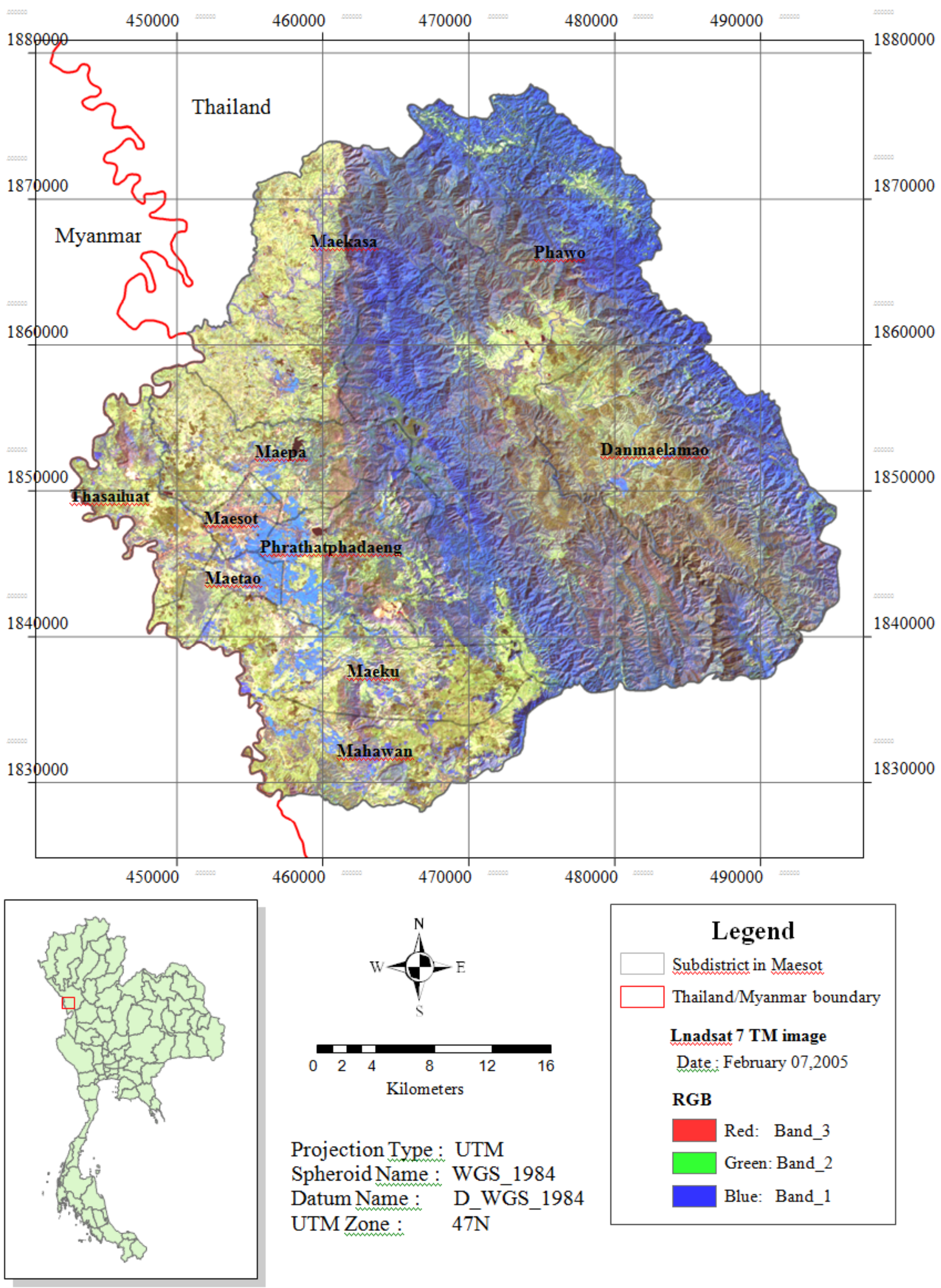



**Figure 1.1** Location map of the study area (Maesot District, Tak Province).

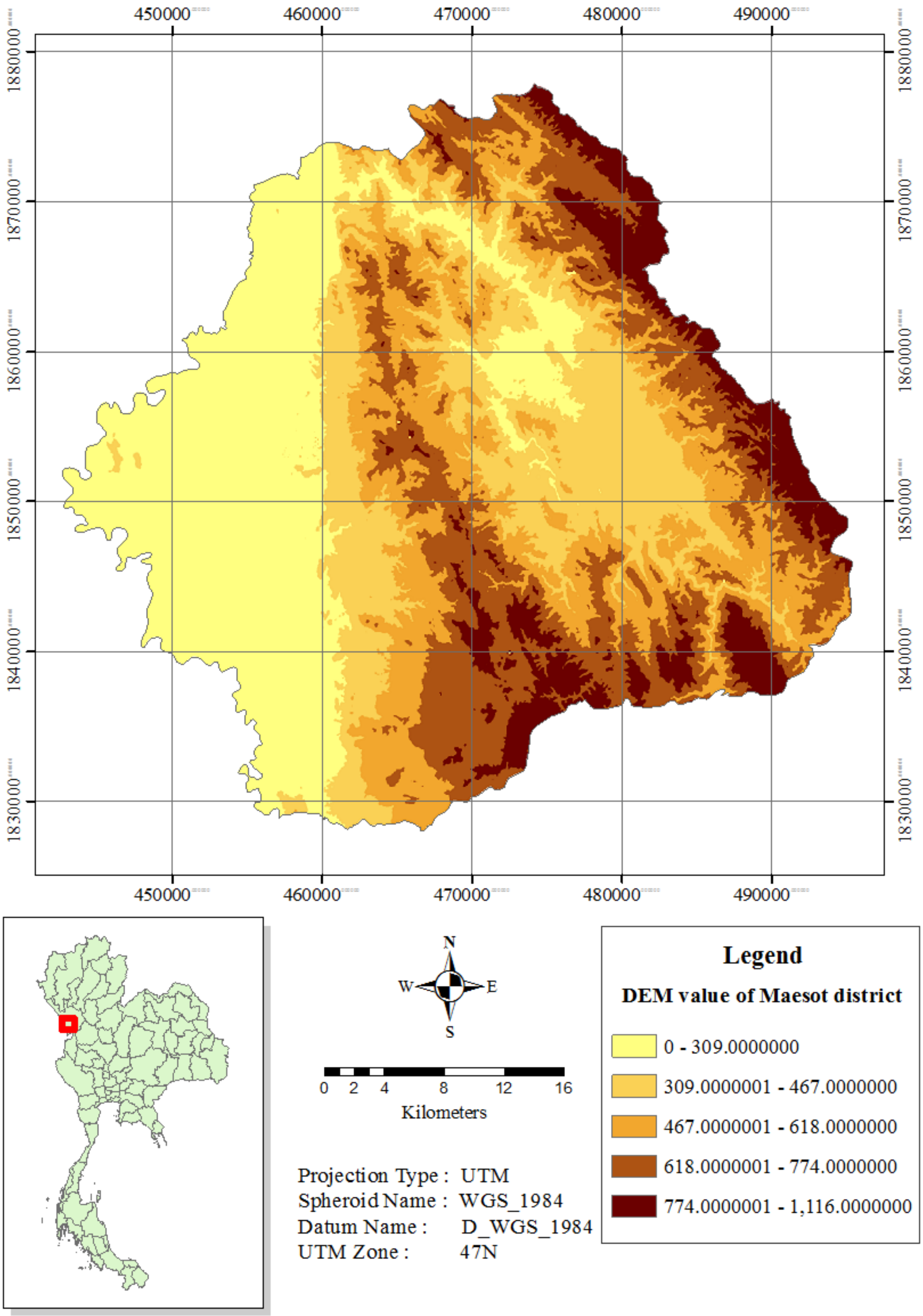



**Figure 1.2** Digital Elevation Model (DEM) of the study area.

# CHAPTER II

# LITERATURE REVIEW

This chapter provides fundamental knowledge of the military terrain analysis, the cross-country movement (CCM) analysis, and also working principles of the two preferred searching algorithms: the breadth first search (BFS) and the A-Star (A*). Review of some works relevant to these topics is also presented.

## 2.1 Mobility and terrain analysis

Mobility is defined, in military terms, as those activities that enable a force to move personnel and equipment on the battlefield without delays due to encountered terrain or obstacles (US Army, 1985). Knowledge of mobility information is crucial for the decision-making process of the military commander to determine best course of further action. In general, possible courses of action are first studied and analyzed by the responsible staffs before presenting them to their commanders for approval and action. Areas of staff input for completing this process normally include:

(1) Military intelligence (enemy activity, terrain and weather);

(2) Intelligence preparation of the battlefield (IPB);

(3) Operations (tactical maneuver, fire support, and engineer support);

(4) Administration/logistics (personnel and combat service support activities); and

(5) Civil affairs.

**Terrain analysis**

In the initial stage of the formal mobility planning, an information search and analysis is performed based on factors of mission, enemy, terrain and weather, troops and resources available, and time/space restrictions (METT-T). The terrain analysis is regarded as being crucial part of the intelligence preparation of the battlefield (IPB) process. It plays key role in any military operation planning as it can provide database for intelligence operations, tactical decisions and operations, and support for the planning and execution of military-related operations. One of major applications of the military terrain analysis is to facilitate a tactical maneuver plan like constructing the cross-country movement (CCM) overlay (US Army, 1985).

According to Shoop (1993), terrain includes two main parts; (1) material that comprises the terrain (e.g. soil, snow, vegetation) itself, and (2) geometry of the terrain surface (topography). In term of vehicle movement, the terrain's ability to support and provide traction for the movement is called trafficability. Trafficability is part of the vehicle's mobility study but its emphasis is mainly on interaction between a specific vehicle and a given surface material, whereas mobility study shall consider the entire effects of the terrain on vehicle's movement, including obstacles and topography.

The interested military terrain database is usually composed of information on existing terrain of tactical military significance within a given area. When in use, this information will be placed on the transparent overlays to highlight different terrain mobility factors. The usual factor overlays are as follows (US Army, 1985):

**Transportation factor overlay;** this includes selected roads, bridges, tunnels, ferries, railroads, and airfields over which the relevant troops and supplies can move effectively during a military operation.

**Obstacles factor overlay;** this includes both natural/artificial terrain features which can hinder military movement. Obstacles may be escarpments, embankments, hydrologic features, or depressions.

**Water resources factor overlay;** this includes water resources, like wells, springs, or groundwater, which may be found in the area. This overlay is made only for arid or desert areas of the world.

**Surface configuration factor overlay;** this depicts categories of the surface slope in combinations from 0 - 45 percent and open water.

**Vegetation factor overlay;** this details all information about vegetation of an area, including type and height of vegetation, canopy closure (percentage of ground covered by the tree crowns), undergrowth (vegetation between the canopy and above the ground), vegetation roughness factor (an estimate of the degree of degradation of vehicle speed through a type of vegetation on level ground), and stem diameter/ tree spacing/vegetation roughness table.

**Surface materials factor overlay;** this often limits to those materials which are significant to the military operations mainly, including soil types (according to the Unified Soils Classification System: USCS), depth of surface material, soil moisture, potential landslide areas, and the surface roughness factors (similar to the vegetation roughness factor, but for a vehicle traveling over level ground and being influenced by the ground conditions).

**Surface drainage factor overlay;** this includes shorelines, offshore islands, large rivers, and lakes. Information on width, depth, velocity, bank heights and slopes, bottom materials, dams, fords, and locks is given for each feature.

Figure 2.1 shows the data flow in a classic terrain analysis procedure. As seen in Figure 2.1, the typical terrain analysis begins with the accumulation of crucial data for the operation which are raw associated terrain data extracted from source imagery (e.g. aerial photos or satellite images), maps (e.g. topographic map), or literature, and field data collected during on-site inspections. These acquired data are then analyzed and reduced to a set of terrain factor products capturing important terrain features and classifications. The next step in the process is to combine these products with the empirical and doctrinal evidence to make complex products associated to activities of the military interest (e.g. the river crossing or cross-country movement).

For example, the cross-country movement shall take several terrain factors such as slope, landform, surface roughness, vegetation, and soils into the analytical models which capture capabilities of specific vehicle (usually empirically derived), to produce maximum vehicle speed in a given area and display in form of the CCM map. For maneuver-like activities, hospitability provides a measure of the support a given local area provides for a given activity (Kastella, Kreucher, and Pagels, 2000).

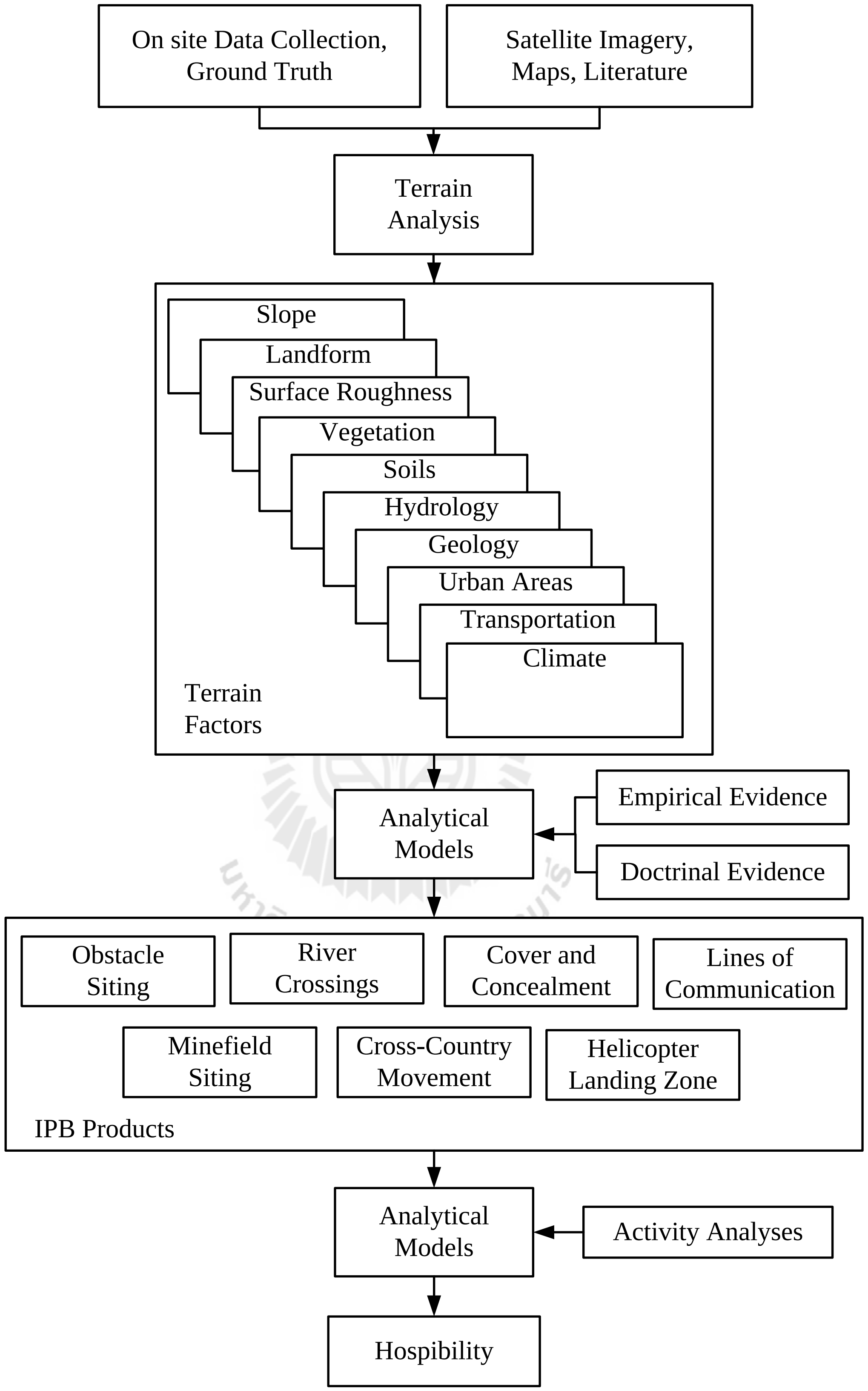



**Figure 2.1** Typical data flow diagram in a classic terrain analysis procedure.

**From:** Kastella et al. (2000).

## 2.2 Cross-country movement analysis

As stated earlier, one of the crucial tasks linked to the military terrain analysis is to find proper routes for the off-road movement of military personals and vehicles called the cross-country movement (CCM). The CCM map is sometimes referred to as an avenue-of-approach map because it portrays the capable paths by which various military vehicles can access to a specific destination when they cannot use the normal roads (off-road movement). It also shows parts of the associated terrain that these vehicles cannot cross. Most details of the CCM analysis described here are concluded from the standard US Field Manual: FM 5-33 (Terrain Analysis) (US Army, 1990).

**Table 2.1** Categories of speeds and their relevant CCM map units.

| Speeds (kph) | Basic descriptor | CCM Map Unit |
|---|---|---|
| > 30 | Go | 1 |
| > 15 - 30 | Restricted Go | 2 |
| > 5 - 15 | Slow Go | 3 |
| > 1.5 - 5 | Very Slow Go | 4 |
| ≤ 1.5 | No Go | 5 |
| - | No Go (Open water) | 6 |
| - | No Go (Built-up area) | 7 |

**Note**: kph = kilometers per hour

**From**: US Army (1990).

According to the US Army's manual on terrain analysis (US Army, 1990), the CCM map can be divided into 7 basic units of terrain based on the potential traveling speeds of the concerned vehicle type or troop unit, which are (see Table 2.1 for more information): (1) Go, (2) Restricted Go, (3) Slow Go, (4) Very Slow Go, (5) No Go, (6) No Go (Open water), (7) Excluded (Built-up area).

These traveling speeds (V) can be found directly from following relationship:

$$V\ (kph) = F1 \times F2 \times F3 \times F4_{D/W} \times F5. \qquad (2.1)$$

Terms F1 to F5 represent the key terrain and environmental characteristics of the area that can influence speeds of the travelling vehicles or troops as follows:

(1) F1 is slope factor as it determines the extent that any slope will deteriorate the vehicle's speed without consideration for any other physical factor;

(2) F2 is slope-intercept-frequency (SIF) factor. SIF is the number of times the ground surface changes between positive and negative slopes over a 1km distance;

(3) F3 is vegetation factor that determine impact of the vegetation density and distributing pattern on the mobility of vehicle's movement;

(4) F4 is soil factor that informs impact of the soil characteristics on vehicle's mobility. The analysis is normally separated into wet (W) and dry (D) conditions; and

(5) F5 is Surface roughness factor that depends on the surface materials.

The F2 - F5 factors have been typically set to have values between 0 - 1 only. More details on the determination of the F1 - F5 terms are as follows (and also stated in Chapter 3 about the research methodology).

### 2.2.1 Determination of the slope factor (F1) and SIF factor (F2)

The first two factors, F1 and F2, in Eq. 2.1 show impact of topography aspect on the CCM analysis. The slope factor (F1) was computed from the following equation:

$$F1\,(\text{kph}) = \frac{\text{Max off-road gradability (\%)} - \text{Surface slope (\%)}}{\text{Max on-road gradability (\%)}} \text{ x Max road speed (kph)}, \quad (2.2)$$

where Max = Maximum. Principally, the F1 factor indicates the extent that any slope will deteriorate speed of a given vehicle without consideration for any other physical factor. It also represents the maximum off-road speed for a vehicle if running on flat terrain (surface slope = 0).

The slope-intercept-frequency factor (SIF) is the number of times that ground surface changes between positive and negative slopes over a 1 km distance. And, as guided by the US Army (1990), the F2 value can be calculated as follows:

$$F2 = \frac{280 - \text{SIF count (adjusted)}}{280}, \quad (2.3)$$

where F2 is slope-intercept-frequency factor. However, measuring the SIF value on the topographic map, or in the field, is usually still an extremely time-consuming task.

### 2.2.2 Determination of the vegetation factor (F3)

The vegetation factor (F3) indicates impact of vegetation characteristics (type, density, or distributing pattern) on the mobility of vehicle movement. This term can be found from the following formula (using the larger value of V1 or V2):

$$F3 = V_R \text{ x } \max(V_1, V_2), \quad (2.4a)$$

$$V_1 = V_F \text{ x } V_C;\ V_C = \frac{SS - SD}{W}, \quad (2.4b)$$

$$V_2 = 1 - \left[ V_T \text{ x } \frac{SD^2}{OD^2} \right]; \; V_T = \frac{(W + SD)}{SS}, \tag{2.4c}$$

where $V_R$ is the vegetation roughness factor, $V_F$ is the vehicle factor, SS and SD are stem spacing and stem diameter, W is vehicle width, OD is override diameter of the vehicle. Note that, stem spacing is the distance from the center of one tree to the center of the nearest adjacent tree. The easiest and fastest method to determine stem spacing is to measure directly from photograph and convert it to ground distance (in meters). The tree stem diameter is diameter of a tree at 1.4 meters (4.5 feet) above the ground. This measurement is also referred to as diameter at breast height (DBH).

In general, if values of SS or SD are not available (for the non-forest types), the F3 is approximated from relation: F3 = $V_R$ (no need for the calculation of $V_1$ or $V_2$). The $V_1$ factor is product of two terms: the vehicle factor ($V_F$) and the vehicle clearance factor ($V_C$). The $V_F$ accounts for the response of drivers when approaching wooded areas while the $V_C$ accounts for the physical ability of a vehicle to maneuver between tree stems in wooded area. If $V_C \leq 1$ then $V_1 = 0$. As $V_1$ must be between 0 - 1, therefore, if $V_1 \leq 0$ then $V_1 = 0$ and if $V_1 \geq 1$ then $V_1 = 1$. Also, if $V_2 \leq 0$ then $V_2 = 0$. In conclusion, to keep F3 varying between 0 to 1, if F3 ≥ 1 then F3 = 1 and if F3 ≤ 0 then F3 = 0 (No Go).

In addition, the $V_2$ factor is used if it would be easier for the vehicle to override the trees rather than maneuver between them (as accounted for by the V1 factor). The $V_T$ portion of the formula is used to calculate minimum number of trees a vehicle can hit at one time. If $V_T \leq 1$ then $V_T = 1$ and if SD > OD then $V_2 = 0$

F3 factor indicates impact of the vegetation on the CCM analysis. In general, plant cover can greatly affect military tactics, decisions, and operations, especially on the evaluation of concealment and CCM obstruction. Types of the vegetation are also useful indication of the climate, soil, drainage, and water supply condition of the area. Types of the vegetation that are typically of most interest to the terrain analysts are trees, scrubs and shrubs, grasses, and crops as they can become serious obstacle to the free passage of vehicle (or troop) or, on the contrary, can provide good concealment or convenient passage (under some conditions). For example, dense pack of the large trees can provide good cover and concealment for the military movement but it also can greatly hinder movement of the vehicles due to the narrow spaces between these trees. However, field of small trees, or scrubs, can be sometimes pushed over by the tanks; but the resulting pileup of vegetation may stop their movement eventually. In general, the pileup effect from pushing over vegetation is greater for wheeled vehicles than for tanks (tracked vehicles). For grass, it often improves the trafficability of soils and relatively tall grass may provide good concealment for foot troops. However, foot movement in savannah grasslands is often slow and tiring while vehicular movement is much easier but fairly visible from the air. Grain crops on flat terrain may improve trafficability of the soils if their areas are not flooded, while others, like the vineyard, can be great obstacles to the vehicles/troops due to their complicated structures. The vegetation map code of the US Army is detailed in Table 2.2 (US Army, 1990).

**Table 2.2** Vegetation map code.

| MAP UNIT CODE | TYPE |
|---|---|
| A1 | Agriculture (dry crops) |
| A2 | Agriculture (wet crops, rice) |
| A3 | Agriculture (terraced crops, both wet and dry) |
| A4 | Agriculture (shifting cultivation) |
| B1 | Brushland (< 5m high, open to medium spacing) |
| B2 | Brushland (< 5m high, medium to dense spacing) |
| C* | Coniferous/Evergreen Forest |
| D* | Deciduous Forest |
| E* | Mixed Forest (Coniferous/ Deciduous) |
| F* | Orchard/Plantation (rubber, palm, fruit, etc.) |
| G1 | Grassland, Pasture, Meadow |
| G2 | Grassland with Scattered Trees, some Scrub Growth |
| H | Forest Clearing (cutover areas, burns, etc.) |
| I** | Swamp (mangrove, cypress, etc.) |
| J | Marsh/Bog (treeless bogs, muskegs, etc.) |
| K | Wetlands (L.S.I., low-lying wet areas) |
| L | Vineyards/Hops |
| M | Bamboo |
| N | Bare Ground |
| W | Open Water |
| X | Built-up Area |

* These vegetation types are given a three digit map unit code. In addition to the letter for the type code, a second digit (number) is added as the canopy closure code, and a third digit (number) is added as the height code. See canopy closure (%), Height (meters), and example below.
** A second digit, representing canopy closure, is added to the swamp code.

**From:** US Army (1990).

### 2.2.3 Determination of the soil factor (F4)

The soil factor informs impact of soil characteristics on vehicle's trafficability over the terrain. The analysis is usually concentrated on determining capability of soil strength to support a specific vehicle's movement under two common conditions, dry (D) and wet (W). The corresponding dry-soil factor ($F4_D$) and wet-soil factor ($F4_W$) mentioned above can be computed as follows:

$$F4_{D/W} = \frac{RCI_{D/W} - VCI_1}{VCI_{50} - VCI_1}, \tag{2.5}$$

where RCI is the rating cone index widely used to represent proportion of the original soil strength being retained after the specified vehicles have passed over the area; the larger the RCI, the stronger the soil. VCI is the vehicle cone index which is a value assigned to a given vehicle for a given number of its passes. The US Army has used the VCI for many years as a performance indicator of the referred vehicles to traverse over soft-soil terrain [see US Army (1963) or Pual (1985) for examples].

The VCI is usually defined as the minimum soil strength necessary for the self-propelled vehicle to consistently conduct a given number of passes in track without going immobilized. Usual tests are focused on measuring minimum soil strength that is required to make 1 or 50 passes for a specific vehicle (called $VCI_1$ and $VCI_{50}$), respectively (US Army, 1994; Priddy and Willoughby, 2006).

The RCI is an on-site or estimated value of the soil strength derived from the product of cone index (CI) and the remolding index (RI). The cone index indicates the shearing resistance of soil measured by a device called the cone penetrometer and the remolding index is a ratio that expresses proportion of the original soil strength that will be retained by a fine-grained soil, or sand with fines, poorly drained, after being subjected to vehicular traffic. Because strength of fine-grained soils (silts and clays) may increase (or decrease) when loaded or disturbed, remolding tests are necessary to measure any expected loss of soil strength after traffic. Hence, the fine-grained soil CI multiplied by the RI produces the rating cone index (RCI) which represents the soil strength that is corrected for remolding (US Army, 1994). RCI depends mainly on type of soils and its humidity in % as seen in Figure 2.2 for the soil types described in the Unified Soil Classification System (USCS). More comprehensive details of the VCI and RCI calculations and measurements are given in, for examples; Shoop (1993), US Army (1994), Ciobotaru (2009), and Nam, Park, and Kim (2010).

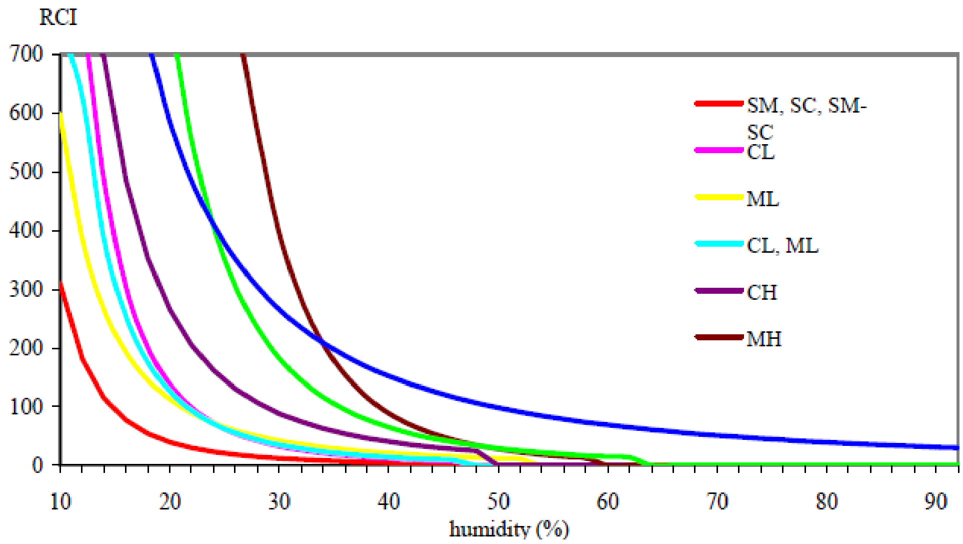



**Figure 2.2** Variation of the Rated Cone Index versus soil humidity.

**From:** Ciobotaru (2009).

Comparison of the RCI with the VCI indicates whether the vehicle can travel through the given soil condition for a prescribed number of passes. In general, if the VCI (of a vehicle) for the interested soil layer exceeds its corresponding RCI, that soil is not trafficable for the specified number of passes (e.g. 1 or 50) of that particular vehicle; otherwise the soil is considered trafficable under the described circumstances. For example, if soil has the RCI value of 30, therefore, it is not trafficable for vehicles with VCI values greater than 30 (at a given number of passes). The F4 values can be calculated directly from Eq. 2.5 using relevant data of the used vehicles presented in Table 3.4 (VCI) and 3.8 (RCI) in Chapter 3. Note that, if F4 $\geq$ 1 then F4 = 1 and if F4 $\leq$ 0 then F4 = 0 (No Go).

**Unified Soil Classification System (USCS) and soil trafficability**

As described in the US Army Field Manual: FM 5-33 (Terrain Analysis), the Unified Soil Classification System (USCS) is a soil classification system commonly used in engineering and geology work to describe texture and grain size of a soil. The USCS works by identifying soils according to their textural and plasticity qualities and on their grouping with respect to behavior. The two-letter abbreviations are used to separate soils into different groups according to characteristics where the primary letter identifies the dominant soil fraction and the secondary letter further describes property of that soil fraction. Information on percent of the gravel, sand, inorganic clay, inorganic silt, and organic silt and clay in the referred soil is used to identify the primary letter mentioned earlier (see Tables 2.3 and 2.4 Figure 2.3 for more details). A comprehensive description of the USCS is available in the US Army Field Manual: FM 5-472 (Materials Testing) (US Army, 1999).

In nature, pure soil type is rarely found but mixed soil type is more prevalent with various proportions of the associated mixture. In term of trafficability, gravel has strong structure which can provide excellent traction for tracked vehicles; however, if not mixed with other soil, its loose composition may roll under pressure, hampering movement of the wheeled vehicles. Sand consists of small rock grains and can give excellent trafficability if wet enough to become compacted or being mixed with clay. However, very dry and loose sand is usually an obstacle to the vehicle's movement, particularly on slopes. For silt, it can provide excellent trafficability in dry condition (although very dusty). However, it can absorb water very quickly and become a deep, soft mud which is a definite obstacle to the vehicle's movement. Clay consists of microscopic particles and, like silt, it can support excellent trafficability if thoroughly dry but as it becomes sticky and slippery under wet condition which is rather difficult for the traffic. Usually, organic matter has relatively loose structure which makes high-ground-pressure vehicles able to travel only a few passes before they break through and become immobilized. Wheeled vehicles usually cannot travel on most of these organic-soil areas. Cone indices denote the relative strength of organic soils. However, the soil-strength vehicle performance relations or organic soils are not as well defined as for fine-grained and coarse-grained soils (US Army, 1990; 1994).

A dry season is time when climatic and vegetation factors combine to produce low soil moistures. In this season, fine-grained soils and remoldable sands of any type are often trafficable and with higher trafficability than dry, coarse-grained soils, in general. Also, the trafficability of dry, coarse-grained soils is usually poorer than that of all wet, coarse-grained soils except quicksand. A wet season is time when weather conditions combine to produce high soil moistures. In temperate, humid climates, the wet season extends from about the first of November to the first of May. High soil moisture normally results from frequent rainfall events but melting of the snow and thawing of previously frozen soils may also generate wet soil conditions. Most soil types have less strength in wet season than in dry season due to gained soil moisture; however, the effect may differ with different soil types (US Army, 1990; 1994).

**Table 2.3** Two-letter abbreviations in the USCS system.

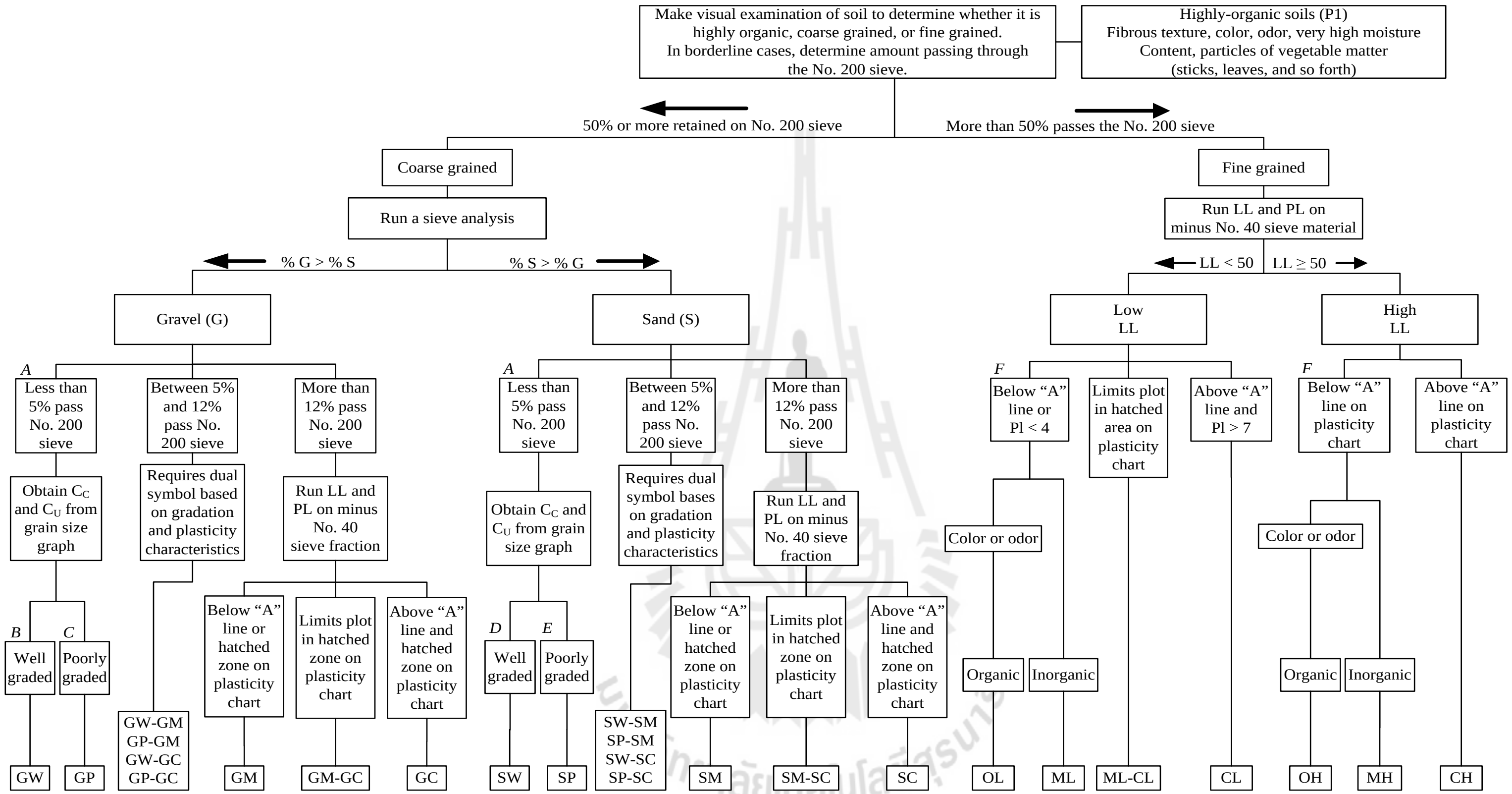
| Major type | Primary letters | | Secondary letters | |
|---|---|---|---|---|
| Coarse-grained soil | G | Gravel/Gravelly soil | W | Well graded (with little or no fines) |
| | | | P | Poorly graded (with little or no fines) |
| | S | Sand/Sandy soil | M | Coarse material with nonplastic fines or fines with low plasticity |
| | | | C | Coarse material with plastic fines |
| Fine-grained soil | C | Inorganic clay | L | Low compressibility |
| | M | Inorganic silt | H | High Compressibility |
| | O | Organic silt and clay | - | - |

**From:** US Army (1999).

**Table 2.4** Principal classified soil types in the USCA.

| Major Divisions | | | Group Symbol | Typical Names |
|---|---|---|---|---|
| **Course-Grained Soils** More than 50% retained on the No. 200 sieve | **Gravels** 50% or more of course fraction retained on the No. 4 sieve | Clean Gravels | **GW** | Well-graded gravels and gravel-sand mixtures. little or no fines |
| | | | **GP** | Poorly graded gravels and gravel-sand mixtures, little or no fines |
| | | Gravels with Fines | **GM** | Silty gravels, gravel-sand-silt mixtures |
| | | | **GC** | Clayey gravels, gravel-sand-clay mixtures |
| | **Sands** 50% or more of course fraction passes the No. 4 sieve | Clean Sands | **SW** | Well-graded sands and gravelly sands, little or no fines |
| | | | **SP** | Poorly graded sands and gravelly sands, little or no fines |
| | | Sands with Fines | **SM** | Silt sands, sand-silt mixtures |
| | | | **SC** | Clayey sands, sand-clay mixtures |
| **Fine-grained soils** More than 50% passes the No. 200 sieve | **Silts and Clays** Liquid Limit 50% or less | | **ML** | Inorganic silts, very fine sands, rock four, silty or clayey fine sands |
| | | | **CL** | Inorganic clays of low to medium plasticity, gravelly/sandy/silty/lean clays |
| | | | **OL** | Organic silts and organic silty clays of low plasticity |
| | **Silts and Clays** Liquid Limit greater than 50% | | **MH** | Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts |
| | | | **CH** | Inorganic clays or high plasticity, fat clays |
| | | | **OH** | Organic clays of medium to high plasticity |
| **Highly Organic Soils** | | | **PT** | Peat, muck, and other highly organic soils |

**From:** ASTM (2012).




A If fines interfere with tree-draining properties, use a double symbol such as GW-GM,

B For well-graded gravel, the $C_U$ must be > 4 and the $C_C$ must be ≥ 1 and ≤ 3,

C For poorly graded gravel, the $C_U$ must be ≤ 4 and/or the $C_C$ is < 1 or >3,

D For well graded sand, the $C_U$ must be > 6 and the $C_C$ must be ≥ 1 and ≤ 3,

E For poorly graded sand, the $C_U$ must be ≤ 6 and/or the $C_C$ is <1 or >3,

F In cases where organic material can't be determined by color or odor, a LL and PL test must be conducted on a sample of nature moisture content and sample that has been oven-dried. Organic soils will show a radical drop in plasticity for the oven-dried sample compared to the retained-moisture sample. Inorganic soils generally fall within + 1 or 2 percent of each other.

**Figure 2.3** The Unified Soil Classification System (USCS).

**From:** US Army (1990).

### 2.2.4 Determination of the surface roughness factor (F5)

The surface roughness factor is used to compute effect of surface characteristics (like surface roughness or slope stability) on the vehicle movement. Its values depend on associated surface materials where lower value indicates higher impact on vehicle trafficability over that referred surface. The values are tailored for each specific job by listing only those features encountered. Influence of the surface roughness, which is an aspect of the surface materials (e.g. boulder fields, gullies, and rugged bedrock) which reduces vehicle speed, is normally represented by numbers from 0.00 to 1.00 in 0.05 increment. The surface roughness factor of 1.00 for a vehicle class indicate no degradation of land trafficability while a 0.80 factor, for example, would degrade vehicle speed by 20 percent (US Army, 1990).

In estimating the magnitude of this factor, all physical characteristics of the land surface as well as the vehicle characteristics (such as ground clearance and wheel size) must be considered. The surface roughness is classified for five types of the movement categories: medium or large tanks, large wheeled vehicles, small wheeled vehicles, small tracked vehicles, and foot troops. The surface roughness factors often vary from one vehicle class to another and their values are given as a code (for each movement type) in the third digit of the used soil layer map as seen, for example, in Tables 2.5 and 2.6. Information of the vegetation classification used by the RTSD Map Center [as described in RTSD Map Center (1997)] is given in Appendix A.

**Table 2.5** Surface material legends (first two digits).

| SOIL TYPE<br>MAP UNIT (1ST TWO DIGITS) | DESCRIPTION |
|---|---|
| GW | Well-graded gravels and gravel-sand mixtures, little or no fines. |
| GP | Poorly graded gravels or gravel-sand mixtures, little or no fines. |
| GM | Silty gravels, gravel-sand-silt mixtures. |
| GC | Clayey gravels, gravel-sand-clay mixtures. |
| SW | Well-graded sand, gravelly sands, little or no fines. |
| SP | Poorly graded sands or gravelly sands, little or no fines. |
| SM | Silty sands, sand-silt mixtures. |
| SC | Clayey sands, sand-clay mixtures. |
| ML | Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity. |
| CL | Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, iron clays. |
| OL | Organic silts and organic silty clays of low plasticity. |
| MH | Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts. |
| CH | Inorganic clays of high plasticity, fat clays. |
| OH | Organic clays of medium to high plasticity, organic silts. |
| PT | Peat and other highly organic soils. |
| RK | Rock outcrops. |
| EV | Evaporites. |
| X | Not evaluated. |
| PS | Permanent snowfields. |
| W | Open water. |

**From:** US Army (1990).

**Table 2.6** Surface material legends (third digits).

| SURFACE ROUGHNESS | | ESTIMATED SURFACE ROUGHNESS FACTORS * | | | | |
|---|---|---|---|---|---|---|
| **MAP UNIT (3RD DIGIT)** | **DESCRIPTION** | **MEDIUM & LARGE TANKS** | **LARGE WHEELED VEHICLES** | **SMALL WHEELED VEHICLES** | **SMALL TRACKED VEHICLES** | **FOOT TROOPS** |
| 0 | No Data | – | – | – | – | – |
| 1 | No surface roughness effect | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 2 | Area of high landslide potential | .00 | .00 | .00 | .00 | .00 |
| 3 | Stony soil with scattered surface rock | .90 | .90 | .80 | .85 | .95 |
| 4 | Quarry | .05 | .05 | .05 | .05 | .75 |

* Surface roughness factors are indicated with 0.00 having maximum and 1.00 having least impact on CCM.

SOIL DEPTHS
_______ < .5 meters

SOIL MOISTURE
……….. Soil normally moist
Soil normally wet

Example: Map unit SC3 = Clayey sands, sand-clay mixtures, stony with scattered Surface rock, normally moist, depth < .5 meters

**From:** US Army (1990).

### 2.2.5 GIS-based terrain analysis

According to Donlon and Forbus (1999), the fundamentals for most military terrain analysis are map data and terrain analysis surveys. However, the integration of all map data and field survey data to the analysis of trafficability for a specific vehicle is still very difficult and labor intensive due to amount of the relevant data to be used. To manage this information overload, each dataset is evaluated independently under the given criteria to identify places that have uniform significance or characteristics relevant to the desired analysis (e.g. cross country moment). These results are often displayed on transparent sheets which can then be integrated to form diagrams (or "overlays" in the military term) for assisting further analysis of interest.

There are two particular products acquired from this stated method that are frequently used by the military analysts. These are the complex factor overlay (CFO) and the combined obstacle overlay (COO) (Figure 2.4). A CFO is derived by creating overlays for each data category (i.e., slope, soil factors, vegetation, surface materials, hydrology), and then combining them systematically to identify areas of homogenous characteristics across all overlays under some criteria. The result is a partitioning map that has scale of details resemble to that of the terrain data in use. The CCM mapping analysis is an example of the CFO in use by the military analysts at present.

In contrast, the COO is derived in a much more general way in which terrain data in each region are classified into three categories: unrestricted (U), restricted (R), or severely restricted (SR) for the movement in the relevant context, e.g., movement of a brigade equipped with the tracked and wheeled vehicles. As a consequence, the COO products provide primary indication of places where military units are likely to be moving and conducting operations.

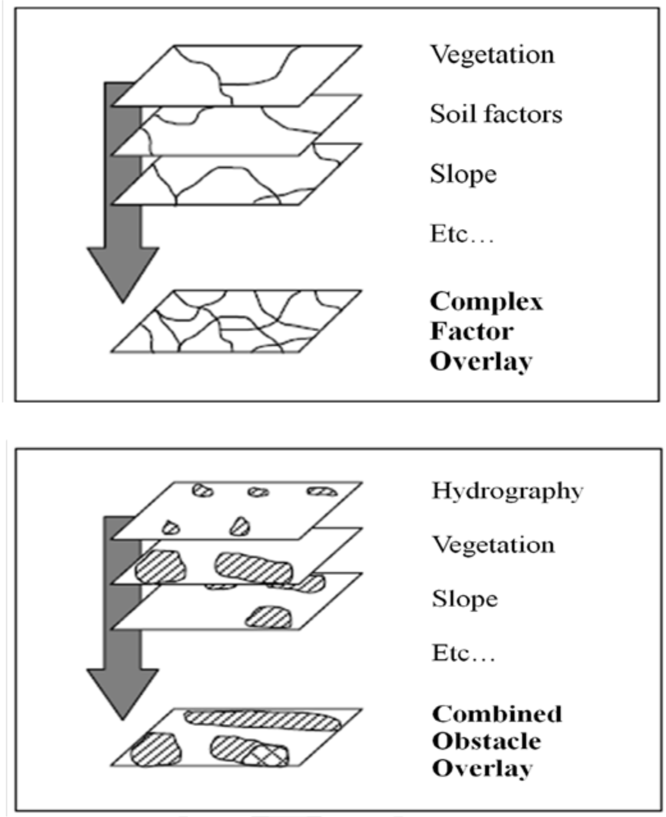



**Figure 2.4** Structure of the complex factor overlay (CFO) and the combined obstacle overlay (COO).

**From:** Donlon and Forbus (1999).

In the past, military terrain analysis was normally a time-consuming process as most working steps have to be carried out manually, especially when being applied to a vast and complex terrain. In these circumstances, some analyzing tools to assist this work are critically needed. At present, the most popular such tool is the computer-based geographic information system (GIS) which is highly capable in storing and processing spatial data needed for data collection and mapping synthesis. Broad scope of GIS applications in the military work is reviewed in Wilson and Gallant (2000), Satyanarayana and Yogandron (2012), Baijal, Arora and Ghosh (2012) and ESRI (2012a, b).

## 2.3 Path finding and search algorithm

One of the notable applications of terrain analysis output for military work is the identification of suitable paths for combat mobility (from a given original location to target destination). This task is usually performed by the military experts based on prior knowledge of key terrain and environmental characteristics of the area like soil properties, dominant vegetation cover, surface roughness and surface configuration. For off-road movement planning, knowledge of CCM is very essential in the finding of the preferred suitable path under some chosen algorithm and optimization criteria such as time (e.g. fastest path), safety, fuel usage, impact, length (e.g. shortest path), etc. (van Bemmelen, Quak, van Hekken, and van Oosterom, 1993).

At present, the automatic path finding algorithm can be developed based on some well-known search algorithms being used in computer science research field. Broadly speaking, a search algorithm is an algorithm that takes a problem as input and returns its solution usually after evaluating a number of possible solutions. The set of all possible solutions to a given problem is called a search space. In principle, the path finding algorithm is normally working within the graph structure framework, which is conceptually consisting of a set of "nodes" (or vertices) containing data and "edges" (or arch) connecting the nodes to each other. Path finding allows us to determine if and how one node can be reached from another. Additionally, we can consider not only if two nodes are connected but also assign some form of cost value to traveling (along a specific edge) between them. We can then search for not only the usual shortest path, but also the cheapest, fastest, or safest one (Jones, 2008).

### 2.3.1 Components of search algorithm

The search algorithms applied in the path finding analysis commonly consist of 4 main components, which are (Smyth, 2007):

(1) State space: It is the set of all discrete states (nodes) in graph structure. This set of states forms a graph where two states are connected if there is an operation that can be performed to transform the first state into the second;

(2) Operator: This term is used to describe one of the available procedures that can be used to connect one state to another;

(3) Start state: It is an initial state where the searching procedure starts; and

(4) Goal state: It is a target state where the searching procedure ends. There might be just only one or several goal states possible in an analysis.

In the problem solving process, one starts at an initial state and uses the allowable operators to move towards a goal state. The sequence of any states and operators that leads from the initial state to the goal state (under some imposed criteria, e.g. shortest, fastest, or cheapest move) is referred to as a path. And the solution to the given problem is a sequence of operators that map an initial state to a goal state which forms a solution path. Among all given criteria, the shortest path is the most widely explored as it has only few operations to achieve the task compared to all other possible solution paths.

Normally, a “Tree-search” concept is often applied to represent this kind of searching procedure as solution path forms a tree structure where each node is a state and lines connecting tree elements (nodes) are called “branches”. Each node in a tree structure may contain a value, a condition, or represent a separate data structure. And every node will have zero or more child nodes situated below it in the tree diagram (by convention, trees are drawn growing downwards from root to leaf nodes as seen for example in Figure 2.5). A node that has a child is called the parent node (or ancestor node, or superior).

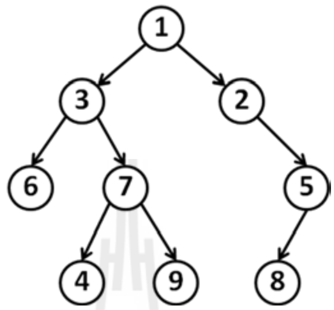



**Figure 2.5** A simple tree-like structure diagram. Here, the node labeled 3 has two children (labeled 6 and 7), and one parent (labeled 1). The root node at the top (labeled 1) has no parent.

Nodes that do not have any children are called leaf nodes, or terminal nodes. Each node has at most one parent. The topmost node in a tree is called the root node. Being the topmost node, the root node will not have parents. This is the node at which operations on the tree commonly begin (although some algorithms may begin with the leaf nodes and work up ending at the root node). All other nodes can be reached from it by following edges or links. In addition, the height of a specific node is defined by the length of the longest downward path to a leaf from that node. The height of the root node is also the height of the tree. The depth of a given node is the length of the path upward to its root. Therefore, searching process is nothing but exploring the tree from the root node to leaf nodes in some arranged order.

### 2.3.2 Types of search algorithm

The probability to get preferred solution path depends critically on the known information in the state space. Usually, when more information is acknowledged, it will be easier to solve the problem. Regarding to amount of information available, the search engines for path finding analysis can be grouped into 2 types (Jones, 2008):

(1) The uninformed (or blind) search; and

(2) The informed search.

**The uninformed (or blind) search**

An uninformed search algorithm is one that does not take into account prior knowledge of the possible solutions. In practice, it is a trivial but very general problem-solving technique that consists of systematically enumerating all possible candidates for the solution and then examining whether each candidate satisfies the problem's statement. The crucial drawback of this technique is that most search spaces will be extremely large, and an uninformed search will take a reasonable amount of time only for small examples. As a result, it is sometimes being referred to as brute-force search or exhaustive search. The main advantage of the uninformed search is that it can find the exact or optimal solutions (if there are any) if given enough time. The well-known methods in this group include various tree search algorithms that view the elements as vertices of a tree structure and traverse that tree in some specific order, for examples, the so-called breadth first search and depth-first search (Figure 2.6).

Breadth first search (BFS), as the name implies, searches tree structure from the initial state breadth-wise, level by level. In the process, it shall explore all states in one level before jumping to the next level. Once the solution is found the search stops. The BFS working concept guarantees to find solution if one exists but this process might probably take very long time if the destination locates at very low-level of the tree structure diagram. Another approach is called depth first search (DFS) method as it shall explore only one particular branch (in the tree-structure diagram) deeper until the solution is discovered, or there is no new state to be explored, and then backtrack and start searching over the adjacent level. The advantage of this technique is that, by chance, the solution may exist in the first few branches of the tree then the search can find this solution rapidly. However, if the solution exists in some other branches rather farther away, then there will not be much difference between the depth first search and the breadth first search approaches (Halton, 2012). Table 2.7 provides summarized details of the uninformed (or blind search) and the informed (or heuristic) search types while Table 2.8 presents some comparisons between main characters of the BFS and DFS methods discussed earlier.

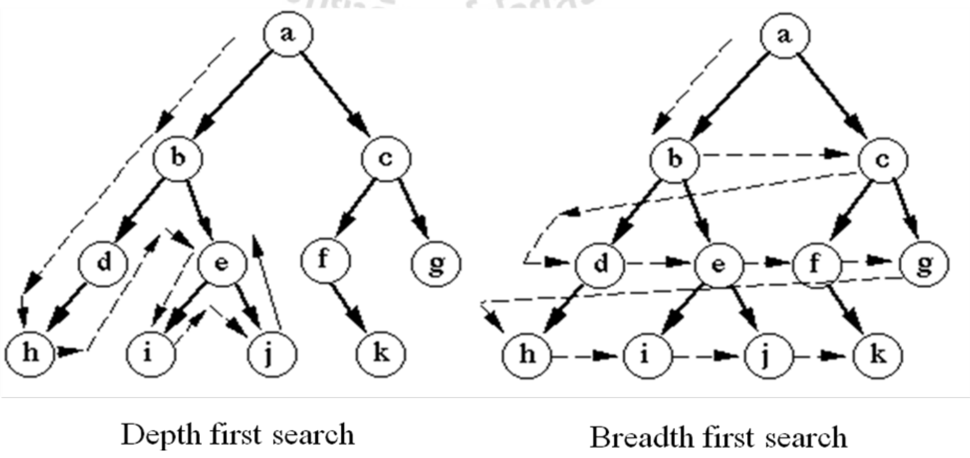



**Figure 2.6** Examples of the breadth first search (BFS) and depth first search (DFS) algorithms.

**From:** William (2012).

**Table 2.7** Summarized details of the uninformed (or blind search) and the informed (or heuristic) search types.

| Type | Search Strategies | Examples |
|---|---|---|
| 1. Blind/Uninformed search | Do not use any specific problem domain information<br>• e.g., searching for a route on a map without using any information about direction. | Breadth First Search<br>Depth First Search |
| 2. Heuristic/Informed search | Use domain specific heuristics<br>• e.g. since Seattle is north of LA, explore northerly routes first.<br>This is the AI approach to search. | A-Star (A*) Search<br>Best First Search |

**Modified from** Varoon (2012).

**Table 2.8** Comparisons between main characters of the BFS and DFS methods.

| Breadth First Search (BFS) | Depth First Search (DFS) |
|---|---|
| 1. Uses more memory because it must retain the status for every path from starting node to find answers. | 1. Uses less memory because only the status of the current path finding is stored. |
| 2. Path will not be very deep. Can find the answer though path is very deep. | 2. May not find answer if path is very deep. |
| 3. If the answer is in a level n+1 all other levels 1 to n must be distributed to find answer. | 3. If the answer is in a level n+1 all other levels 1 to n not need to be distributed. |
| 4. The shortest path answer can be definitely found if there is any. | 4. The obtained answer may not be the shortest path as required. |

**Modified from** Varoon (2012).

Another popular approach in this category is called Dijkstra’s algorithm. This algorithm begins with a start node and an “open set” of candidate nodes. At each step, the node in the open set with the lowest distance from the start is examined. The node is marked “closed”, and all adjacent nodes are added to the open set if they have not already been examined. This process will repeat until a path to the destination has been found. Since the lowest distance nodes are examined first, the first time that the destination is found, the path to it will be the shortest path. More information of the Dijkstra’s algorithm can be found in Mount (2003) and Cormen, Leiserson, Rivest, Stein (2009).

**The informed search**

The path finding problem can be solved more efficiently if we have relevant information, clues or hints, that lead to the preferred solutions. This stated knowledge constitute heuristic information, therefore, the informed search is also called heuristic search. Instead of finding solution blindly as seen in the uninformed search, informed search uses the known heuristic information to decide whether or not to explore the current state further. This decision can significantly reduce the amount of time spent searching before finding the preferred solutions. An analogy in this case would be a person walking across a room; rather than examining every possible route in advance, the person would generally move in the direction of the destination and only deviate from the path to avoid an obstruction, and make deviations as minor as possible. The popular approach in this category is called the best-first search. It is a search algorithm which explores a graph by expanding the most promising nodes chosen in according to a specified rule (the potential best nodes). As these nodes are visited, an evaluation function is used to estimate their value (in terms of a problem solution). Table 2.9 presents some comparisons between the A-Star and Best First Search methods.

**Table 2.9** Comparisons between the A-Star and Best First Search methods.

| A-Star (A*) Search | Best First Search |
|---|---|
| 1. A* is a best first graph search algorithm that finds the least cost path from a given initial node to one goal node (out of one or more possible goals). | 1. Best First Search is a simple algorithm of A*. |
| 2. Heuristic function of A* search is F(x) = g(x) + h'(x) | 2. Heuristic function of Best First Search is F(x) = h'(x) |
| 3. A* is complete in the sense that it will always find a solution if there is one. | 3. Best First Search is greedy and tries to move towards the goal even if it's not the right path. |

**From:** Nuntawong (2012).

The widely-used A* algorithm is a good example of the best first search method (Figure 2.7). The A* search (pronounced A-Star) is a variant of the Dijkstra's algorithm mentioned earlier. Instead of looking at the distance from the starting node, A* chooses nodes based on the estimated distance from the start to the finish. The estimate is formed by adding the known distance from start to a guess of the distance to the goal. The guess, called the heuristic, improves behavior relative to Dijkstra's algorithm. When the heuristic is 0, A* is equivalent to Dijkstra's algorithm. As the heuristic increases and gets closer to the true distance, A* continues to find optimal paths, but runs faster (by virtue of examining fewer nodes). Whenever the heuristic is exactly the actual distance, A* examines the fewest nodes. As the heuristic increases, A* will examine fewer nodes but it no longer guarantees an optimal path in return. More information about A* search concept is described in Morelli (2010), and Nosrati, Karimi, and Hasanvand (2012).

General concept of the A* searching algorithm is as follows:

**Evaluation function**:

$$f(n) \quad = \quad g(n) + h(n), \qquad (2.6)$$

where f(n) = estimated total cost of path from start node through n to goal;

g(n) = cost so far to reach node n; and

h(n) = estimated cost to goal from node n.

**Optimality requirement** for A* tree search:

A* needs an admissible heuristic, i.e., $0 \leq h(n) \leq h^*(n)$ for all states n, where h*(n) is the true cost from n. [Thus h(G) = 0 for any goal G.]

**Theorem**:

If the optimality requirement is satisfied, then A* tree search never returns a non-optimal solution (or it will always find the optimal solution).

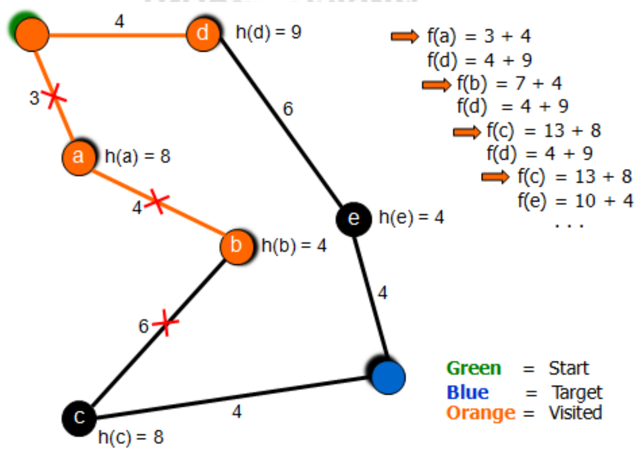



**Figure 2.7** An example of the A-Star (A*) algorithm.

## 2.4 Literature review

### 2.4.1 Terrain analysis

Due to the importance of terrain analysis on the intelligence preparation of the battlefield (IPB) process, several analytic models have been formulated to facilitate this task. For examples, Richbourg and Olson (1996) designed a software suite that relies on several different ideas and methodologies which are combined to function as an expert system in the domain of terrain analysis to support relevant tactical planning for small unit operations, e.g., identifying likely enemy courses of action or selecting the most favorable friendly course of action. This tool had been developed within the artificial intelligence field with knowledge of the representation schemes, spatial reasoning techniques, autonomous agent planning methods, rule-based paradigms, and heuristic search strategies is included and operated. It was found therein that no single technique in isolation can fully solve the broad problems of military operations planning. However, a hybrid system where different tools are combined has proven to be more effective in solving problem of interest.

Also, Kim et al. (1994) formulated and implemented a computerized tactical terrain analysis system for a battlefield operation whose result can be used to enhance combat capability of a military unit and efficiency of the weapon system. This system was mainly designed to create a computer graphics environment in which the analyst can interactively operate the whole analyzing process like selecting the area of interest, performing analysis functions, simulating required battlefield operation and display the analyzed results. Their system was divided into three major sections; the terrain analysis modules, utilities, and graphic editor. The terrain analysis module includes surface analysis, line of sight analysis, enemy dispositon, 3D display, radar coverage, logistic route analysis, shortest path analysis, atmospheric phenomena prediction, automated IPB, and other applied analysis. The integration techniques of remotely sensed images and GIS-based data such as precision registration, overlay, and on-line editing was also developed and implemented.

Fleming, Jordan, Madden, Usery, and Welch (2009) have applied GIS to create prototype models for military operations in coastal environment at US Marine Corps Base Camp Lejeune, North Carolina. The ultimate goal is to use developed models, along with methodologies, to produce large-scale littoral warfare database to aid the National Geospatial-Intelligence Agency's littoral warfare analysis, modeling and mapping as required by the US military organizations. Three basic steps were done in this work: (1) database preparation; (2) map product design; and (3) development of GIS applications for littoral operations. The methodology includes selection of data resources including high resolution satellite images (mainly from the QuickBird and Ikonos satellites, and Lidar), establishment of analysis/modeling parameters, conduct of vehicle mobility analysis, development of models and generation of products (such as a continuous sea-land DEM and geo-visualization of changing shorelines with tidal levels). It was concluded that this research can provide examples of improved digital datasets, map products and analysis procedures which are useful for future Littoral Warfare Database military applications of National Geospatial-Intelligence Agency.

### 2.4.2 CCM analysis

Although the CCM analysis for military operation is well recognized among responsible agencies, its published works are still rarely found. For example, van Bemmelen et al. (1993) have presented an explicit comparison between vector-based and several raster-based algorithms to solve CCM planning problem. It was found in their work that the raster-based algorithms have several advantages, i.e., are relatively easy to implement and perform reasonably well. However, in theory, it is still not able to provide exact solutions of interest and only approximation of the true solution is given. On the contrary, the vector-based method can return exact solutions but its performance is still not satisfactory. Therefore, to improve performances of both algorithms, a hierarchical approach was created which can be applied in both vector and raster domain. This method has better performance and the optimal path solution can be achieved.

Rybanský (2003) synthesized the CCM map with three categories of vehicle's trafficability: GO, SLOW GO, NO GO, based on knowledge of terrain properties including surface slope, vegetation cover, surface water, soil conditions; urban/built-up, lines of communication, other natural and man-made features and weather condition.

Samruai Khotcharit (2004) has applied GIS to process military terrain analysis in Kanchanaburi Province. The weight-linear-combination (WLC) method was used to identify suitable areas for the following purposes: (1) for the military movement in dry/wet season; (2) for military surveillance; (3) for military file of fire; and (4) for cover and concealment. Main factors being considered in this research are as follows: surface slope (1/3); soil (1); vegetation cover (1/2/3/4); transportation (1); obstacle (1); rainfall (1); and built-up area (1/2/3/4). Numbers in each blanket refer to category of suitable area addressed earlier. It was found most areas can moderately support the military movement in both seasons (about 80-90% of the whole area).

However, the severely restricted area for the movement has risen significantly from about 9.17% in dry season to 18.79% in wet season. The most suitable areas for military surveillance, military file of fire, and cover/concealment were found to be about 35.61%, 33.36%, and 62.39% of the total area, respectively.

Gumos (2005) applied GIS for the modeling of a cross-country trafficability in South-Eastern Sweden. The task was achieved by the analysis of reciprocal relationships between the soil deposits, local hydrology, geology and geomorphology in relation to the study area. The three distinguishable soil wetness conditions: dry, moist, and wet, were determined, and used consequently for creation of the static ground conditions map which indicates soils susceptibility to the specific traffic of interest. The work resulted in a conceptual scheme for cross-country trafficability modelling, which was put into effect while modeling in GIS. The multi-criteria evaluation method was used to produce cross-country trafficability maps that can be used to assess vehicle's maneuverability in the study area.

Jones, Horner, Sullivan, and Ahlvin (2005) presented a quantitative method for assessing the environmental impact of terrain/vehicle interactions during tactical missions for three standard US military tracked/wheeled vehicles over terrain of both fine-grained and course-grained soils. The NATO reference mobility model (Vers.2), or NRMM II, was used to predict the vehicle rut depth performance for the different vehicles and terrain conditions. NRMM II is an automated, computerized model being designed to predict physically constrained interaction of vehicles operating in an on- and off- road environment. Comparison of the results gained from various operational conditions, areas, specific missions, traverses, vehicle combinations, etc., provides initial knowledge of the environmental impact on vehicle rutting which is useful for better mission planning, based on the seasonal and climate conditions. It also reveals which vehicles cause the minimum amount of environmental impact.

Suvinen (2005) developed a GIS-based simulation model for the assessment of terrain tractability and optimal off-road routing for the logging vehicles operating in the forest. General structure of the model is based on an object-oriented concept that uses the cost surface technique to describe actual conditions in the terrain. The cost surface is defined as kind of a mobility index which is based on different factors, e.g., vehicle, wheel, terrain, tree coverage, road, and weather objects. A regular raster analysis was used to determine alternative routes for off-road movement in different conditions. It has been shown that the adequate number of useful parameters can be extracted from national level digital maps to support the preferred off-road analyses. Due to its GIS-based structure, the model enables effective sensitivity analyses to be carried out. For examples, effects of the variations in load, wheels and engine of the vehicle on the model's solution can be assessed independently based on the different input of the concerned GIS data, e.g. when load size differs or the lower tyre pressure is used, etc. This also makes it easier to enter ready-made objects (e.g. most common tyre types) via the system's user interface.

Bacon McDonald, Baker, Caldwell, and Stullenbarger (2008) have conducted the systematic classification and mapping of terrain property under desert environment which is related to vehicle's movement in the Sonoran Desert of Arizona. Methods used in this study comprised office-based terrain mapping using satellite imagery, field verification of the mapping, compilation of existing soils information. These data were systematically analyzed and integrated to produce differentiated map unit that contributes to a range of terrain property maps. The analysis of landform and surface cover (upper 1 m) characteristics was succeeded by geomorphic mapping based on 1-m resolution IKONOS satellite imagery, 10-m digital elevation models, pre-existing soil surveys and geologic maps, as well as site-specific investigations. The results obtained provide an assessment of each chosen test course (route), including information on the landform, geology, surface materials, soil type, degree of the desert pavement development, dust content, and percent of slope. It was concluded that this study presented an example of how to systematically characterize one vehicle endurance test course that crosses diverse desert terrain at the study area, and also provided an example of how to make comparisons between that terrain and other terrain within the World's desert, such as in the country of Afghanistan.

Affleck, Melloh, and Shoop (2009) conducted a cross-country vehicle performance analysis on various snow and soil conditions on virtual terrain based on the North Atlantic Treaty Organization (NATO) Reference Mobility Model (NRMM). Their main objective was to evaluate whether the terramechanics representation of a virtual site is improved by adding spatially distributed snow and soil properties, rather than using the uniform properties. It was found that snow cover reduces the speed that a vehicle can achieve because the mechanical weakness of snow reduces traction and the presence of snow in front of the tire increases resistance. In addition, the vehicle's speed will differ significantly depending on the snow depth and density, and speed predictions using uniform snow cover will not represent accurate results of vehicle performance.

Hošková-Mayerová, Hofmann, Kubícek, and Talhofer (2010) described an application of the GIS-based model to construct a simple CCM map for the Czech Army based on knowledge of some given factors, which are: (1) terrain relief; (2) vegetation cover condition; (3) soil conditions; (4) meteorological conditions; (5) hydrology; (6) built-up area; and (7) road network. The impact of each factor can be evaluated as a coefficient of deceleration “$C_i$” from the scale of 0 to 1. The coefficient of deceleration shows the real (simulated) speed of vehicle (V) in the landscape compared to the maximum speed of given vehicle ($V_{max}$). The impact of the whole 7 factors can be expressed using the formula:

$$V(kph) = (C_1 \times C_2 \times C_3 \times C_4 \times C_5 \times C_6 \times C_7) V_{max} , \qquad (2.7)$$

where V is the speed of vehicle (in kilometer per hour). By using above formula, they found that it is possible to create a cost map in which the value of each pixel is the final (modeled) speed.



### 2.4.3 Search algorithm

A* has been applied in Stewart and White (1991) in which they presented the multiple objective A* algorithm (or MOA*). The research was motivated by their observation that most real world problems have multiple, independent, and possibly conflicting objectives. MOA* explicitly addresses this problem by identifying the set of all non-dominated paths from a specified start node to the given set of goal nodes in an OR graph. This work shows that MOA* is completed and is admissible, when used with a suitable set of heuristic functions.

BFS has been applied by Yun (2002) to analyze dispatching system of the China Railway Communication network. This work was used as an integral part of the intelligent communication network resources dispatching system of China Railway-Communication Corporation. Main functions of the system focus on two aspects. One is to collect/classify fundamental data and establish communication network resources information database. The other is to search paths of links, circuit between nodes on the basis of the information database. In the system, BFS is used in the routing process. It was concluded that, though there are several kinds of searching algorithms, and some are very complex, BFS is considered the best one in the system when the factors (for example, practical demands, complexity, searching time) are taken into account.

Yue and Shao (2007) applied the A* in optimal path searching of urban traffic. The analysis focuses on the heuristic function of A* search algorithm. Travel time is adopted to compute path cost in the optimal path search. Because there are often delays for intersection crossing, travel time includes the road section travel time and the time of intersection delay. The evaluation function f (n) is given by:

$$f(n) = g(n) + h(n), \tag{2.8}$$

where f(n) = estimated travel time from starting node to goal node through node n;

g(n) = actual forecasted travel time from starting node to node n; and

h(n) = estimated travel time from node n to goal node.

It was found that A* algorithm is an effective method in finding the shortest path in the urban road network with improved speed of the optimum path search.

# CHAPTER III

# METHODOLOGY

## 3.1 Conceptual framework of the study

This work comprises of 4 main parts in accordance with the proposed objectives described earlier (see flowchart in Figure 3.1). The first part describes the collection and dataset construction of data necessary for further production of the CCM maps that can be divided into 2 main categories (see more details in Table 3.1):

(1) Vehicle/troop characteristics; these include 6 types of the military combat units: Standard infantry, Armored infantry, Mechanized infantry, Tank cavalry, Armored cavalry, and Reconnaissance cavalry.

(2) Terrain/LULC characteristics; these include surface configuration (slope), vegetation cover, surface materials (soil), road network, and water body. All data are acquired from the responsible agencies.

The second part focuses on the construction of CCM maps for each associated military unit mentioned above based on Eq. 3.1 (under the wet and dry conditions). There are 7 major classes depicted in the derived CCM maps as detailed in Table 3.2. The third part deals with the analysis on capability of the 2 chosen search algorithms, the breadth first search (BFS) and A-star search, in the identification of the required shortest and fastest paths on a specific CCM map derived earlier (under the provided initial state and target state).

The final part provides detailed development process of the automatic search program (to identify shortest path or fastest path on the obtained CCM map) based on the superior search algorithm identified in the third part.

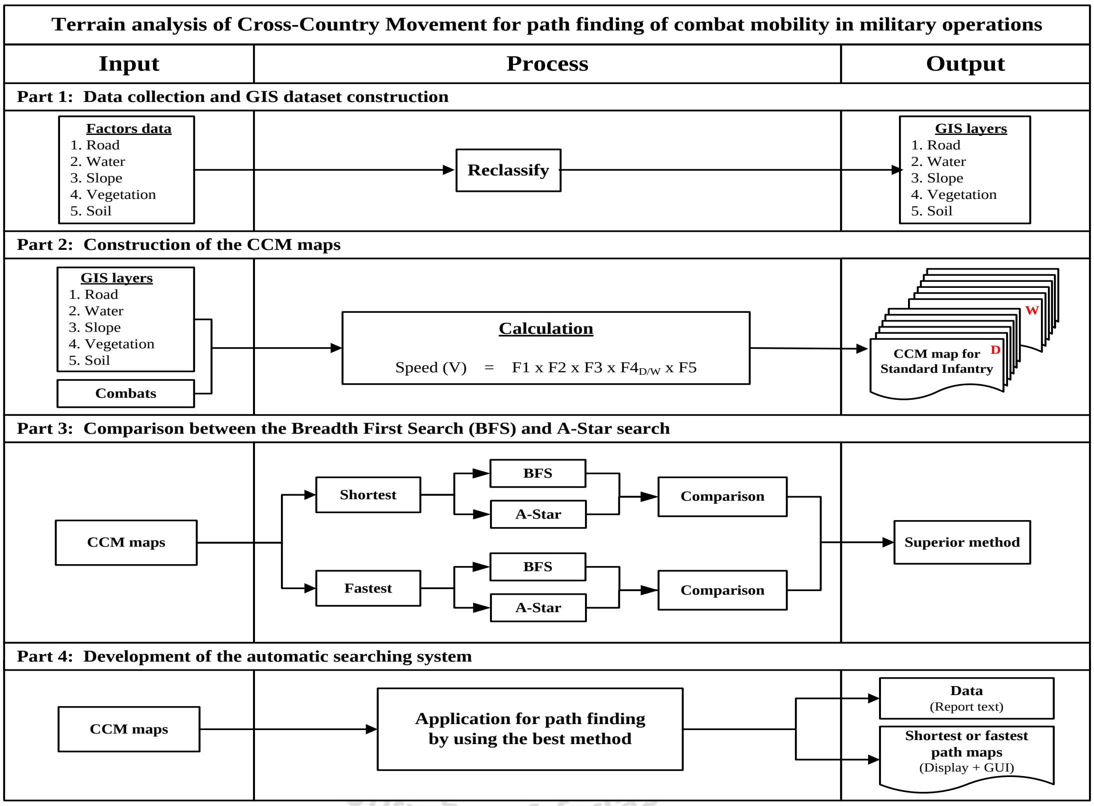



**Figure 3.1** Work flowchart of the research methodology.

## 3.2 Data collection and GIS-based dataset construction

The first step of this work is to assemble data necessary for the construction of preferred CCM maps from responsible agencies. These can be separated into 2 broad groups (for vehicles/troops and terrain/LULC) as shown in Table 3.1, which are then systematically organized to be separated GIS-based dataset (or GIS map layer) using the ArcGIS software. These feature classes shall represent either a factor or a constraint for further use in the CCM analysis.

**Table 3.1** Information of crucial data needed in the study.

| Category | Combat unit | Chosen vehicle/troop | Data type | Scale | Year | Source |
|---|---|---|---|---|---|---|
| Troop/ Vehicle | Standard infantry (ทหารราบมาตรฐาน) | Foot troops | Attribute | – | – | The 3rd Army Area |
| | Armored infantry (ทหารราบยานเกราะ) | M113 | Attribute | – | – | The 3rd Army Area |
| | Mechanized infantry (ทหารราบยานยนต์) | M35 truck (2½ Ton) | Attribute | – | – | The 3rd Army Area |
| | Tank cavalry (ทหารม้ารถถัง) | Stingray Light Tank | Attribute | – | – | The 3rd Army Area |
| | Armored cavalry (ทหารม้ายานเกราะ) | M113 | Attribute | – | – | The 3rd Army Area |
| | Reconnaissance cavalry (ทหารม้าลาดตระเวน) | Scorpion Tank | Attribute | – | – | The 3rd Army Area |
| **Category** | **Factor class** | **Factor characteristics** | **Data type** | **Scale** | **Year** | **Source** |
| Terrain/ LULC | Road | Road network | Polyline | 1:50,000 | 2004 | DOH |
| | Water body | Water area | Polygon/ polyline | 1:50,000 | 2004 | MNRE |
| | Surface slope | Slope area | Raster | 30x30m | 2007 | CU |
| | Vegetation cover | Vegetation type<br>Stem spacing/diameter<br>Surface roughness | Polygon | 1:50,000 | 2004 | RTSD, MNRE |
| | Soil | Soil type/strength | Polygon | 1:50,000 | 1999 | RTSD |

**Note:** CU = Chulalongkorn University, RTSD = Royal Thai Survey Department,
DOH = Department of Highways, MNRE = Ministry of Natural Resources and Environment.

**Table 3.2** Category for speeds and CCM map units.

| Speeds (kph) | Basic descriptor | CCM Map Unit |
|---|---|---|
| > 30 | Go | Go |
| > 15 - 30 | Restricted Go | Slow Go |
| > 5 - 15 | Slow Go | Slow Go |
| > 1.5 - 5 | Very Slow Go | Slow Go |
| ≤ 1.5 | No Go | No Go |
| – | No Go (Open water) | No Go |
| – | No Go (Built-up area) | No Go |

**From:** US Army (1990).

## 3.3 Construction of the CCM maps

The CCM maps (for each chosen vehicle/troop unit informed in Table 3.1) were produced based on Eq. 3.1 (Figure 3.2):

$$V\ (\text{kph}) = F1 \times F2 \times F3 \times F4_{D/W} \times F5, \qquad (3.1)$$

where V is the traveling speed of vehicle (in kilometer per hour).

Terms F1 to F5 represent key terrain and environmental characteristics of the study area, where F1 is speed/slope factor; F2 is slope-intercept-frequency (SIF) factor; F3 is vegetation factor; F4 is soil factor; and F5 is surface roughness factor. The formulas for the calculation of F1 - F5 factors are given in Table 3.3 and needed vehicle data are given in Table 3.4. The CCM mapping results are reported separately for each studied combat unit in both dry (D) and wet (W) seasons.

The obtained cross-country movement (CCM) map, sometimes being referred to as an avenue-of-approach map, can be used to identify the best routes by which various troops or vehicles can get to an objective when they cannot use the prepared roads. It also shows parts of terrain that these troops or vehicles cannot cross which is very important information for the planning of combat strategy.

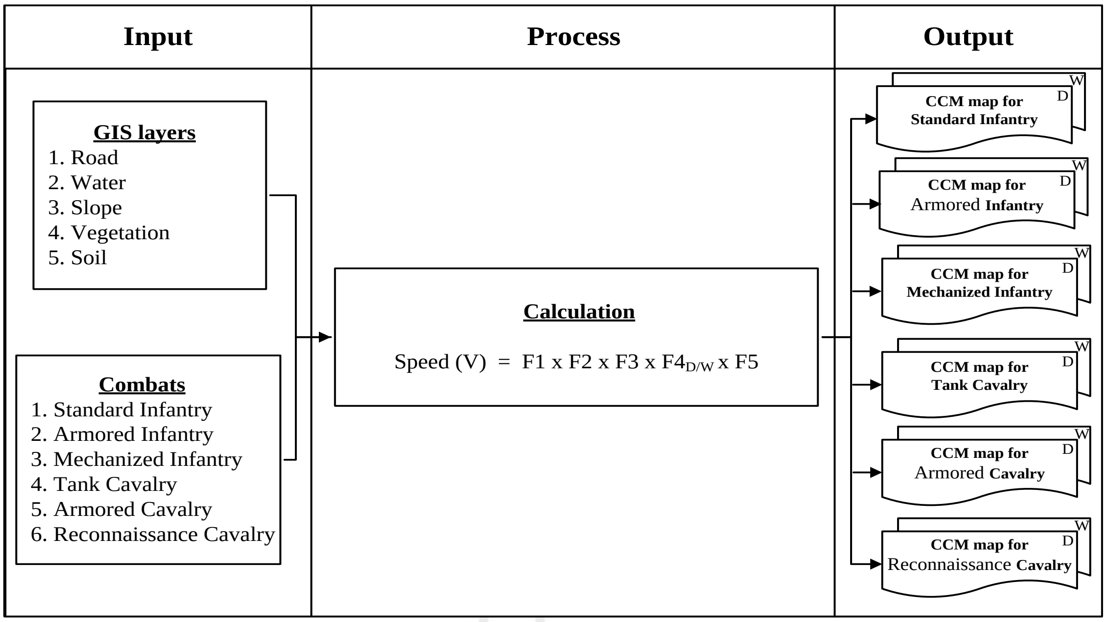



**Figure 3.2** Detailed structure of the CCM map construction.

**Table 3.3** Information of the formulas used to calculate F1 - F5 factors.

| Factor | Formula | Note |
|---|---|---|
| F1 | $F1\,(kph) = \frac{\text{Max off-road gradability (\%)} - \text{Surface slope (\%)}}{\text{Max on-road gradability (\%)}}$ x Max road speed (kph); Max = maximum, | If F1 $\leq$ 0, F1 = 0 (No Go). |
| F2 | $F2 = (-0.0008888)\,[slope] + 1$ | – |
| F3 | $F3 = V_R \text{ x } \max(V_1, V_2)$; $V_1 = V_F \text{ x } V_C$ ; $V_C = \frac{SS - SD}{W}$, $V_2 = 1 - \left[V_T \text{ x } \frac{SD^2}{OD^2}\right]$; $V_T = \frac{(W + SD)}{SS}$, | 1. If $V_1 \leq 0$, $V_1 = 0$,<br>2. If $V_1 \geq 1$, $V_1 = 1$,<br>3. If F3 $\geq$ 1, F3 = 1,<br>4. If F3 $\leq$ 0, F3 = 0 (No Go),<br>5. If values of SS/SD are not available, F3 = $V_R$. |
| | $V_R$ = Vegetation roughness factor, $V_F$ = Vehicle factor, W = Vehicle width (m), SS = Stem spacing (m), SD = Stem Diameter (m), OD = Override diameter of the vehicle. | |
| F4 | $F4_{D/W} = \frac{RCI_{D/W} - VCI_1}{VCI_{50} - VCI_1}$; | 1. If F4 $\leq$ 0, F4 = 0 (No Go),<br>2. If F4 $\geq$ 1, F4 = 1. |
| | $RCI_D$ = RCI value for dry condition, $VCI_1$ = Vehicle cone index (1 pass), | $RCI_W$ = RCI value for wet condition, $VCI_{50}$ = Vehicle cone index (50 pass). |
| F5 | F5 = Surface roughness factor (0 - 1) | – |

**Table 3.4** Vehicle characteristics.

| Characteristics | Infantry | | | Cavalry | | | Note |
|---|---|---|---|---|---|---|---|
| | FTP | M113 | M35 | SLT | M113 | SCT | |
| Vehicle width: W (m) | – | 2.69 | 2.43 | 2.70 | 2.69 | 2.23 | F3 |
| Vehicle factor: $V_F$ | – | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | F3 |
| Override diameter of the vehicle: OD (m) | – | 0.1 | 0.06 | - | 0.1 | - | F3 |
| Maximum road speed (kph) | – | 48 | 56 | 69 | 48 | 72.4 | F1 |
| Maximum on-road gradability (%) | – | 60 | 64 | 60 | 60 | 60 | F1 |
| Maximum off-road gradability (%) | – | 45 | 30 | 40 | 45 | 45 | F1 |
| Vehicle cone index 1 pass: $VCI_1$ | – | 17 | 30 | 23.6 | 17 | 13.5 | F4 |
| Vehicle cone index 50 passes: $VCI_{50}$ | – | 40 | 48 | 54.4 | 40 | 32.3 | F4 |

**Note**: 1. FTP = Foot troops, SLT = Stingray Light Tank, SCT = Scorpion Tank, kph = kilometers/hour.
2. $V_F$ = The response of drivers when approaching wooded areas.
3. F1 = Speed/slope factor, F3 = Vegetation factor, F4 = Soil factor.

**Modified from** US Army (1990); and RTSD Map Center (1997).

Details of main factors seen in Eq. 3.1 and Table 3.3 are as follows:

### 3.3.1 Determination of the speed/slope factor (F1)

The speed/slope factor (F1) was computed from the following equation:

$$F1\,(\text{kph}) = \frac{\text{Max off-road gradability (\%)} - \text{Surface slope (\%)}}{\text{Max on-road gradability (\%)}} \text{ x Max road speed (kph)}, \quad (3.2)$$

where Max = Maximum. Values of the vehicle-related parameters presented in this equation are listed in Table 3.4. Principally, the F1 factor indicates the extent that any slope will deteriorate speed of a given combat vehicle without consideration for any other physical factor. Examples of the F1 values for surface slopes of 0, 10, 20, 30, 40, and 50% for all vehicles listed in Table 3.1 are shown in Table 3.5. Note that, the negative values of F1 indicate the No Go areas and they are represented by F1 = 0 on the reported map for convenience.

**Table 3.5** Examples of the F1 values at different values of the surface slope.

| Surface slope (%) | F1 (Infantry) (kph) | | | F1 (Cavalry) (kph) | | |
|---|---|---|---|---|---|---|
| | **FTP** | **M113** | **M35** | **SLT** | **M113** | **SCT** |
| 0 | - | 36.00 | 26.25 | 46.00 | 36.00 | 54.30 |
| 10 | - | 28.00 | 17.50 | 34.50 | 28.00 | 42.23 |
| 20 | - | 20.00 | 8.75 | 23.00 | 20.00 | 30.17 |
| 30 | - | 12.00 | 0.00 | 11.50 | 12.00 | 18.10 |
| 40 | - | 4.00 | - 8.75 | 0.00 | 4.00 | 6.03 |
| 50 | - | - 4.00 | - 17.50 | - 11.50 | - 4.00 | - 6.03 |

**Note**: 1. FTP = Foot troops, SLT = Stingray Light Tank, SCT = Scorpion Tank.
2. The negative values of F1 are represented by F1 = 0 on map (No Go).

### 3.3.2 Determination of the SIF factor (F2)

The slope-intercept-frequency factor (SIF) is the number of times that ground surface changes between positive and negative slopes over a 1 km distance. And, as guided by the US Army (1990), the F2 value can be calculated as follows:

$$F2 = \frac{280 - \text{SIF count (adjusted)}}{280}. \quad (3.3a)$$

However, measuring the SIF value on the topographic map, or in the field, is usually an extremely time-consuming task. Therefore, the following formula was modified to find the F2 value from the surface slope value directly:

$$F2 = (-0.0008888)\,[\text{slope}] + 1. \quad (3.3b)$$

This relation was achieved based on standard values of F2 at different ranges of the surface slope recommended by the Royal Thai Survey Department (Table 3.6). The detailed derivation of this formula is illustrated in Figure 3.3.

**Table 3.6** Examples of the F2 values at different values of surface slope.

| Slope range (%) | 0 - 3 | 3 - 10 | 10 - 20 | 20 - 30 | 30 - 45 | ≥ 45 |
|---|---|---|---|---|---|---|
| Given F2 value | 1.0 | 0.99 | 0.98 | 0.97 | 0.96 | – |

**From:** RTSD Map Center (1997).

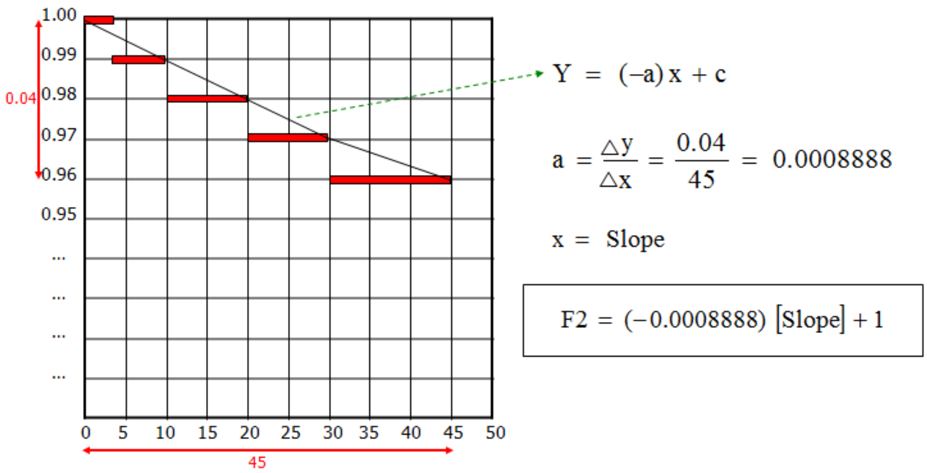



**Figure 3.3** The derivation of Eq. 3.3b for the F2 calculation.

### 3.3.3 Determination of the vegetation factor (F3)

The vegetation factor (F3) indicates impact of vegetation characteristics (type, density, or distributing pattern) on the mobility of vehicle movement. This can be found from the following formula (using the larger value of V1 or V2):

$$F3 = V_R \text{ x } \max(V_1, V_2), \tag{3.4a}$$

$$V1 = V_F \text{ x } V_C;\ V_C = \frac{SS - SD}{W}, \tag{3.4b}$$

$$V2 = 1 - \left[V_T \text{ x } \frac{SD^2}{OD^2}\right];\ V_T = \frac{(W + SD)}{SS}, \tag{3.4c}$$

where $V_R$ is the vegetation roughness factor (expressed in Table 3.7); $V_F$ is the vehicle factor (0.2 for wheeled and tracked vehicles without trailers as detailed in Table 3.4), SS and SD are stem spacing and stem diameter (as listed in Table 3.7); W is vehicle width (Table 3.4), and OD is override diameter of the vehicle (Table 3.4).

**Table 3.7** Information of the vegetation factor data.

| ID | LULC class | Stem Diameter (SD) (m) | Stem spacing (SS) (m) | Vegetation Roughness ($V_R$) |
|---|---|---|---|---|
| A1 | Agriculture (dry crops) | Null | Null | 0.85 |
| A2 | Agriculture (wet crops/rice) | Null | Null | 0.90 |
| A3 | Agriculture (terraced crops both wet/dry) | Null | Null | 0.90 |
| C32 | Coniferous/Evergreen forests | 0.06 | 1.50 | 1.00 |
| E22 | Mixed forest | 0.05 | 2.00 | 0.90 |
| F12 | Fruit bearing trees (orchard/plantation) (**1:** Canopy closure = 0 - 25 %, **2:** Height = 2 - 5 m.) | 0.05 | 5.50 | 0.70 |
| F21 | Fruit bearing trees (orchard/plantation) (**1:** Canopy closure = 25 - 50 %, **2:** Height = 0 - 2 m.) | 0.04 | 5.00 | 1.00 |
| F22 | Fruit bearing trees (orchard/plantation) (**1:** Canopy closure = 25 - 50 %, **2:** Height = 2 - 5 m.) | 0.08 | 3.00 | 0.80 |
| G2 | Grassland with scattered trees/some scrub | Null | Null | 0.85 |
| X | Built-up areas | Null | Null | 0.30 |

**Note**: Null = Data are not available.

**From:** RTSD Map Center (1997).

In general, if values of SS or SD are not available (for the non-forest types), the F3 is approximated from relation: F3 = $V_R$ (no need for the calculation of V1 or V2). The V1 factor is the product of two terms: the vehicle factor ($V_F$) and the vehicle clearance factor ($V_C$). The $V_F$ accounts for the response of drivers when approaching wooded areas while the $V_C$ accounts for the physical ability of a vehicle to maneuver between tree stems in wooded area. If $V_C \leq 1$ then V1 = 0. As $V_1$ must be between 0 - 1, therefore, if V1 $\leq$ 0 then V1 = 0 and if V1 $\geq$ 1 then V1 = 1.

In addition, the V2 factor is used to determine if it would be easier for the vehicle to override the trees rather than maneuver between them (as accounted for by the V1 factor). The $V_T$ portion of the formula is used to calculate minimum number of trees a vehicle can hit at one time. If $V_T \leq 1$ then $V_T = 1$ and if SD > OD then V2 = 0. Also, if V2 ≤ 0 then V2 = 0. However, if V2 factor cannot be calculated (as OD value is not known), V1 factor will be chosen for the use in Eq. 3.4a automatically. To keep F3 varying between 0 to 1, if F3 ≥ 1 then F3 = 1 and if F3 ≤ 0 then F3 = 0 (No Go).

### 3.3.4 Determination of the soil factor (F4)

The soil factor informs on the impact of the soil characteristics on vehicle's mobility. The analysis is usually separated into dry (D) and wet (W) conditions. The calculation of F4 shall determine if a particular soil type will support the vehicular movement and to what extent the speed will decrease due to that soil type. The dry-soil factor ($F4_D$) and wet-soil factor ($F4_W$) can be computed as follows:

$$F4_{D/W} = \frac{RCI_{D/W} - VCI_1}{VCI_{50} - VCI_1}, \tag{3.5}$$

where RCI is the rating cone index widely used to represent proportion of the original soil strength retained after the given vehicles have passed over the area (US Army, 1990). The larger RCI indicates stronger soil, and VCI is the vehicle cone index which is a value assigned to a given vehicle for a given number of passes. The US Army has used VCI as a performance indicator of the referred vehicles to traverse over soft-soil terrain. The VCI is defined as the minimum soil strength necessary for self-propelled vehicle to consistently conduct a given number of passes in the track without going immobilized. The usual testing focused on finding VCI for cases of 1 and/or 50 passes ($VCI_1$ and $VCI_{50}$) (Priddy and Willoughby, 2006).

The RCI values for the relevant unit of soil groups are provided in Table 3.8, while the VCI values for all considered vehicles are shown in Table 3.4. For example, VCI for 1 and 50 passes of M113 (infantry) is 17 and 40, respectively. Comparison of the RCI with the VCI indicates whether the vehicle can travel through the given soil condition for a prescribed number of passes. In general, if the VCI for a considered soil layer exceeds the corresponding RCI, that soil is not trafficable for the specified number of passes of that particular vehicle; otherwise the soil is trafficable under the described circumstances. For example, if soil has the RCI value of 30, therefore, it is not trafficable for vehicles with VCI values greater than 30 (at a given number of passes). The F4 is calculated from Eq. 3.5. Note that, if F4 ≥ 1 then F4 = 1 and if F4 ≤ 0 then F4 = 0 (No Go).

**Table 3.8** RCI data for different soil units.

| Soil unit | Type | RCI | | Soil unit | Type | RCI | |
|---|---|---|---|---|---|---|---|
| | | Dry | Wet | | | Dry | Wet |
| **GW** | Gravel or Sandy Gravel, Well Graded | 163 | 83 | **CL** | Clays | 123 | 40 |
| **GP** | Gravel or Sandy Gravel, Poorly Graded | 160 | 81 | **OL** | Organic Silts | 111 | 3 |
| **GM** | Gravel, Silty | 120 | 32 | **MH** | Inorganics elastic silts | 114 | 8 |
| **GC** | Gravel or Sand Gravel, Clayed | 130 | 52 | **CH** | Fat clays | 136 | 62 |
| **SW** | Sand, Well Graded | 155 | 78 | **OH** | Fat organic clays | 107 | 1 |
| **SP** | Sand, Poorly Graded | 145 | 73 | **PT** | High organic soils or peat | 106 | 0 |
| **SM** | Sand, Silty | 119 | 25 | **RK** | Rock outcrops | 165 | 165 |
| **SC** | Sand, Clayed | 126 | 46 | **NE** | Not evaluated | Null | Null |
| **ML** | Silts | 118 | 20 | **W** | Open Water | 0 | 0 |

**Note**: The grey highlight is for existing soil units identified in the study area as illustrated in Figure 4.3.

**From:** US Army (1990).

### 3.3.5 Determination of the surface roughness factor (F5)

The surface roughness factor depends on surface materials and its values range at 0 - 1. Normally, lower value indicates higher impact on vehicle trafficability over that surface. The relevant F5 values applied in this study are shown in Table 3.9.

### 3.3.6 Creation of the CCM maps

Eventually, the CCM maps for each specified vehicles can be generated by using Eq. 3.1 and knowledge of the relevant factors (F1 to F5) described earlier.

**Table 3.9** Information of the surface roughness factor data.

| Map Unit (3rd Digit) | Description | Estimated surface roughness factors (F5) | | | |
|---|---|---|---|---|---|
| | | Medium/ large tanks | Large wheeled vehicles | Small Wheeled vehicles | Small Tracked vehicles |
| 0 | No Data | null | null | null | null |
| 1 | No surface roughness effect | 1.00 | 1.00 | 1.00 | 1.00 |
| 2 | Stony soil with scattered surface rock | 0.90 | 0.90 | 0.80 | 0.85 |
| 3 | Stony soil with large rocks | 0.70 | 0.70 | 0.70 | 0.70 |
| 4 | Area with a variety of soils and landscapes | 0.50 | 0.50 | 0.50 | 0.50 |
| 5 | Disturbed areas (quarry, mining and excavations) | 0.20 | 0.20 | 0.20 | 0.20 |
| 6 | Area of high landslide potential | 0.00 | 0.00 | 0.00 | 0.00 |

**Note**: 1. Surface roughness factors are indicated with 0.00 having maximum effect and 1.00 having no impact on CCM.
2. This schema is an RTSD modification of the Defense Mapping Agency (DMA) standard.

**From:** US Army (1990).

## 3.4 Comparison between the breadth first search (BFS) and A* search

This context presents the analysis on capability of two chosen search algorithms, the breadth first search (BFS) and A-star (A*) search, in the finding of the preferred shortest and fastest paths on a generated CCM map (under the provided initial state and target state) (see algorithm in Figures 3.4a and 3.4b). Algorithms for both methods are illustrated in Figures 3.5a and 3.5b, respectively.

As described in Section 2.3.2, the major difference between these two methods is the use of heuristic function in the A* technique [function h(n) in Eq.2.6] but not in the BFS techniques. For the BFS, it searches possible solution from the initial state breadth-wise, level by level without any prior hints or assumptions. In the process, it shall explore all states in one level before jumping to the next level. Once the solution is found the search stops. On the contrary, integration of the heuristic function, in theory, leads to fewer nodes to be explored and less processing time being used to complete the required search for the A* when compared to the BFS.

To examine capacity of the two chosen algorithms, BFS and A*, in determining the shortest or fastest paths of interest, four specific details of their performances, or quality indices, were compared (under the same situation) which are:

(1) Completeness;

(2) Space complexity;

(3) Time complexity; and

(4) Optimality.

More details of each index are given in Table 3.10.

**Table 3.10** Performance criteria for the BFS and A* search algorithms.

| **Performance criteria** | **Details** |
|---|---|
| 1. Completeness | Ability to find its specific solution if one exists. |
| 2. Space complexity | Amount of the memory in use (to find solution). |
| 3. Time complexity | Amount of the processing time in use (to find solution). |
| 4. Optimality | Ability to find the right solution of interest (shortest/fastest path). |

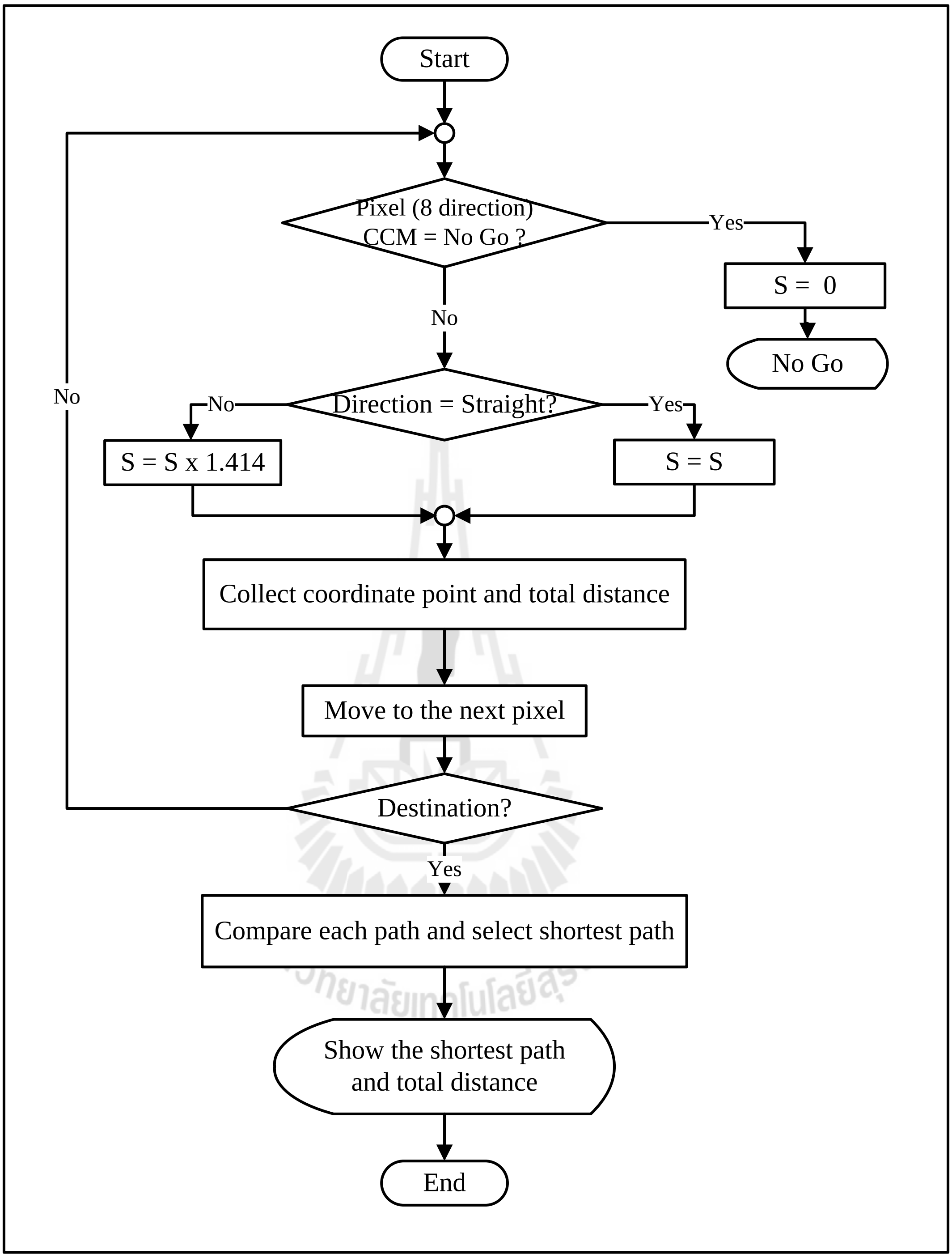



**Figure 3.4a** Algorithm for the determination of shortest path on a given CCM map.

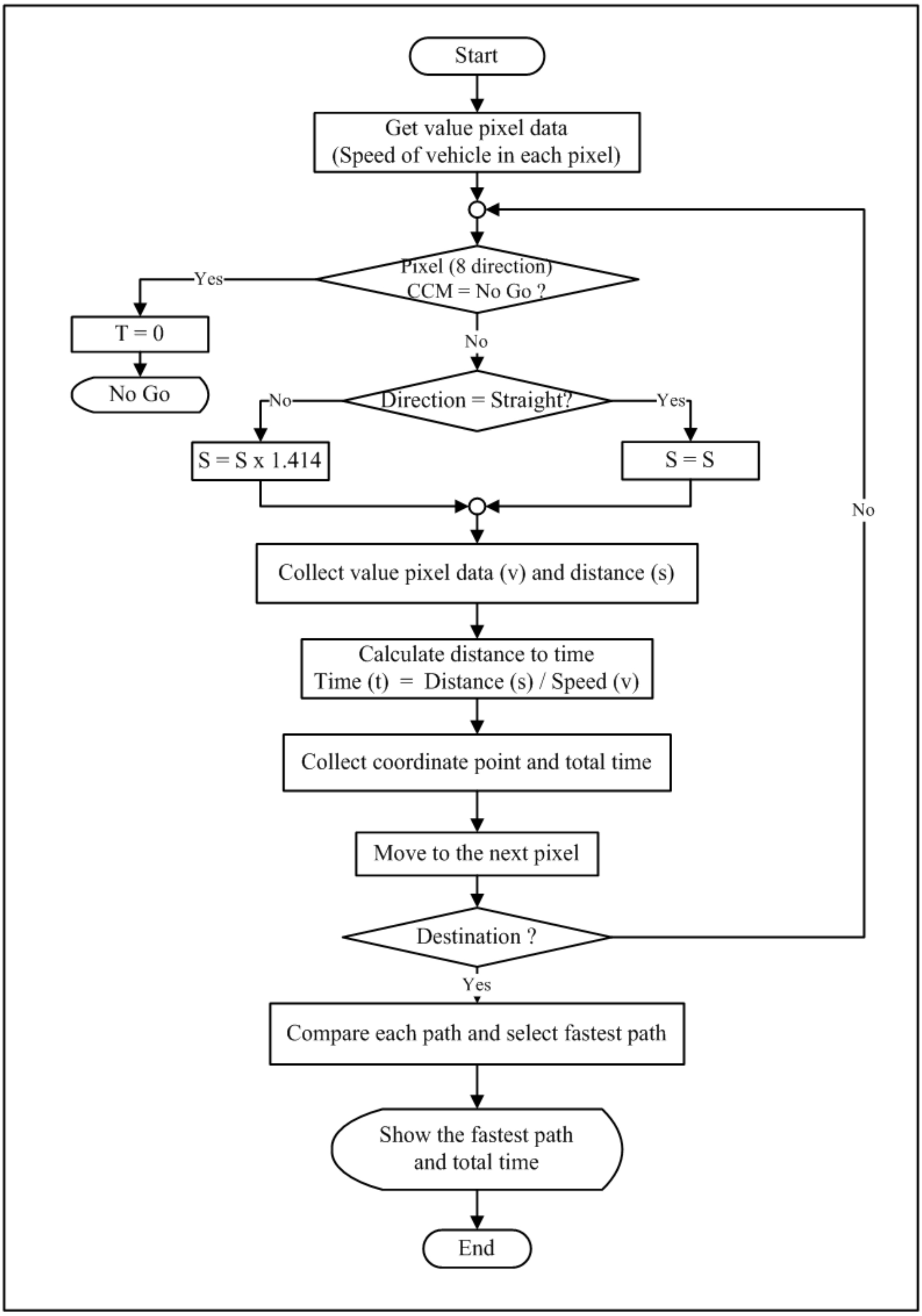



**Figure 3.4b** Algorithm for the determination of fastest path on a given CCM map.

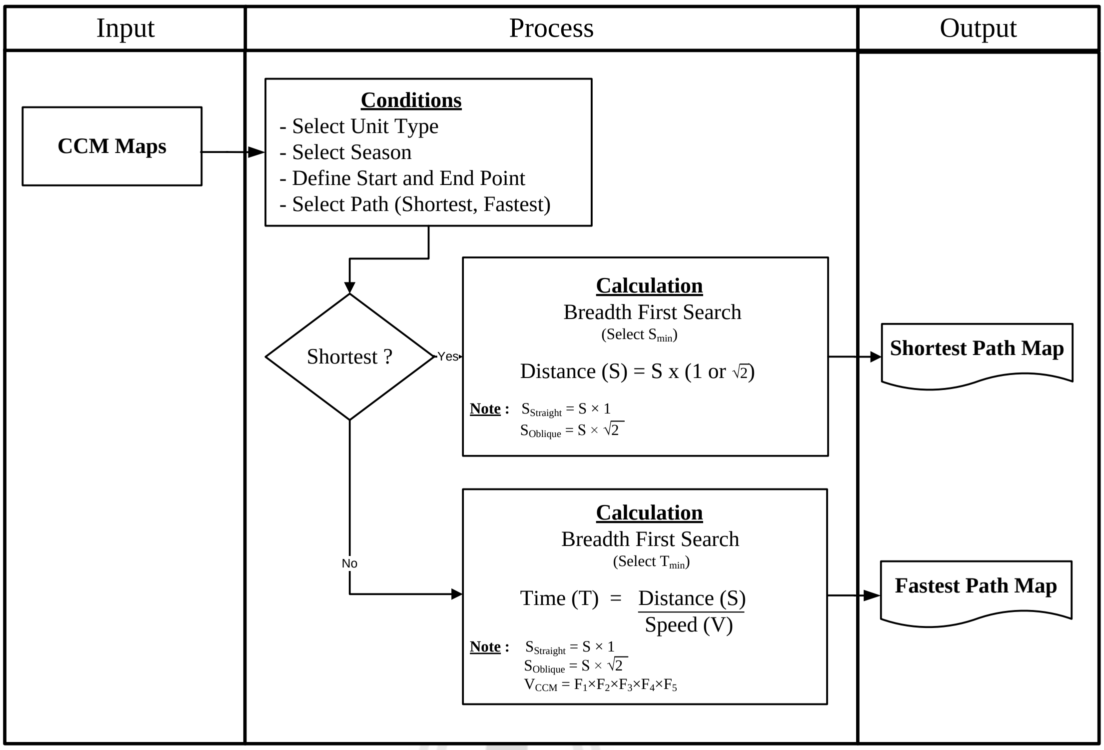



**Figure 3.5a** Work flowchart of the Breadth First Search (BFS) algorithm.

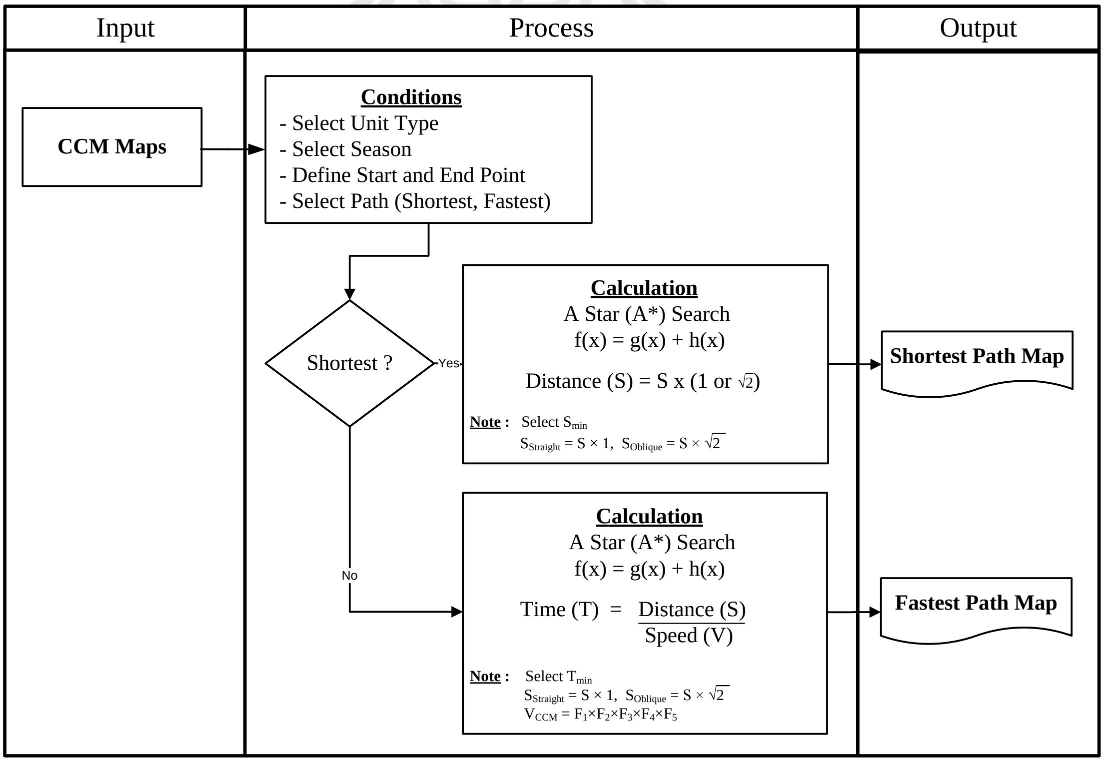



**Figure 3.5b** Work flowchart of the A* search algorithm.

## 3.5 Development of the automatic searching system

The fourth part is to use the superior searching algorithm found in Section 3.4 (BFS or A*) to develop automatic path finding program called "CCM4CM" operating system. To achieve this, the database system was established by the Microsoft Access 2007 and user interface was utilized with Microsoft Visual Basic 2010. Conceptual work flowchart of the program is as shown in Figures 3.4 and 3.5 for each candidate search algorithm respectively. Main outputs of the system are the preferred paths (shortest or fastest condition) over a given CCM map of the interested area.

### 3.5.1 Main components of the system

There are 3 main components of the designed system.

**(1) Administrative component**

This component contains information of all users of the system that can be divided into 2 main groups: administrators and general users. An administrator is a set-up account that has full control of the operating system and can assign basic rights or access level into the system for general users. In contrast, the general users have been granted only specific permissions and level of access to use the system. An administrator account is used to make systematic changes to the system, such as:

(a) Creating or deleting user accounts (general users);

(b) Creating or changing account passwords for the general users;

(c) Modifying or running the operating system; and

(d) Managing or modifying databases needed for the system's operation.

At present, the general users have restricted right only to run the system based on the prepared input data and choices of working modes available (see Figure 3.6 for more details).

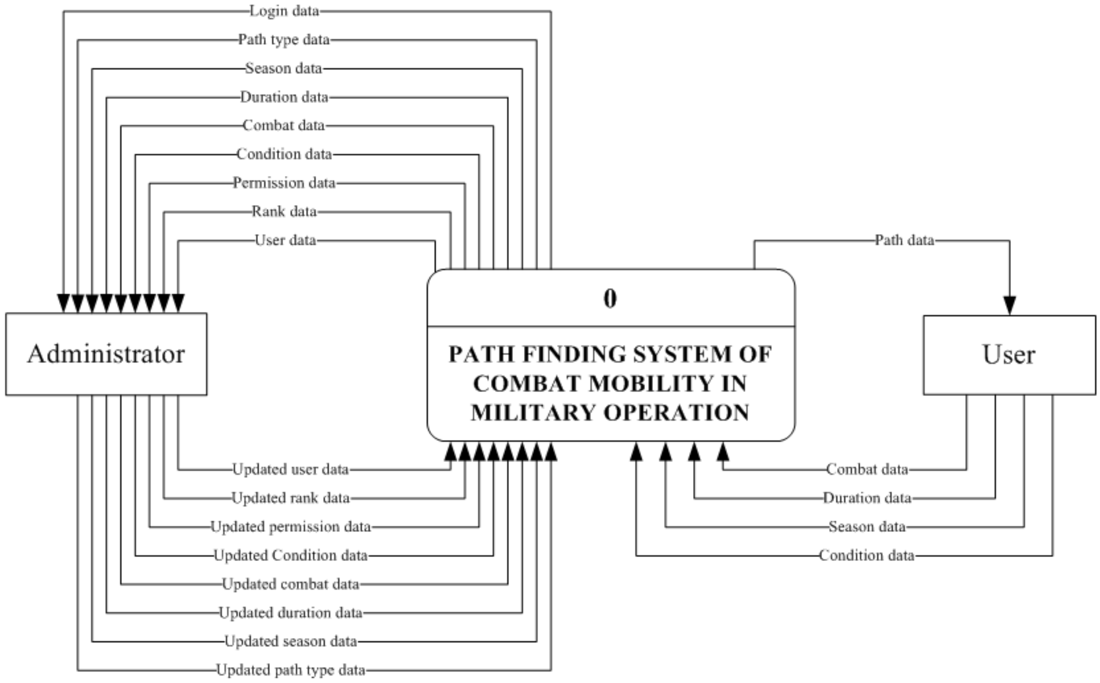



**Figure 3.6** Context diagram showing rights to access and modify system's database of the administrators and general users.



**(2) Operating component**

This component contains operating codes or commands to find possible solutions of the preferred tasks (determination of the shortest or fastest paths under given criteria). The two algorithms in use here (to carry out the stated tasks) are BFS and A* where their processing concepts of are described in Figures 3.5a and 3.5b respectively. Flow diagrams of the data used in the operation are depicted in Figures 3.7 - 3.11. The relevant data dictionary is shown in Section 3.5.3.

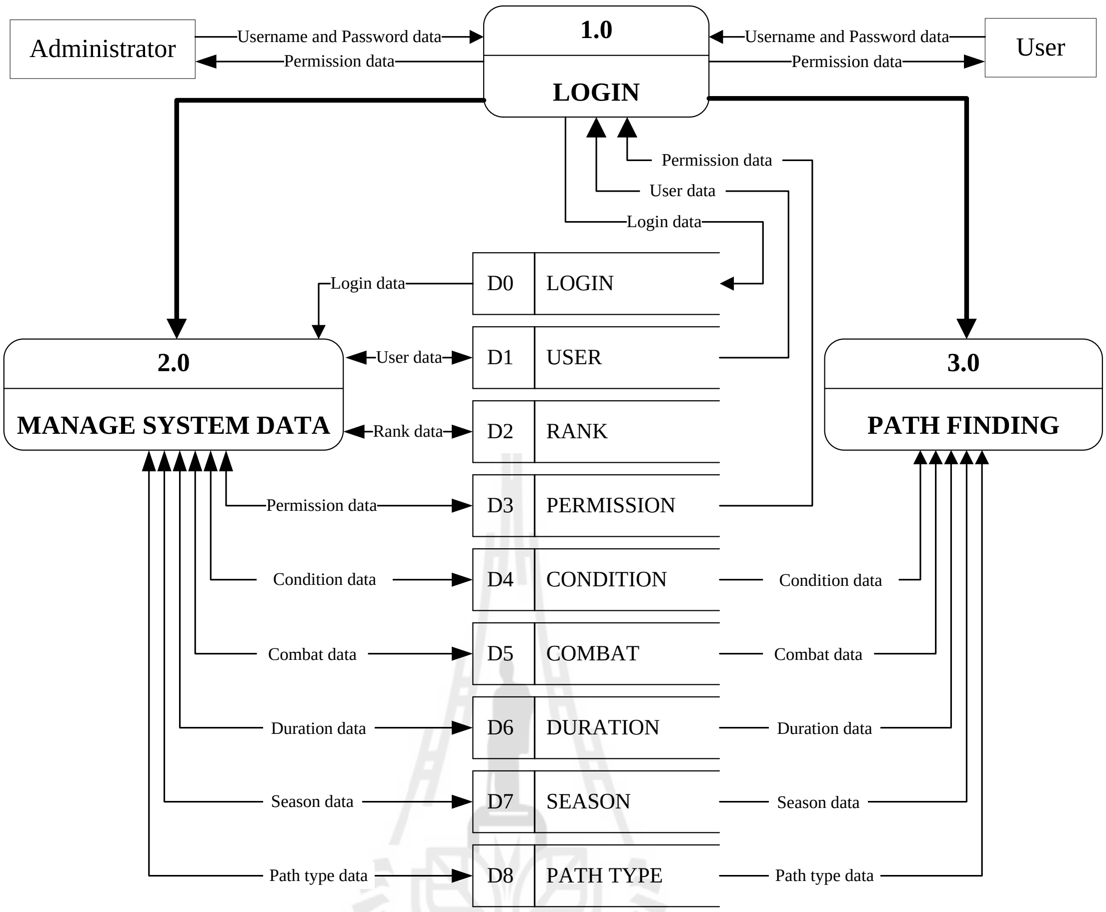



**Figure 3.7** General data flow diagram for the CCM4CM operating system.

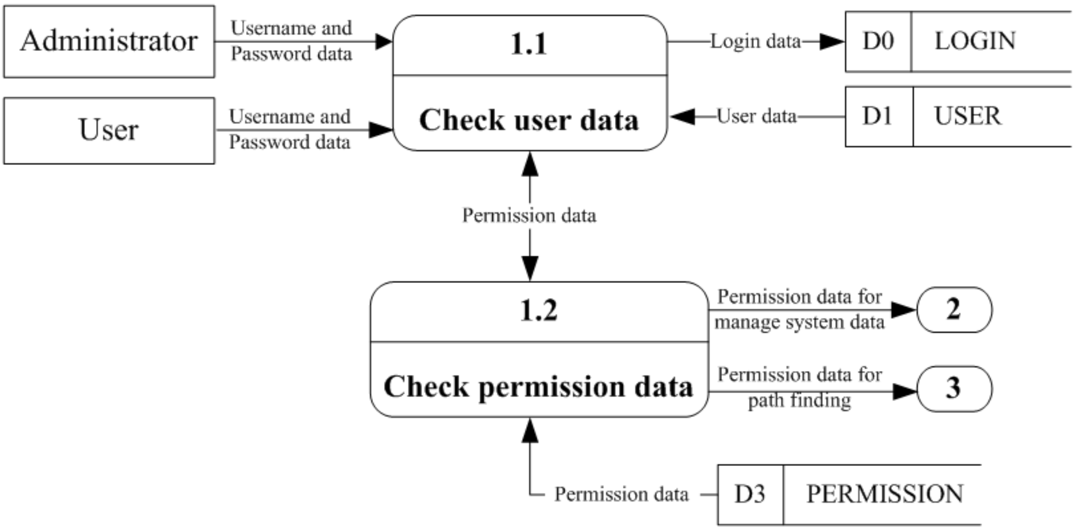



**Figure 3.8** Data flow diagram level 2 of the system login.

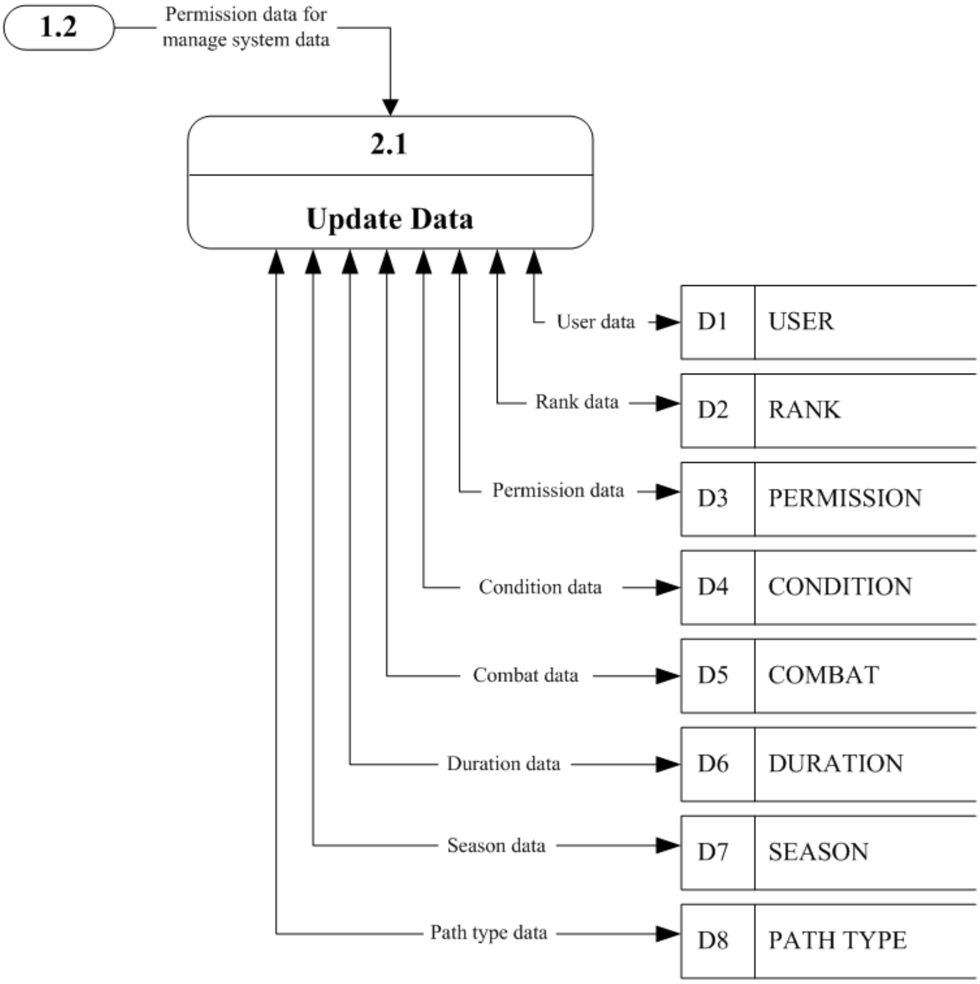



**Figure 3.9** Data flow diagram level 2 of the manage system data.

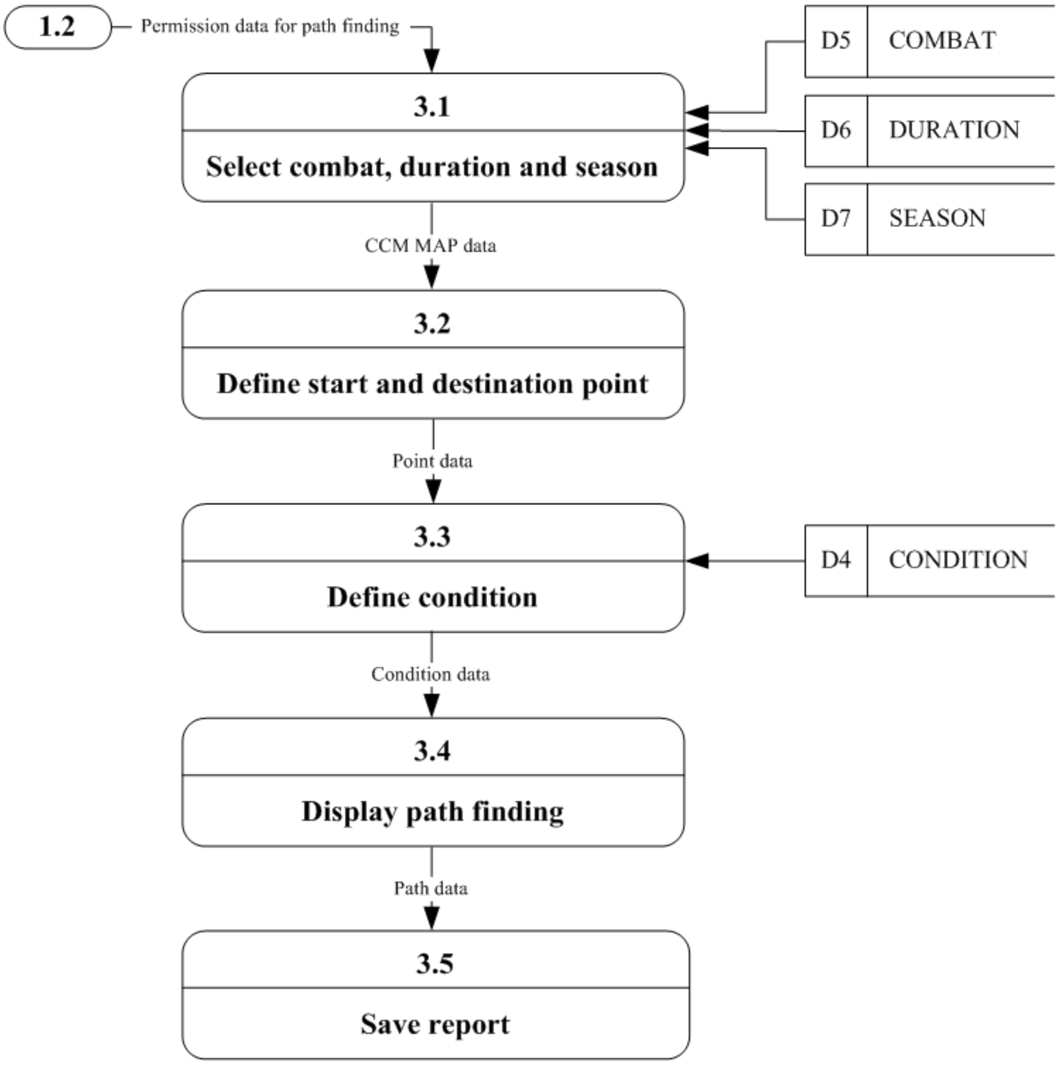



**Figure 3.10** Data flow diagram level 2 of the path finding system.

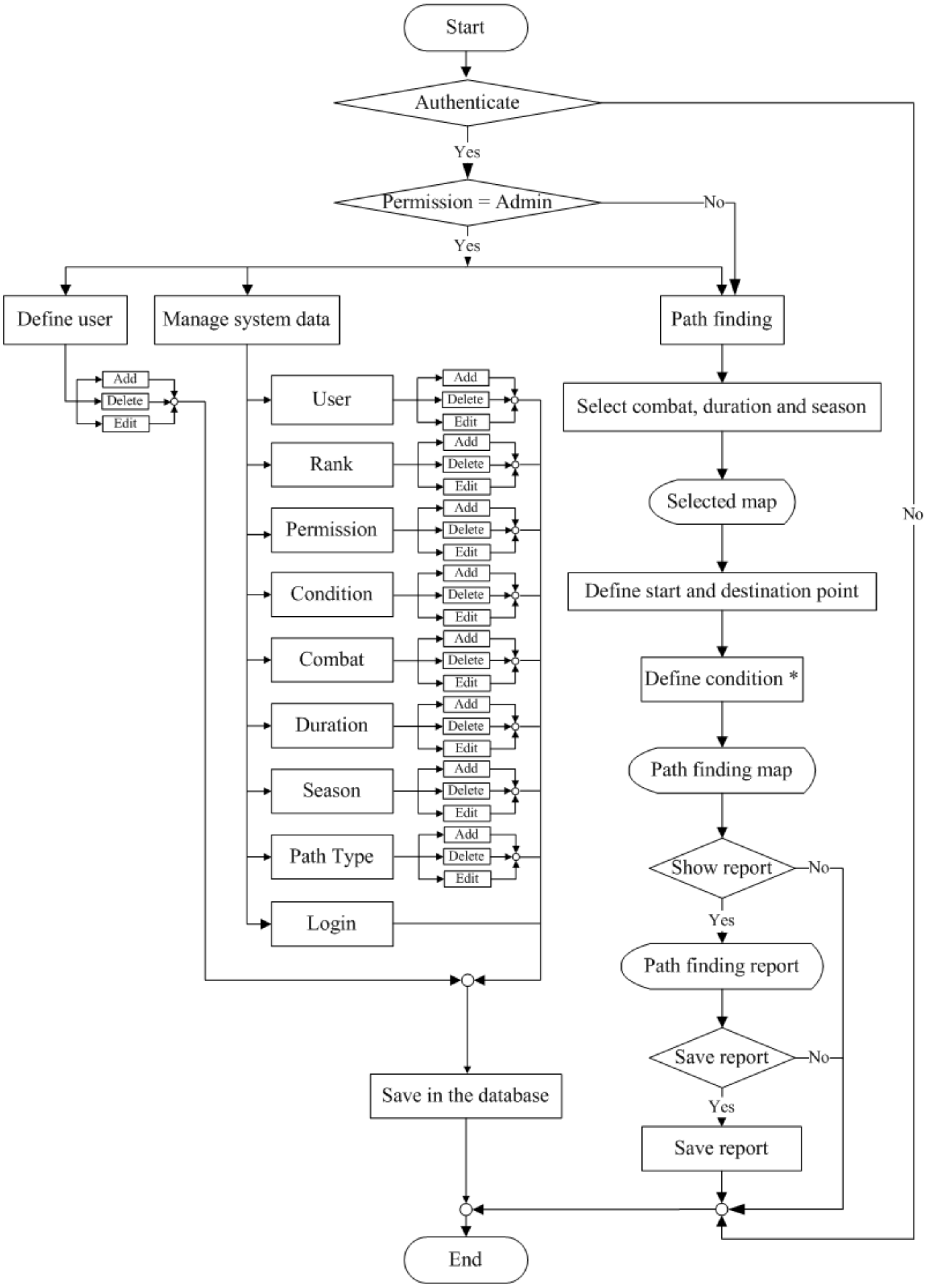



**Figure 3.11** Work flow diagram of the path finding operation.

**(3) Graphic user interface component**

This component contains the accessing interface that separates administrators from general users based on the set-up account and password (Figure 3.12) and the graphic user interface that gives users opportunities to select initial conditions of the processing of interest (Figure 3.13), for examples, type of the preferred route (shortest/fastest), type of combat unit (as stated in Table 3.1), time (day/night), season (dry/wet), and start/end positions. Results of the processing will be reported as continuous lines on map and specific details of the identified routes given in text, e.g. total length, travelling time (Figure 3.13). Table 3.11 compares rights of administrator and general users in using the constructed system.


**Figure 3.12** Graphic user interface of the system.

**Table 3.11** Comparison of rights of the administrator and general user accounts.

| Type of user | User management | Database management | Running the system | Producing output report |
|---|---|---|---|---|
| Administrator | ✓ | ✓ | ✓ | ✓ |
| General user | – | – | ✓ | ✓ |


**Figure 3.13** Structure of the output graphic user interface.

### 3.5.2 Hardware and software components

The aforementioned system was established based on the hardware and software components listed in Tables 3.12 - 3.14. The used hardware specifications are listed in Table 3.12 while suggestions on proper specification of the hardware components are detailed in Table 3.13. Table 3.14 lists actual software components in use in the study.

**Table 3.12** Hardware specifications used in the study.

| **Component** | **Specification** |
|---|---|
| CPU | Intel® Core$^{TM}$ i5 - 2410 M Dual-Core Processor |
| Harddisk | 500 GB 7200 rpm SATA Hard Drive |
| RAM | DDR3 SDRAM at 1333 MHz 4 GB |
| Graphics Card | AMD Radeon HD 6630 M With 1 GB VRAM |
| Operation System | Windows 7 |

**Table 3.13** Minimum and suggested specifications of the suitable hardware.

| Specification | CPU | Harddisk | RAM | Operation System |
|---|---|---|---|---|
| Minimum | ≥ 2.0 GHz | ≥ 2 GB | ≥ 1 GB | Windows XP Professional Service Pack 3<br>Windows Vista Service Pack 2, Windows 7 |
| Suggested | ≥ 2.6 GHz | ≥ 20 GB | ≥ 2 GB | Windows 7 |

**Table 3.14** Software components used in the study.

| Category | Software |
|---|---|
| Operation System | Microsoft Windows 7 Ultimate |
| Database Management System | Microsoft Access 2007 |
| Programming | Microsoft Visual Basic 2010 |
| GIS Software | ArcGIS 9.3.1, MapWinGIS |
| Preparing/presentation data | Microsoft Office 2007, Microsoft Visio 2007 |

### 3.5.3 Database schema diagram and data dictionary

The relevant database schema diagram and data dictionary of the established system stated in Section 3.5.1 are shown in Figure 3.14 and Tables 3.15a - 3.15j, respectively.

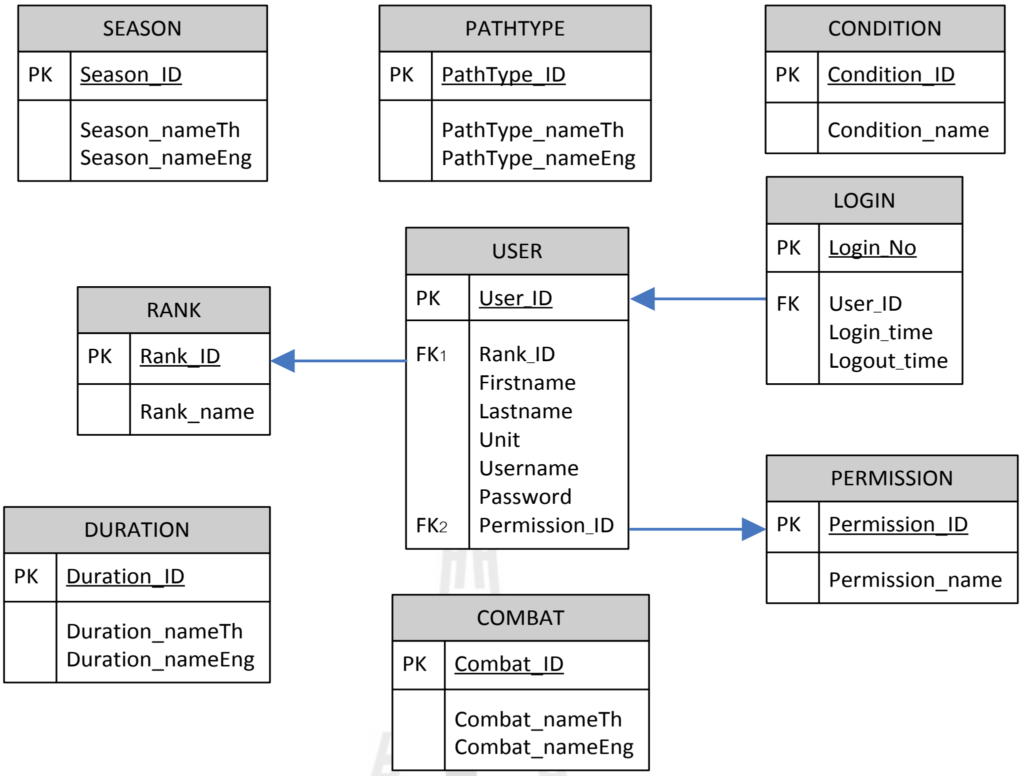



**Figure 3.14** Database schema diagram.

**Table 3.15a** List of the associated data.

| No. | Table name | Description |
|---|---|---|
| 1. | USER | User data |
| 2. | RANK | Rank data |
| 3. | PERMISSION | Permission data |
| 4. | CONDITION | Condition data |
| 5. | COMBAT | Combat data |
| 6. | DURATION | Duration data |
| 7. | SEASON | Season data |
| 8. | PATH TYPE | Path data |
| 9. | LOGIN | Login data |

**Table 3.15b** Details of the USER data.

| Field name | Description | Data type | Size | Key |
|---|---|---|---|---|
| User _ID | User code | Integer | 2 | PK |
| Rank_ID | User rank | Integer | 2 | FK |
| Firstname | User name | Text | 50 | |
| Lastname | User last name | Text | 50 | |
| Permission_ID | User permission code | Integer | 2 | FK |
| Unit | User unit | Text | 50 | |
| Username | User account | Text | 50 | |
| Password | User password | Text | 50 | |

**Table 3.15c** Details of the RANK data.

| Field name | Description | Data type | Size | Key |
|---|---|---|---|---|
| Rank _ID | Rank code | Integer | 2 | PK |
| Rank_name | Rank name | Text | 50 | |

**Table 3.15d** Information of the COMBAT data.

| Field name | Description | Data type | Size | Key |
|---|---|---|---|---|
| Combat_ID | Unit code | Integer | 2 | PK |
| Combat _nameTh | Unit name (Thai) | Text | 50 | |
| Combat _nameEng | Unit name (English) | Text | 50 | |

**Table 3.15e** Details of the LOGIN data.

| Field name | Description | Data type | Size | Key |
|---|---|---|---|---|
| Login _No | Login number | Integer | 2 | PK |
| User_ID | User code | Text | 50 | FK |
| Login_time | Login time | Data/Time | | |
| Logout_time | logout time | Data/Time | | |

**Table 3.15f** Details of the PERMISSION data.

| Field name | Description | Data type | Size | Key |
|---|---|---|---|---|
| Permission_ID | Permission code | Integer | 2 | PK |
| Permission_name | Permission name | Text | 50 | |

**Table 3.15g** Details of the CONDITION data.

| Field name | Description | Data type | Size | Key |
|---|---|---|---|---|
| Condition_ID | Condition code | Integer | 2 | PK |
| Condition_name | Condition name | Text | 50 | |

**Table 3.15h** Details of the DURATION data.

| Field name | Description | Data type | Size | Key |
|---|---|---|---|---|
| Duration_ID | Duration code | Integer | 2 | PK |
| Duration_nameTh | Duration name (Thai) | Text | 50 | |
| Duration_nameEng | Duration name (English) | Text | 50 | |

**Table 3.15i** Details of the SEASON data.

| Field name | Description | Data type | Size | Key |
|---|---|---|---|---|
| Season_ID | Season code | Integer | 2 | PK |
| Season_nameTh | Season name (Thai) | Text | 50 | |
| Season_nameEng | Season name (English) | Text | 50 | |

**Table 3.15j** Details of the PATH TYPE data.

| Field name | Description | Data type | Size | Key |
|---|---|---|---|---|
| PathType_ID | Path type code | Integer | 2 | PK |
| PathType_nameTh | Path type name (Thai) | Text | 50 | |
| PathType_nameEng | Path type name (English) | Text | 50 | |

# CHAPTER IV

# CONSTRUCTION OF THE CCM MAPS

This chapter reports results of the CCM map derivation detailed in Chapter 3. These include data collection, GIS dataset construction, and resulting CCM maps for each combat unit of interest, respectively.

## 4.1 Results of data collection and GIS dataset construction

Collected data were divided into 2 groups.

### 4.1.1 Combat unit

At present, the Royal Thai Army (RTA) has been divided into 13 corps with different missions and functions (e.g., infantry, cavalry, artillery, engineer, medical). Among these, the main two corps that have direct functions relating to the combat are infantry and cavalry. As a consequence, these are a prime interest of the study in which only main vehicles of each combat unit are considered as follows:

(1) Infantry

The infantry is the main land combat force and core fighting strength of the army. For the RTA, there are three main types of the infantry:

(a) Standard infantry

Standard infantry are not equipped with armored vehicles, and trained specifically to fight on foot to engage the enemy face to face.

(b) Armored infantry

Armored infantry are equipped with warrior armored personnel carriers (APC), or infantry fighting vehicles (IFV). They can be tracked or wheel vehicles that are able to deploy for troop transportation and combat. The main vehicle being chosen for this study is the M113 APC (Figure 4.1a).

(c) Mechanized infantry

Mechanized infantry are equipped with the transport armored personnel carrier, or cargo trucks, for the transportation of troops and military supplies. Example of the vehicle chosen for this study is M35 truck (Figure 4.1b).

(2) Cavalry

Originally, cavalry were troops trained to fight on the horseback (horse cavalry). Nowadays, they become a highly mobile army unit using motor vehicles, e.g., light armor or helicopters. There are three main cavalry units in the RTA:

(a) Tank cavalry

The main missions of this unit are to operate and destroy the enemy with artillery tanks. The vehicle selected for the study is Stingray tank (Figure 4.1c).

(b) Armored cavalry

The armored cavalry began to replace horse cavalry in most armies after the First World War. It differs from the regular armor units in that the main armored fighting vehicles (AFV) were armored or scout cars, with some light or medium tanks or infantry in trucks rounding out the unit. Main vehicle chosen for this study is M113.

(c) Reconnaissance cavalry

The unit is responsible for exploring beyond areas occupied by friendly forces to obtain information about enemy forces or features of the field environment.

A reconnaissance vehicle, also known as a scout vehicle, is a military vehicle used for forward reconnaissance and one to be studied here is the Scorpion tank (Figure 4.1d).

(a) M113

(b) M35 truck

(c) Stingray tank


(d) Scorpion tank

**Figure 4.1** Type of the main vehicles chosen for each considered military unit listed in Table 4.1: (a) M113; (b) M35 truck; (c) Stingray tank; and (d) Scorpion tank.

Characteristic of the aforementioned vehicles stated earlier are as summarized in Table 3.4.

### 4.1.2 Data preparation process and products

The factors involved include surface slope, soil, vegetation cover, water and transportation. The relevant details are seen in Tables 4.1 and 4.2. Characteristics or format of all gained data were examined and transformed to be in required format for the use in the CCM map derivation process (in form of the GIS data layers and .dbf files). The main process also includes the clipping and converting polygon or polyline into 30 × 30 meters raster cells.

(1) Surface slope

The slope data covering the whole study area were prepared by Department of Survey Engineering, Chulalongkorn University at scale of 1:50,000 (Figure 4.2). Slope levels have significant impacts on the military operations, especially, the slowed-down movement of vehicles on the steep slopes.

(2) Soil

The data were modified from original data gained from the RTSD at scale of 1:50,000 using the Unified Soil Classification System (USCS) (Figure 4.3). Type of soil can limit maximum possible speed for mobility of the combat unit but the magnitude of this effect will be different for different vehicles. For example, a tracked vehicle will perform better in "soft" soils such as sand than a wheeled vehicle will.

(3) Vegetation cover

These data were classified by RTSD and rechecked by MNRE (Figure 4.4). Vegetation can significantly influence military tactics, decisions, and operations, notably the natural concealment or effective movement of troops and vehicles.

(4) Water

These data were acquired from the MNRE and had been separated into two seasons, dry and wet (Figures 4.5a and 4.5b). Location, size and form of surface water features (rivers, streams, etc.) can affect the cross-country movement, notably to limit or enhance troop or vehicle movements.

**Table 4.1** Data layers applied in the present study.

| Data Layer | Data Type | Scale | Source | Year |
|---|---|---|---|---|
| Slope | Raster | 30 x 30 m. | CU | 2007 |
| Soil | Polygon | 1:50,000 | RTSD | 1999 |
| Vegetation cover | Polygon | 1:50,000 | RTSD, MNRE | 2004 |
| Water | Polygon, Polyline | 1:50,000 | MNRE | 2004 |
| Road | Polyline | 1:50,000 | DOH | 2004 |

**Note:** CU = Chulalongkorn University, RTSD = Royal Thai Survey Department.
DOH = Department of Highways, MNRE = Ministry of Natural Resources and Environment.

**Table 4.2** Specific sub-classes of the terrain/LULC category (grid-based structure).

| Factor | Sub-classes | Output maps | Remark |
|---|---|---|---|
| Surface slope (%) | 0 - 3, 3 - 10, 10 - 20, 20 - 30, 30 - 45, $\geq$45 | Fig. 4.2 | for F1, F2 |
| Soil (group) (USCS system) | Fat clay (CH), clay (CL), silt (ML), rock outcrop (RK), sand/silty (SM), poorly-graded sand (SP) | Fig. 4.3 | for F4, F5 |
| Vegetation (type) | Dry crops, wet crops/rice, terraced crops, built-up area, coniferous/evergreen forest, grassland with scattered trees, mixed forest (coniferous/deciduous), orchard/plantation | Fig. 4.4 | for F3 |
| Water body (0/1) | Water (1), No water (0) | Dry season [Fig. 4.5(a)]<br>Wet season [Fig. 4.5(b)] | 1 (No Go),<br>0 (Go) |
| Road (0/1) | Road (1), No road (0) | Dry season [Fig. 4.6(a)]<br>Wet season [Fig. 4.6(b)] | 1 (Go),<br>0 (No Go) |

(5) Transportation

These data were obtained from the DOH and had been separated into two seasons, dry and wet (Figures 4.6a and 4.6b). These consist of all highways, railways, waterways over which the troops or supplies can be moved over. The importance of the data depends on nature of the military operation involved. Trafficability in cross-country movement is greatly influenced by the availability of road or railway network of the area. A well-paved road can support the speeds close to the maximum, but in the cross-country mobility, maximum theoretical speed of any listed vehicle is reduced by the encountered environmental factors along the path.

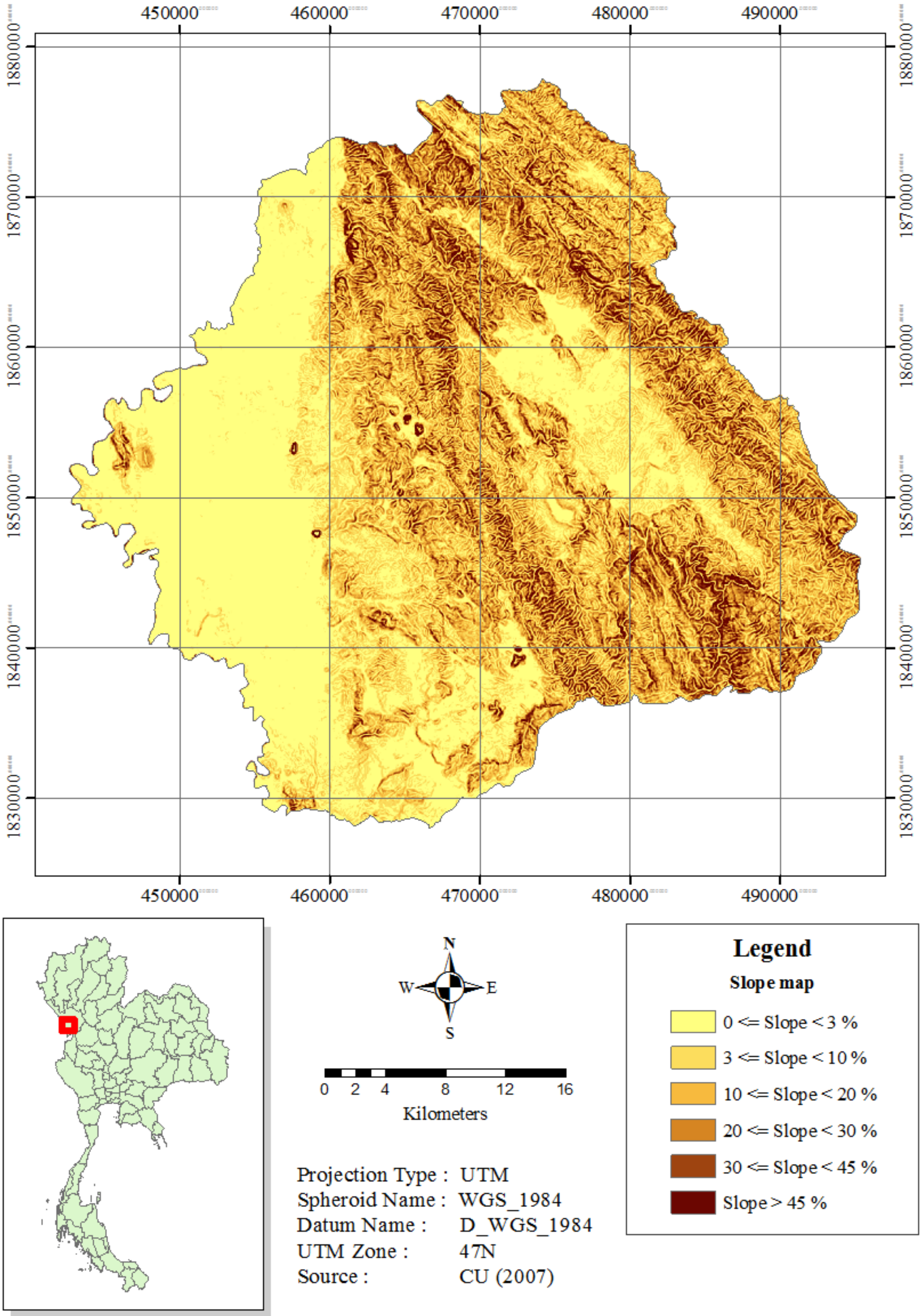
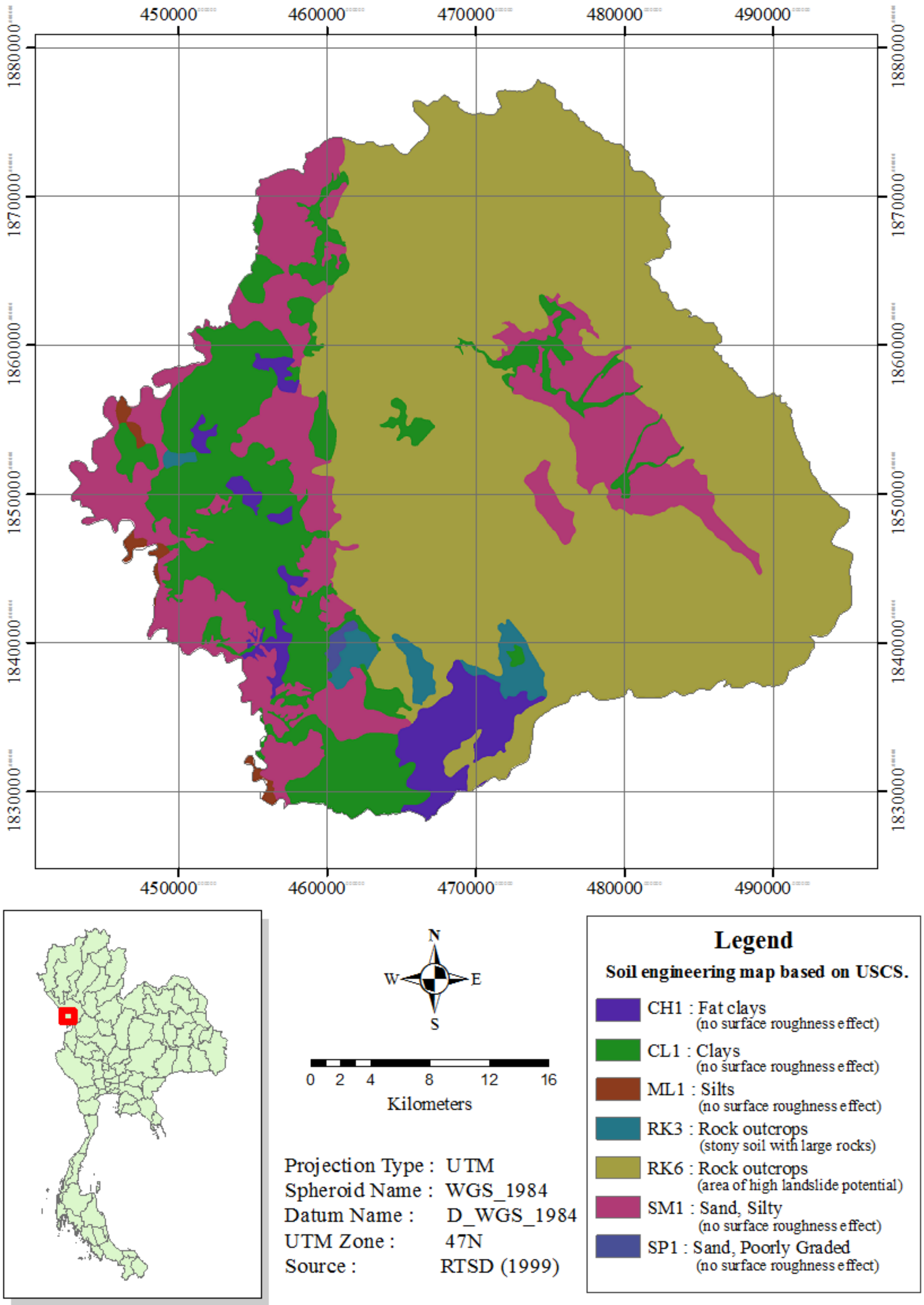



**Figure 4.2** Slope map.




**Note:** The given number at each soil type is for the identification of surface roughness factor data (Table 3.9).

**Figure 4.3** Soil engineering map based on the USCS.

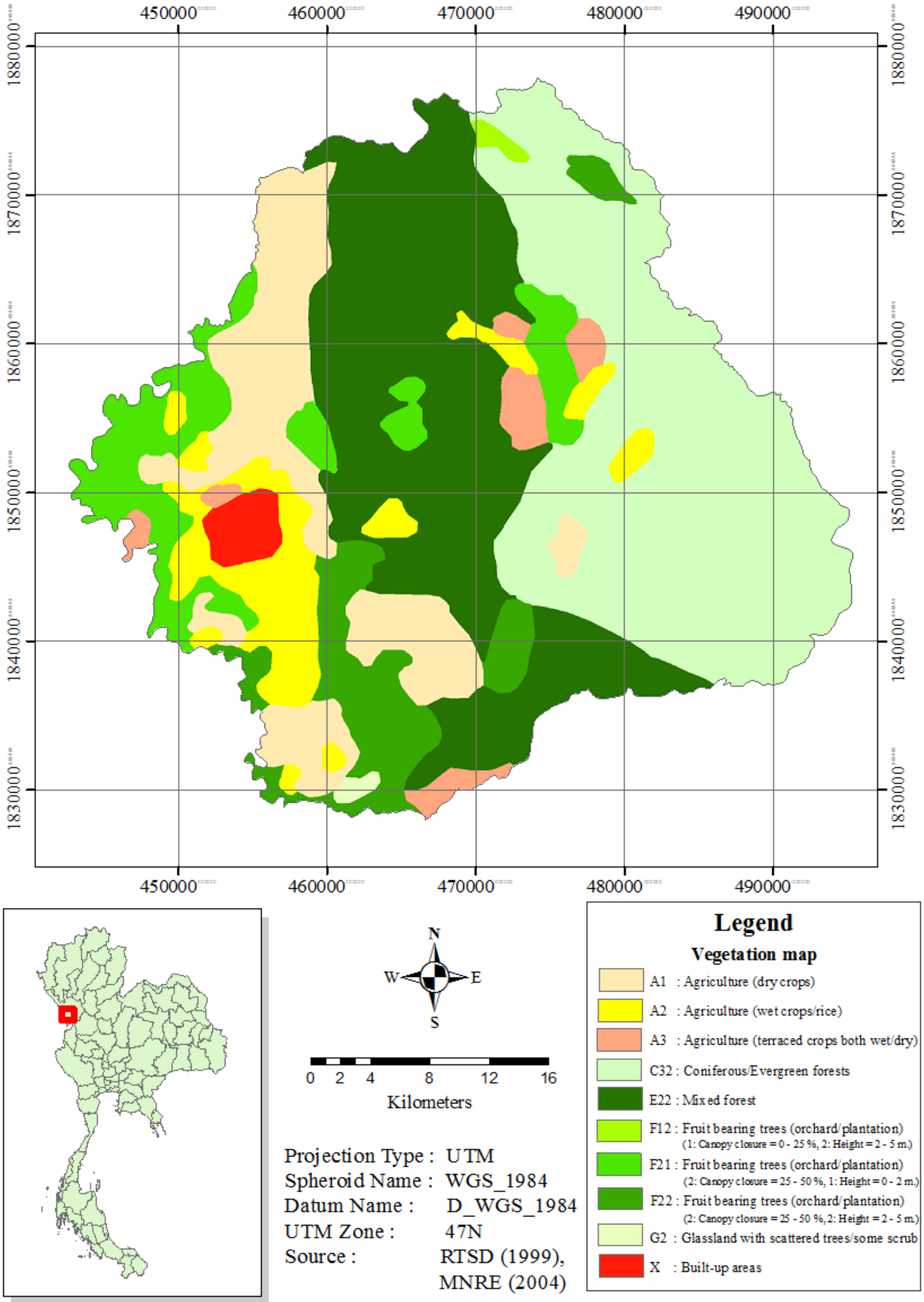



**Figure 4.4** Vegetation map.

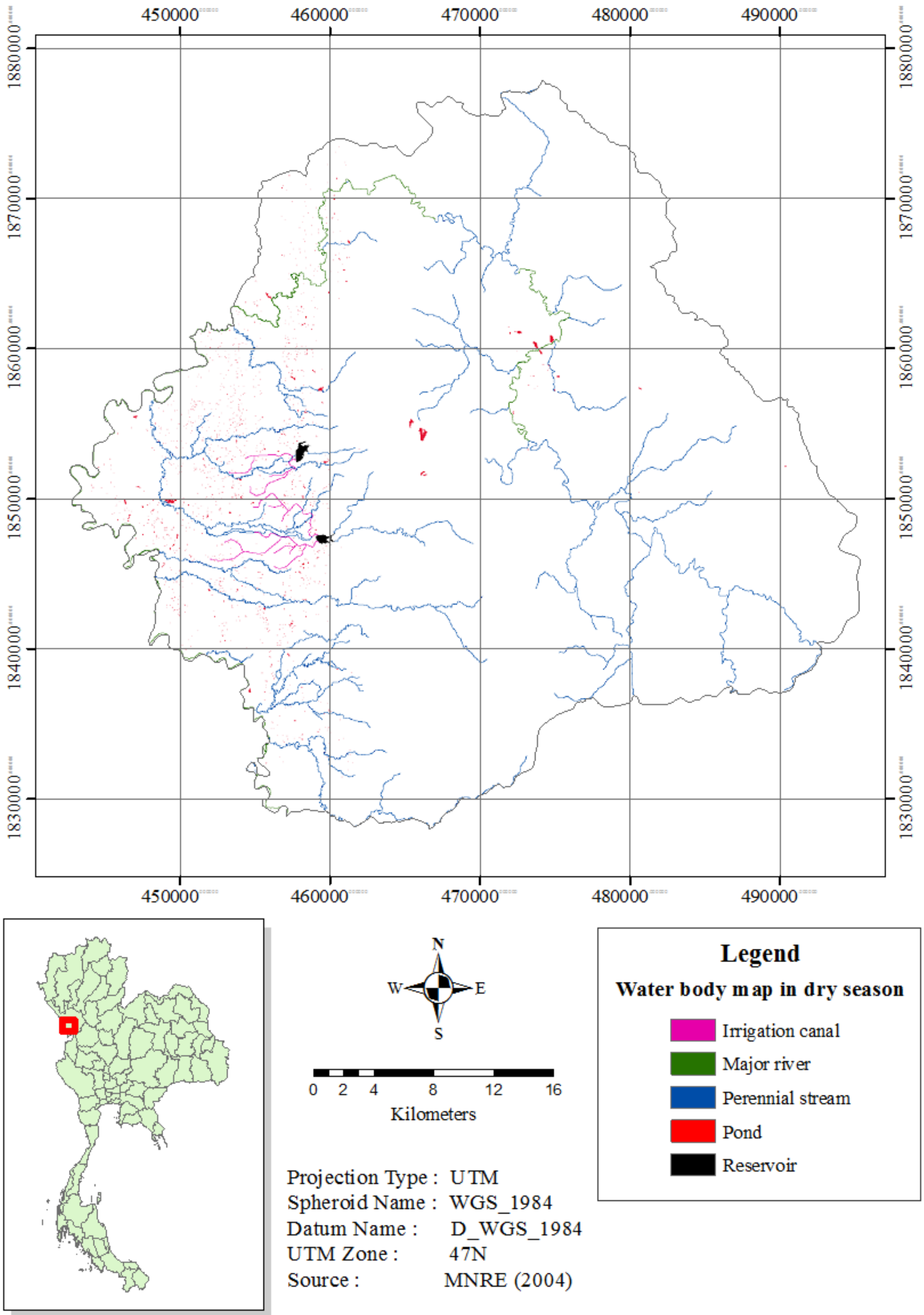



**Figure 4.5a** Water body map in dry season.

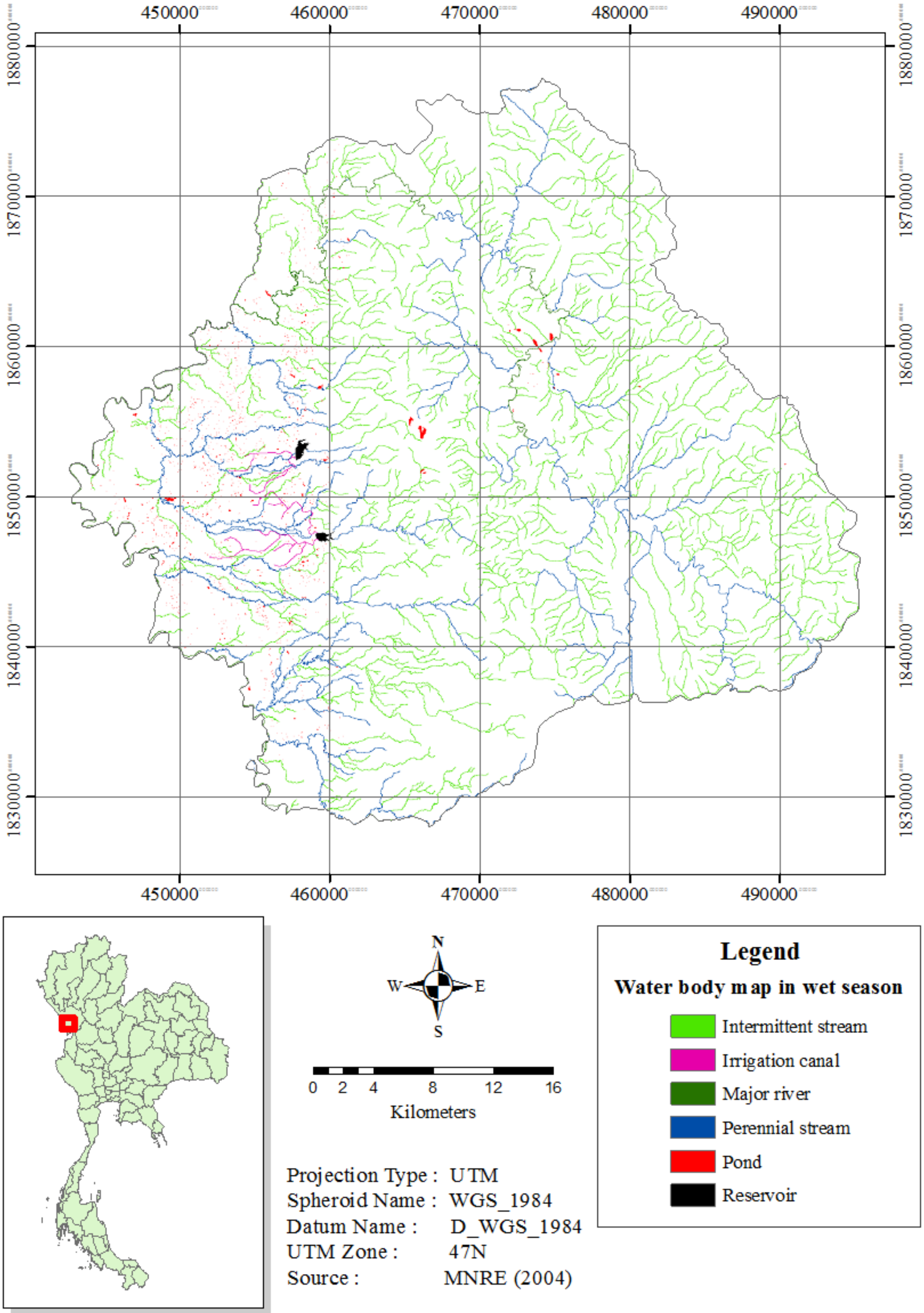



**Figure 4.5b** Water body map in wet season.

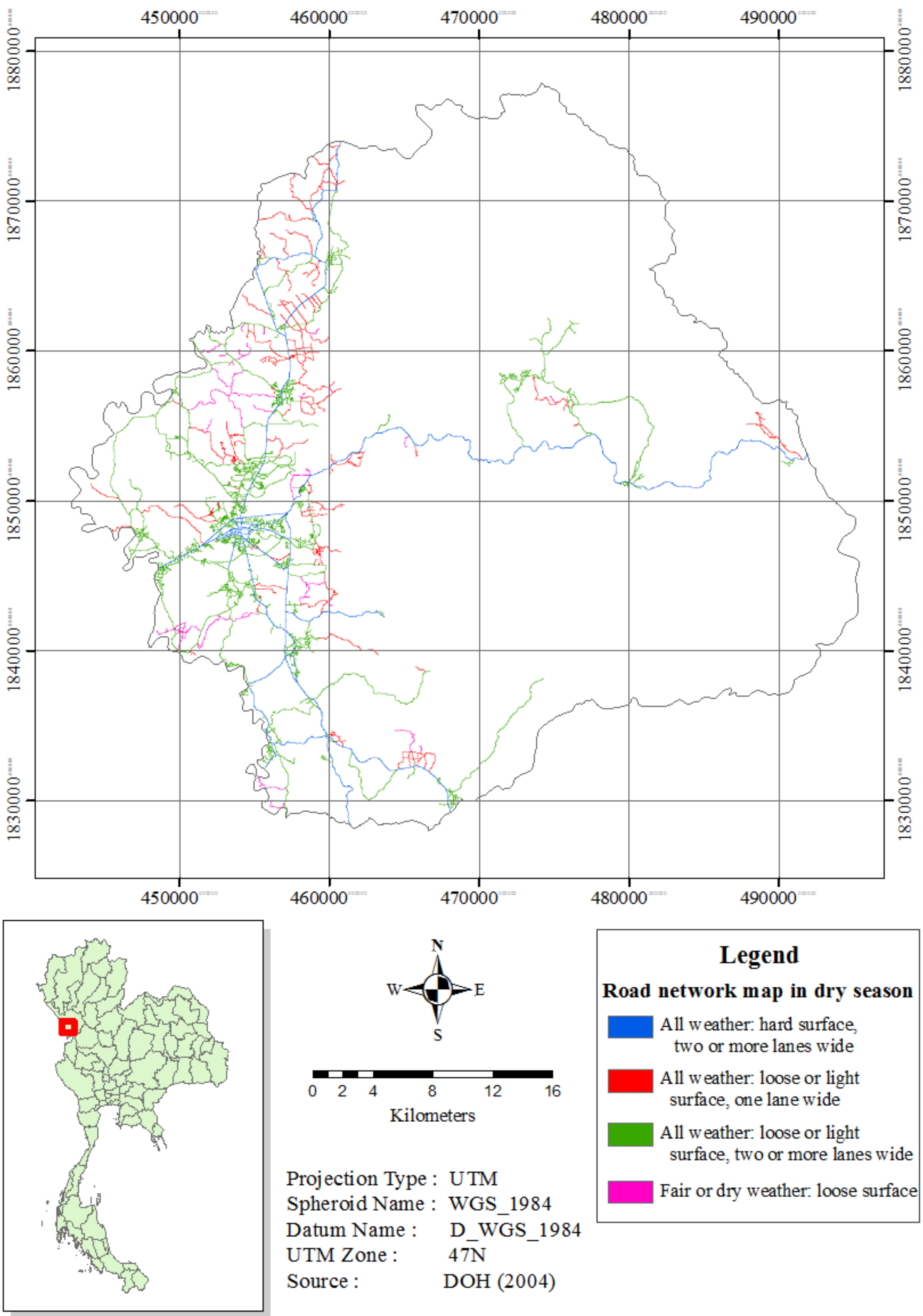



**Figure 4.6a** Road network map in dry season.

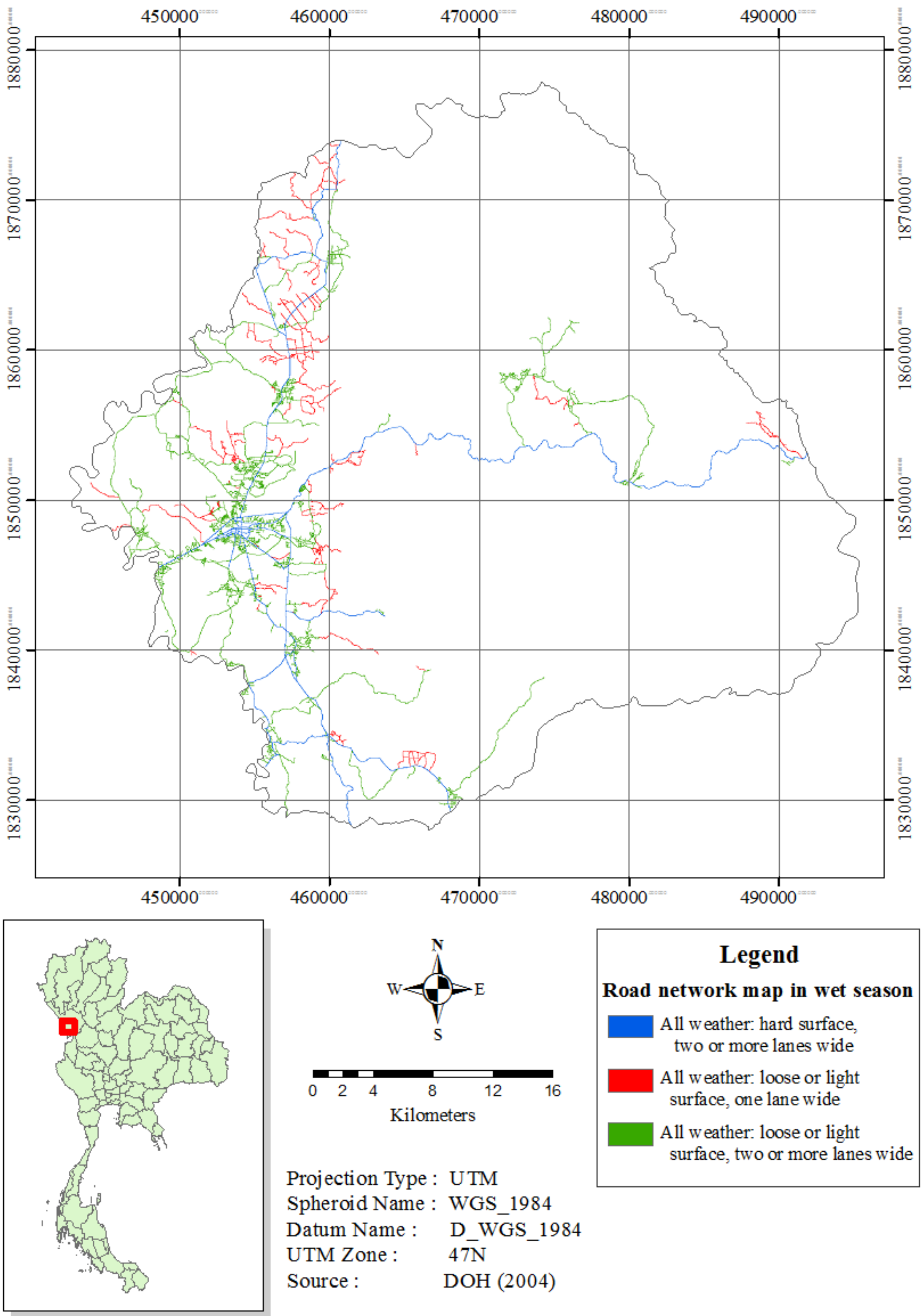



**Figure 4.6b** Road network map in wet season.

## 4.2 Results of the CCM factor construction

The CCM maps (for each chosen vehicle/troop unit mentioned in Table 3.1) were produced based on relationship given in Eq. 3.1:

$$V\ (\text{kph}) = F1 \times F2 \times F3 \times F4_{D/W} \times F5, \tag{3.1}$$

where F1 to F5 represent key terrain and environmental characteristics of the study area, F1 is speed/slope factor, F2 is slope-intercept-frequency (SIF) factor, F3 is vegetation factor, F4 is soil factor, and F5 is surface roughness factor. The formulas used to calculate F1 to F5 factors are given in Table 3.3 and needed vehicle data are given in Table 3.4 and Figures 4.2 - 4.6.

Figures 4.7a - 4.7d present the derived F1 maps (speed/slope factor) for the M113, M35, Stingray and Scorpion vehicles, respectively. The obtained F1 values on each map were divided into 3 categories: No Go (0 - 1.5 km/hr), Slow Go (1.5 - 30 km/hr), Go (> 30 km/hr). It was found that, for all four vehicles stated above, their Go areas mainly concentrate on the rather flat portion of the district on the western side, e.g. areas with slope 0 - 3%, while the No Go areas situate mainly along high slope areas (mountainous region) on the middle and eastern parts of the district with the Slow Go areas distribute in-between. Among the four considered vehicles, the Scorpion tank can attain the highest moving speed in the area (regarding to the found maximum F1 values) at about 54.29 km/hr (Figure 4.7d) while the M35 truck cannot move faster than 30 km/hr (Figure 4.7b). Note that, the potential maximum speed for each type of the vehicle occurs when surface slope equals zero (in Eq. 3.2) and the results are as seen in Table 3.5 (for surface slope = 0).

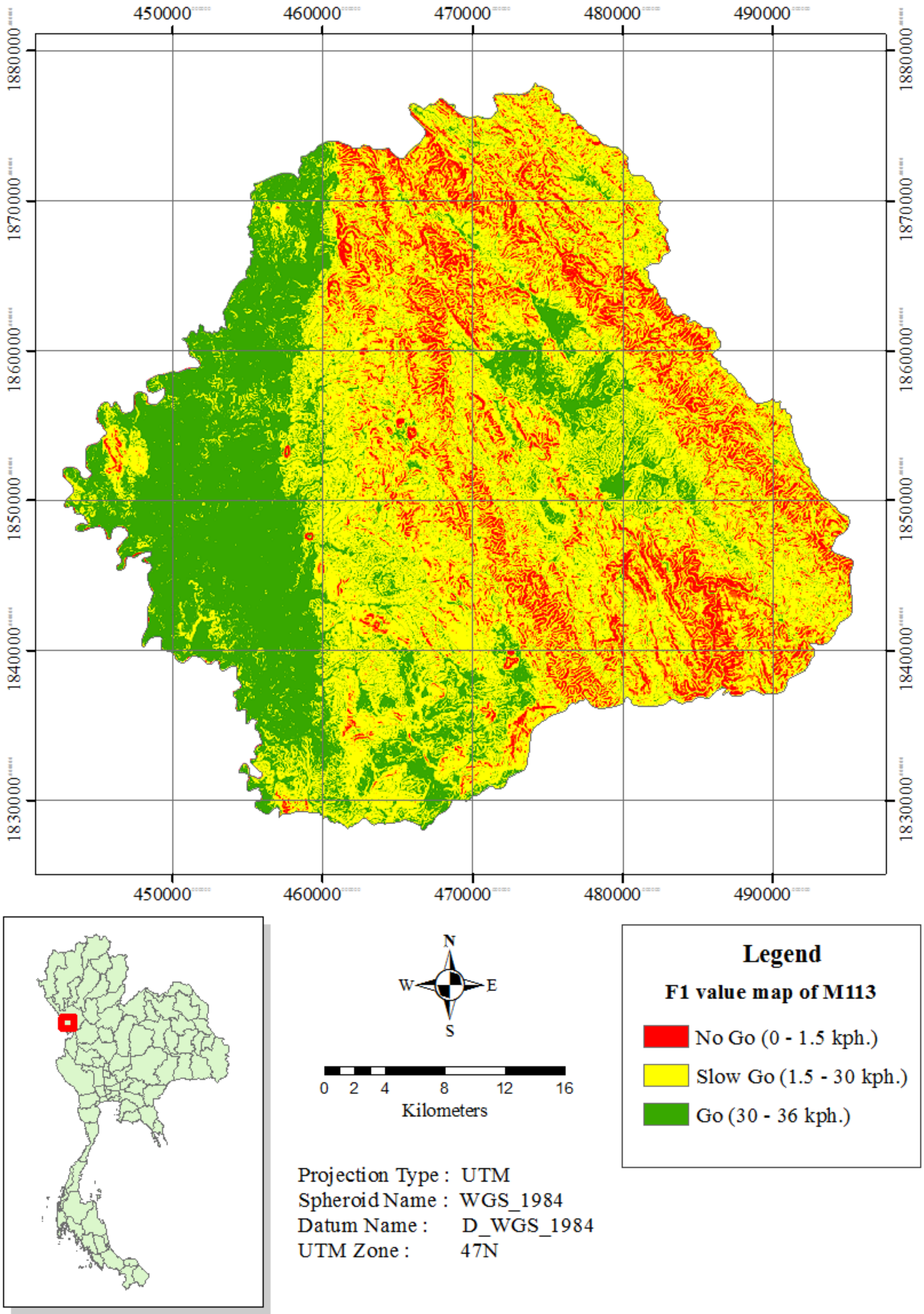



**Figure 4.7a** Speed/slope factor (F1) map for the M113.

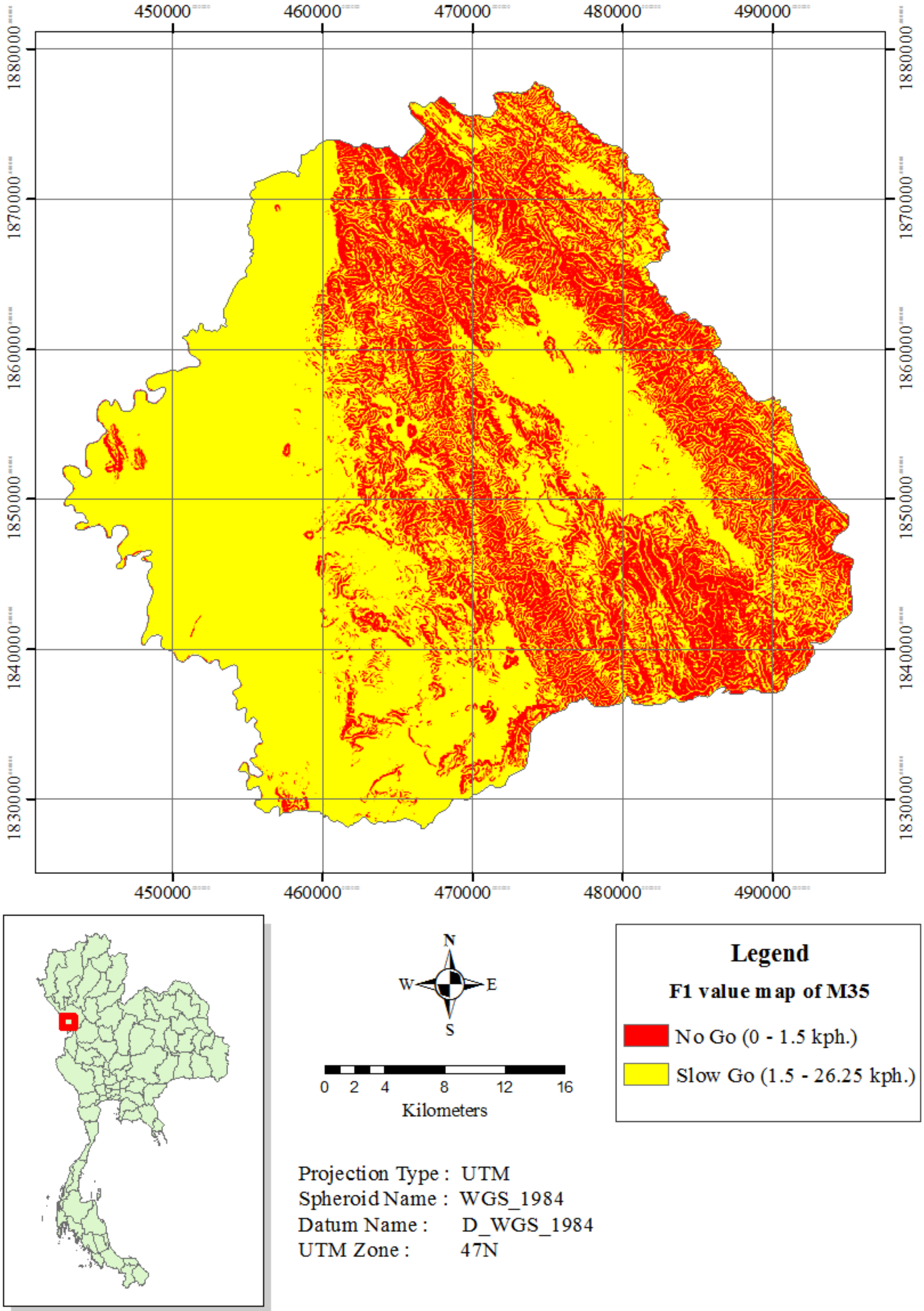



**Figure 4.7b** Speed/slope factor (F1) map for the M35.

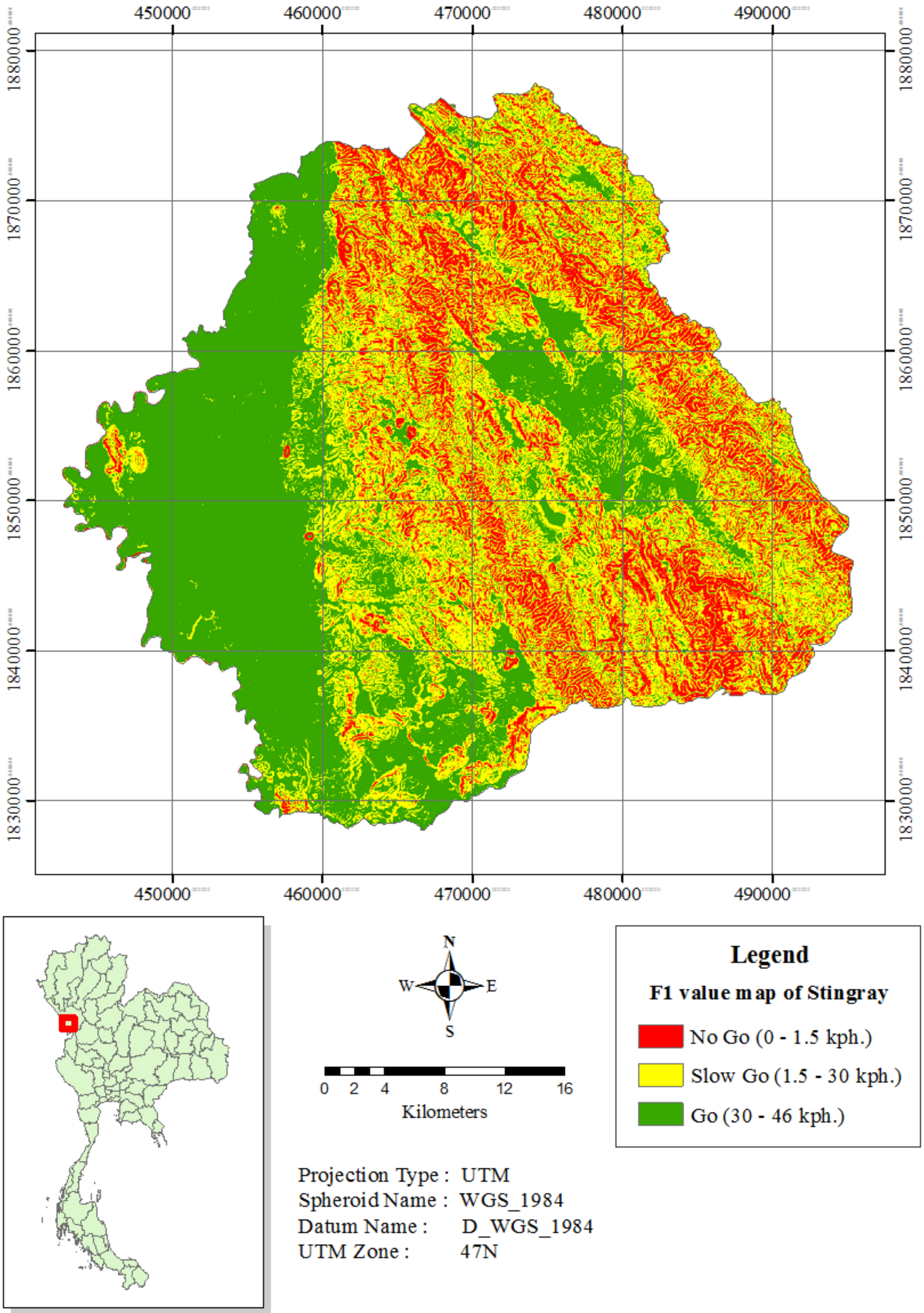



**Figure 4.7c** Speed/slope factor (F1) map for the Stingray.

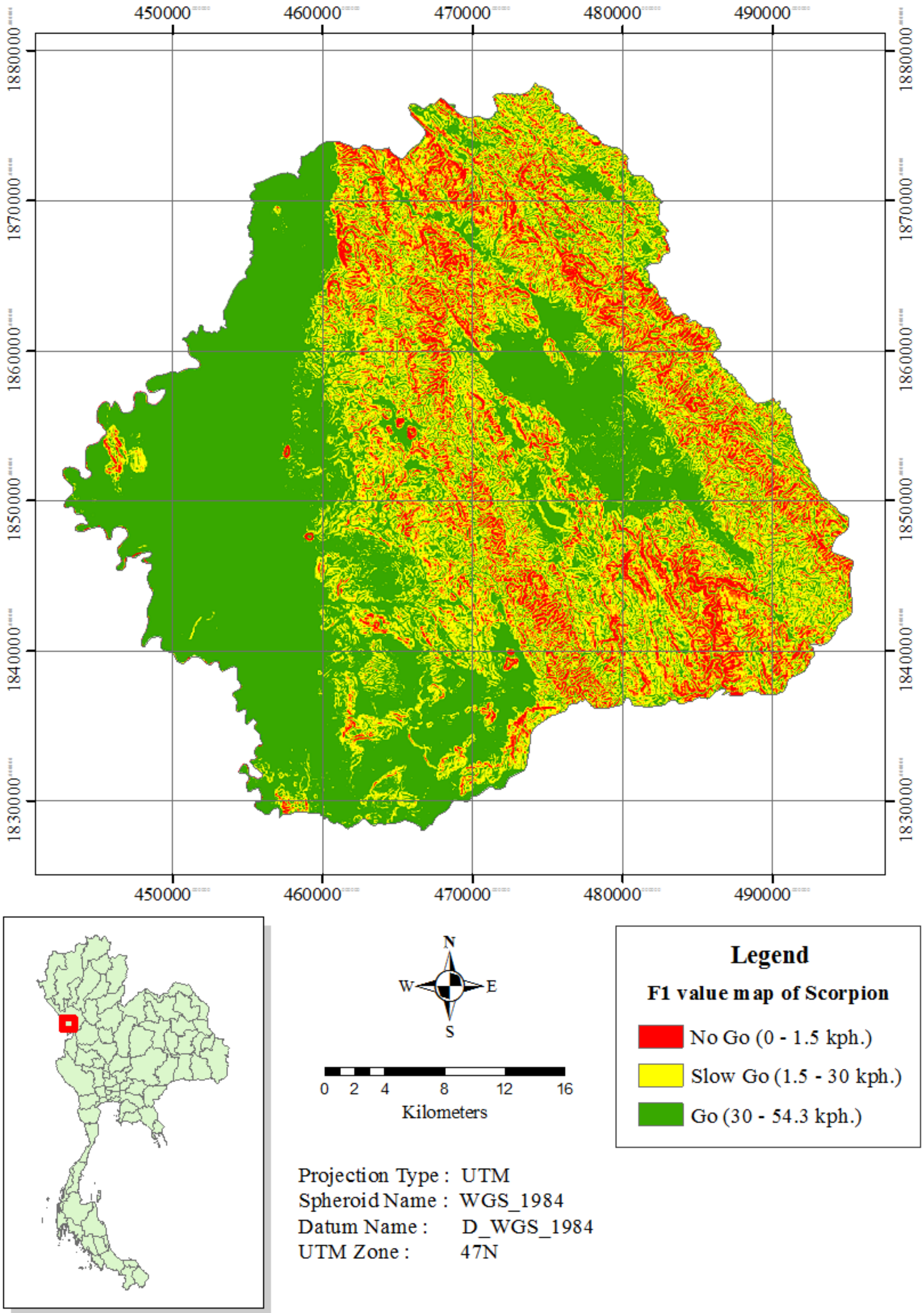



**Figure 4.7d** Speed/slope factor (F1) map for the Scorpion.

The slope-intercept-frequency factor (SIF), or F2, is the number of times that ground surface changes between positive and negative slopes over a 1 km distance that can be calculated by using Eq. 3.3b (as recommended by the RTSD guideline for Thailand). The computed F2 map for the study area is illustrated in Figure 4.8 where the highest values concentrate mostly on the western side of the area (due to low surface slope) and lower values appear mostly on the middle and eastern regions of the study area. Note that, as the defined F2 values depend directly on values of the surface slope (Eq. 3.3b) which is similar to those of the F1 values (Eq. 3.2), therefore, both maps resemble each other very much.

The vegetation factor (F3) indicates impact of vegetation cover characteristics (type, density, or distributing pattern) on the mobility of vehicle movement and can be calculated from equations 3.4a - 3.4c. In principle, values of F3 can be between 0 - 1 where 0 means high impact of the vegetation factor on the CCM movement (speed) of the specified vehicles (No Go) and 1 mean no impact arises. Table 4.3 and Figures 4.9a - 4.9d presents values of F3 for different vehicle and vegetation types (as stated in Table 3.7).

As seen in Table 4.3, the F3 values depend significantly on both the preferred vehicle type and the relevant vegetation type. The highest values for all listed vehicles were found at 0.90 (A2/A3 classes) and 0.85 (A1/G2 classes). In general, the M113 has highest F3 values in all other vegetation types and Stingray tank has the lowest.

**Table 4.3** F3 values for each vehicle type regarding to different vegetation type.

| Vehicle type | F3 values | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **A1** | **A2** | **A3** | **C32** | **E22** | **F12** | **F21** | **F22** | **G2** | **X** |
| M113 | 0.85 | 0.90 | 0.90 | 0.34 | 0.59 | 0.52 | 0.84 | 0.29 | 0.85 | 0.30 |
| M35 | 0.85 | 0.90 | 0.90 | 0.12 | 0.14 | 0.31 | 0.41 | 0.19 | 0.85 | 0.30 |
| Stingray | 0.85 | 0.90 | 0.90 | 0.11 | 0.13 | 0.28 | 0.37 | 0.18 | 0.85 | 0.30 |
| Scorpion | 0.85 | 0.90 | 0.90 | 0.13 | 0.15 | 0.34 | 0.44 | 0.21 | 0.85 | 0.30 |

**Note**: **A1** = Agriculture (dry crops), **A2** = Agriculture (wet crops/rice), **A3** = Agriculture (terraced crops both wet/dry),
**C32** = Coniferous/Evergreen forests, **E22** = Mixed forest,
**F12** = Fruit bearing trees (orchard/plantation) (1: Canopy closure = 0-25%, 2: Height = 2-5 m.),
**F21** = Fruit bearing trees (orchard/plantation) (1: Canopy closure = 25-50%, 2: Height = 0-2 m.),
**F22** = Fruit bearing trees (orchard/plantation) (1: Canopy closure = 25-50%, 2: Height = 2-5 m.),
**G2** = Grassland with scattered trees/some scrub, **X** = Built-up areas.

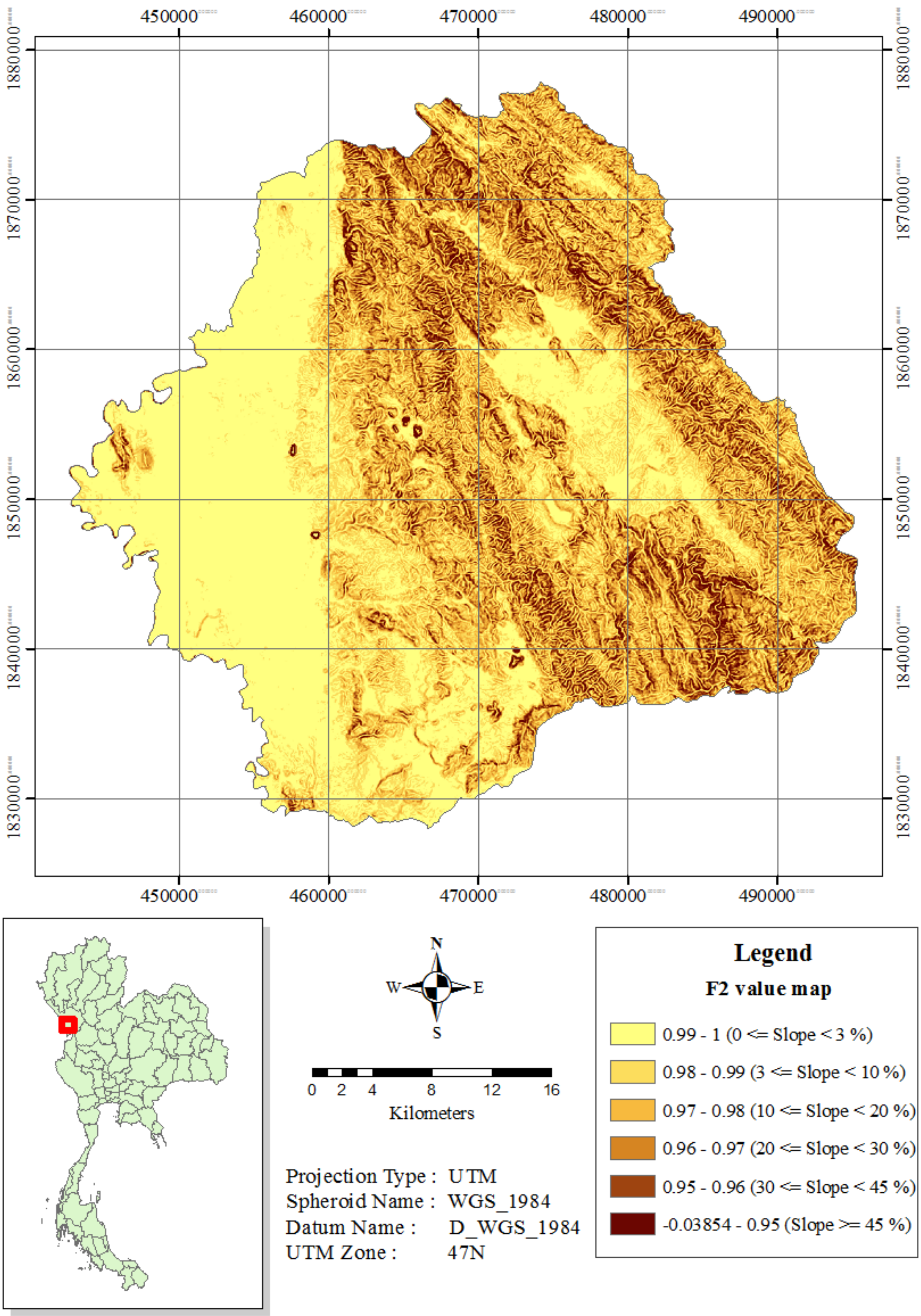



**Figure 4.8** Slope-intercept-frequency (SIF) factor (F2) map (for all vehicles).

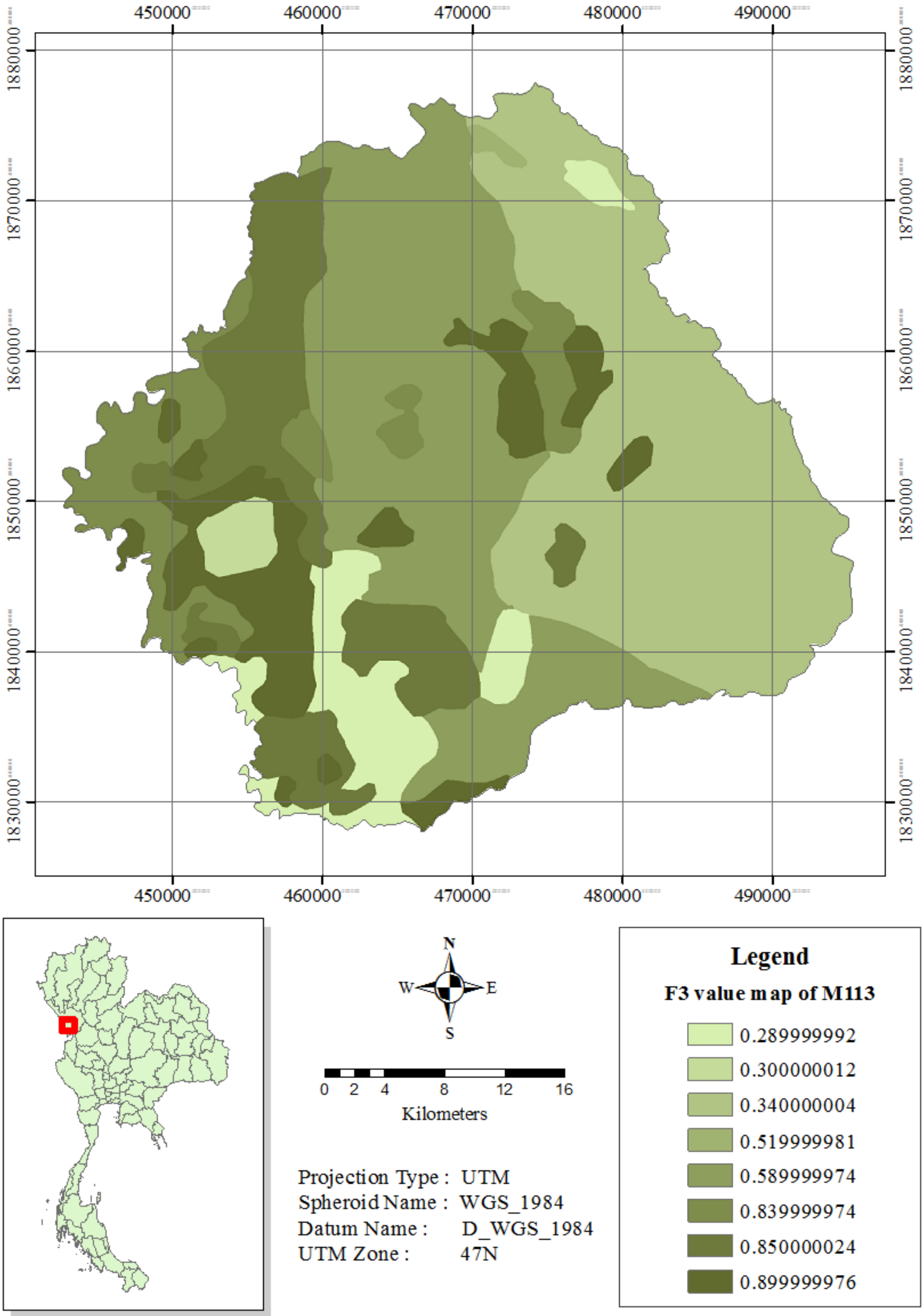



**Figure 4.9a** Vegetation factor (F3) map for the M113.

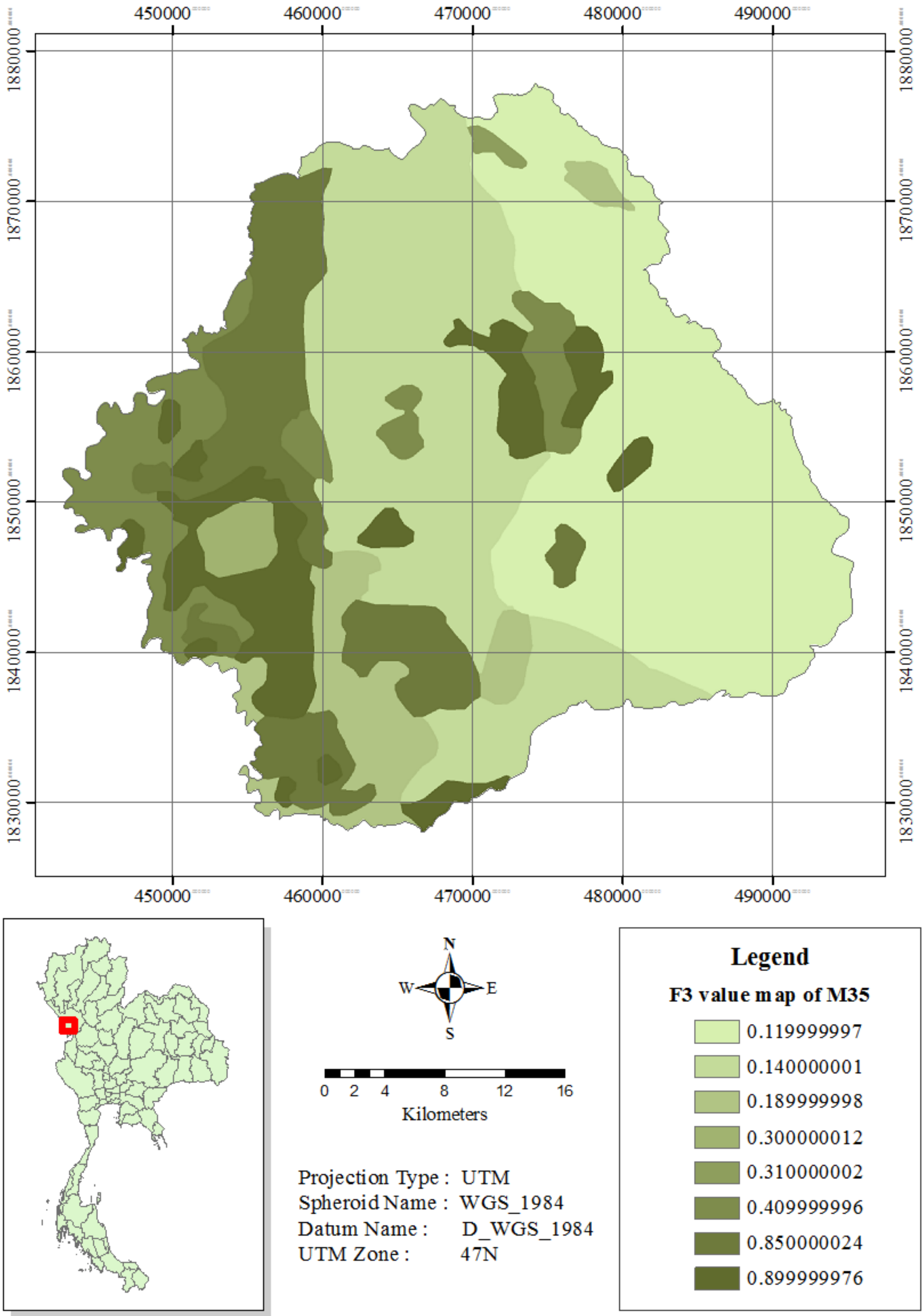



**Figure 4.9b** Vegetation factor (F3) map for the M35.

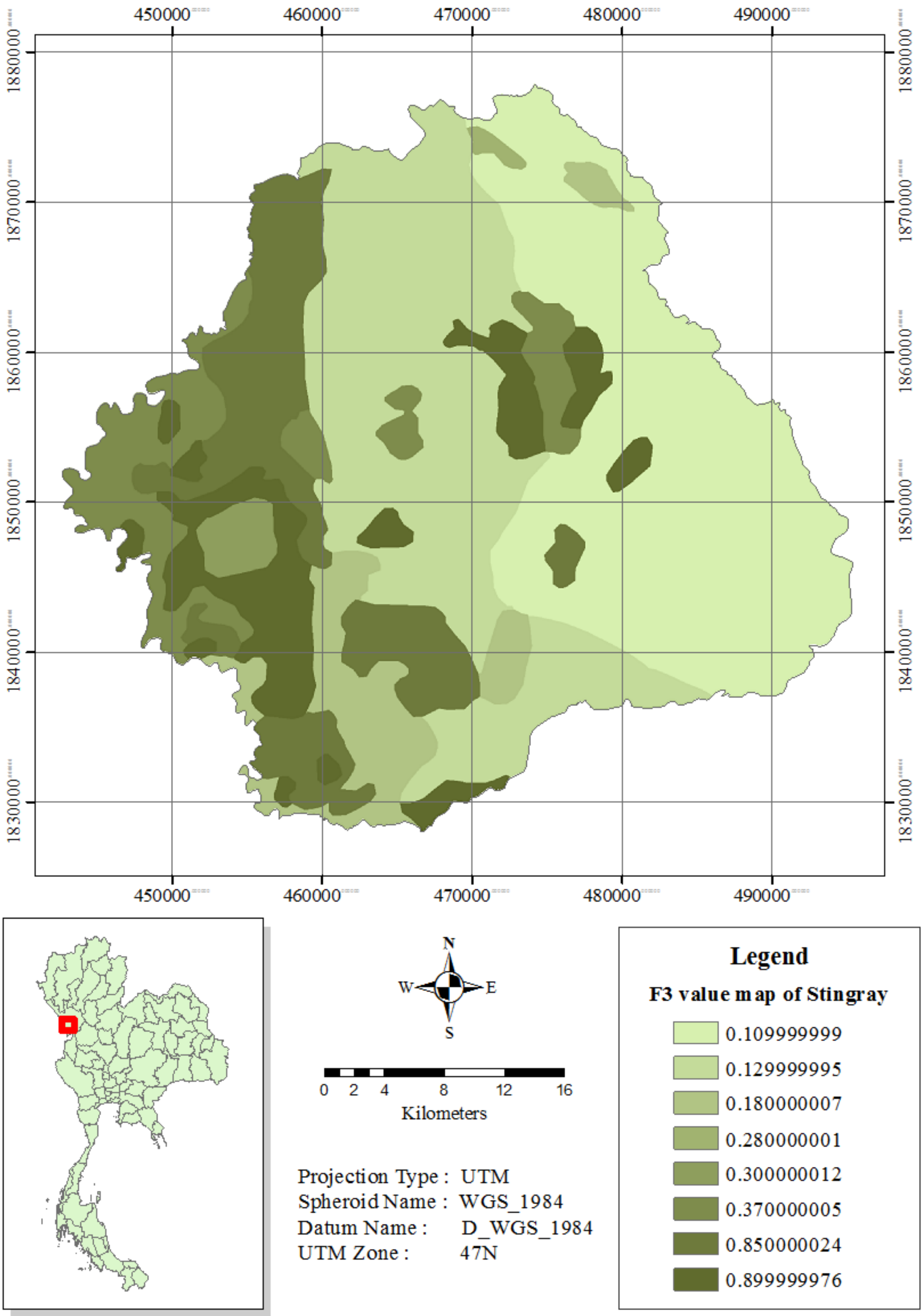



**Figure 4.9c** Vegetation factor (F3) map for the Stingray.

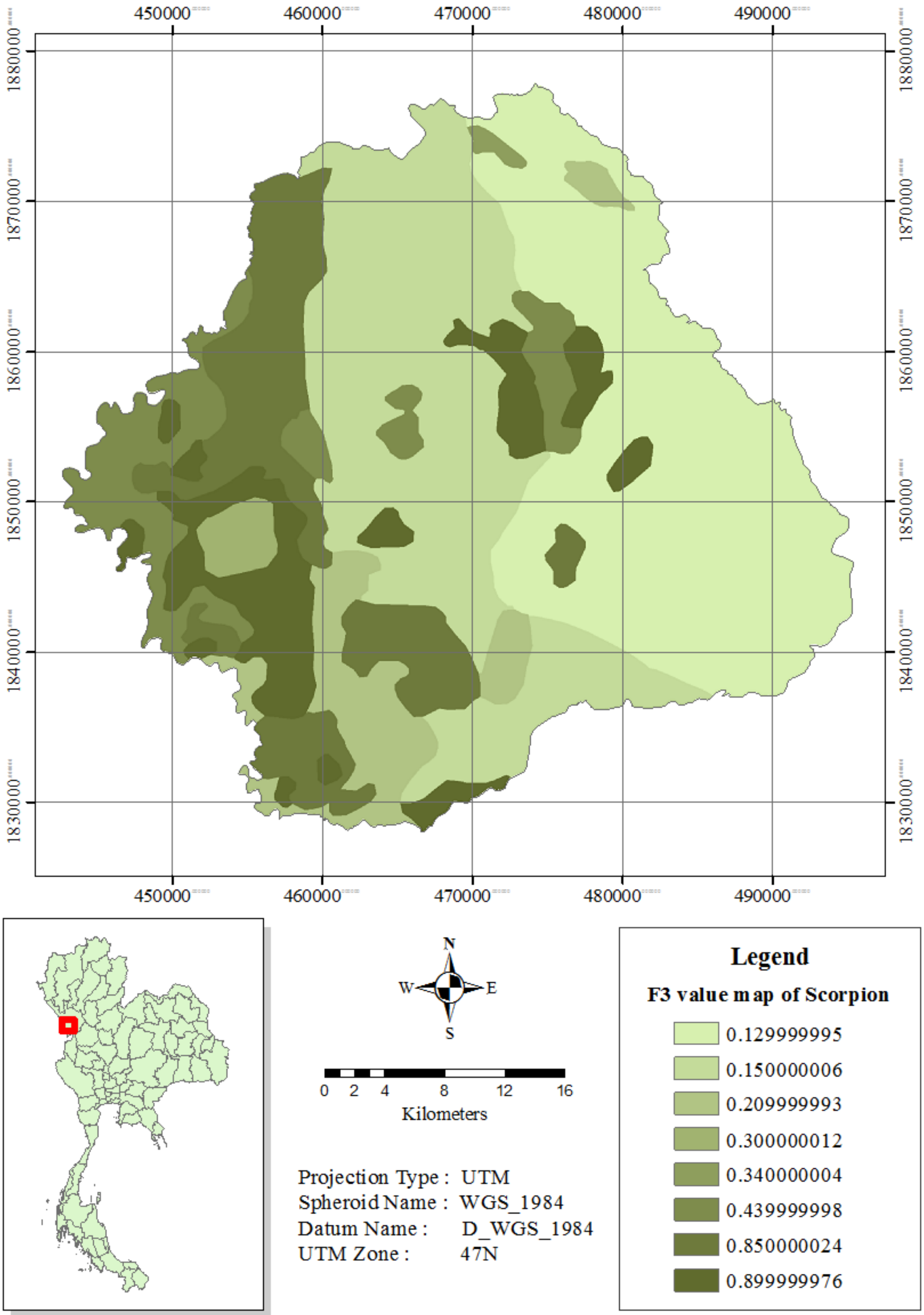



**Figure 4.9d** Vegetation factor (F3) map for the Scorpion.

The soil factor (F4) indicates impact of soil characteristics on vehicle's mobility. The analysis is separated into dry (D) and wet (W) conditions and the calculation is based on Eq. 3.5. Results of F4 for each vehicle type (for dry/wet season) are displayed in Table 4.4 and Figures 4.10 and 4.11a - 4.11d (for each soil type depicted in Figure 4.3).

**Table 4.4** F4 values for each vehicle type regarding to different soil type.

| Vehicle type | Season | F4 values | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | CH1 | CL1 | ML1 | RK3 | RK6 | SM1 | SP1 |
| M113 | Dry | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Wet | 1 | 1 | 0.13 | 1 | 1 | 0.35 | 1 |
| M35 | Dry | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Wet | 1 | 0.56 | 0 | 1 | 1 | 0 | 1 |
| Stingray | Dry | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Wet | 1 | 0.53 | 0 | 1 | 1 | 0.05 | 1 |
| Scorpion | Dry | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Wet | 1 | 1 | 0.35 | 1 | 1 | 0.61 | 1 |

**Note:** **CH1** = Fat clays (no surface roughness effect), **ML1** = Silts (no surface roughness effect),
**CL1** = Agriculture (wet crops/rice) (no surface roughness effect),
**RK3** = Rock outcrops (Stony soil with large rocks), **RK6** = Rock outcrops (Area of high landslide potential),
**SM1** = Sand, Silty (no surface roughness effect), **SP1** = Sand, Poorly Graded (no surface roughness effect)

The F4 value shall determine if a particular soil type will support the vehicular movement and to what extent the speed will decrease due to that soil type. In general, dry soil can afford the CCM movement of a vehicle much better than the wet soil (as seen from the RCI values shown in Table 3.8). For examples, the RCI values for clays (CL) in dry and wet seasons are 123 and 40, while for the silts (ML) are 118 and 20, respectively. As a result, the F4 values for a specified vehicle are usually much higher in dry season than in wet season in almost all soil types (Table 4.4). In dry season, rock, sand and gravel can support the CCM movement the best while in wet season, rock and gravel can do the best. Note that, as in dry season the RCI are higher than $VCI_{50}$ in all considered vehicles, therefore, F4 shall always become 1 (Figure 4.10).

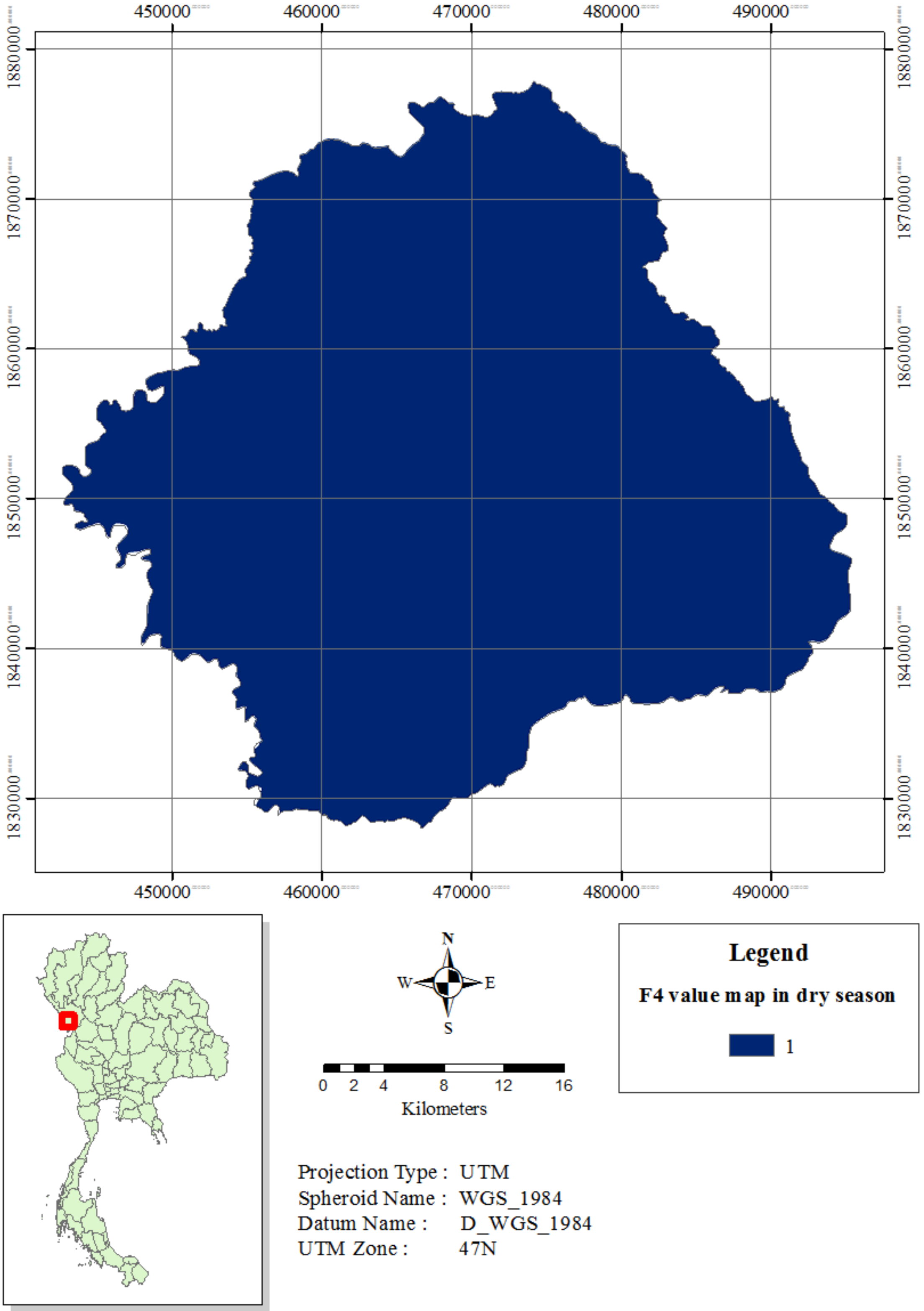



**Figure 4.10** Soil factor (F4) map in dry season (for all vehicles).

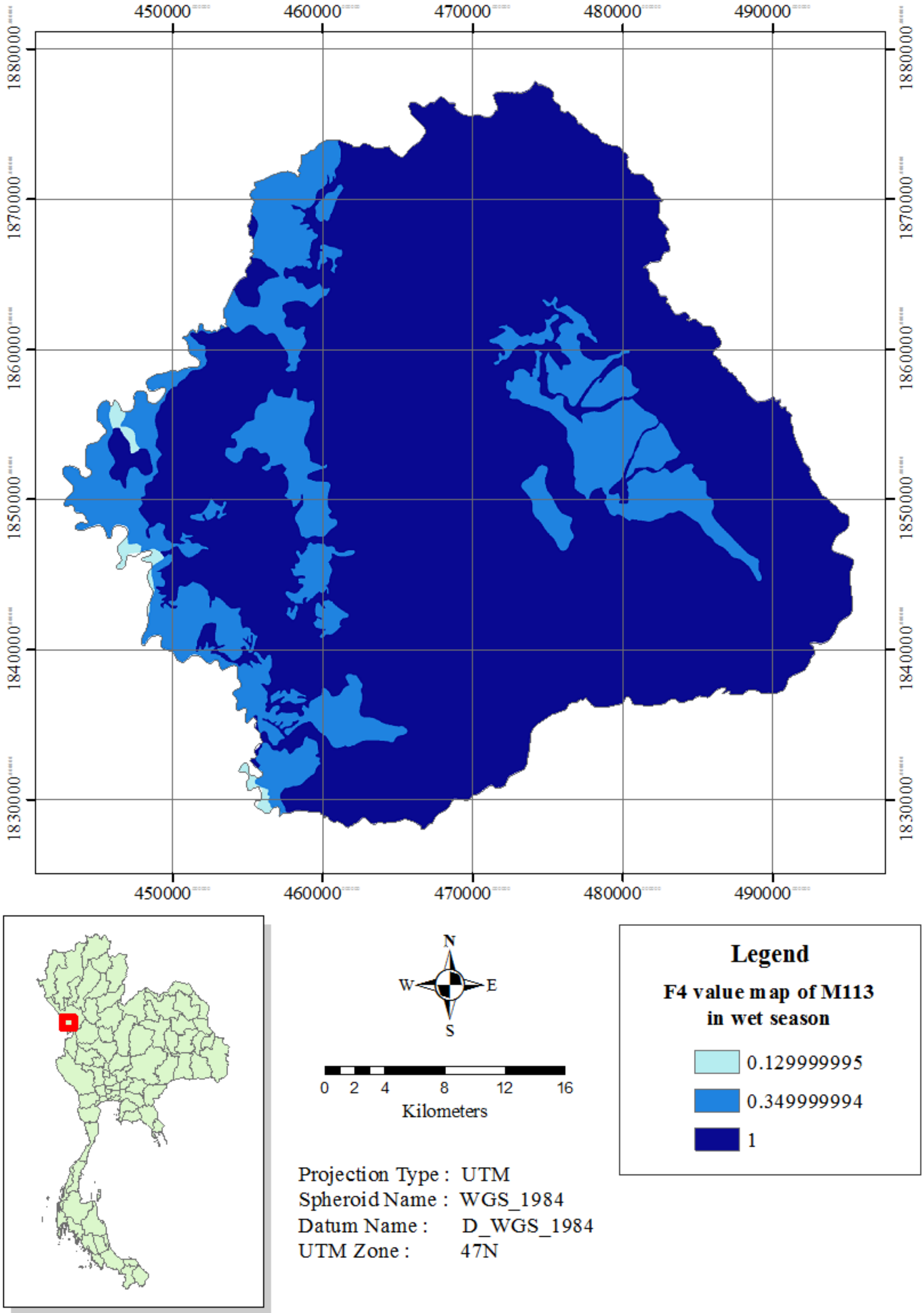



**Figure 4.11a** Soil factor (F4) map for M113 (wet season).

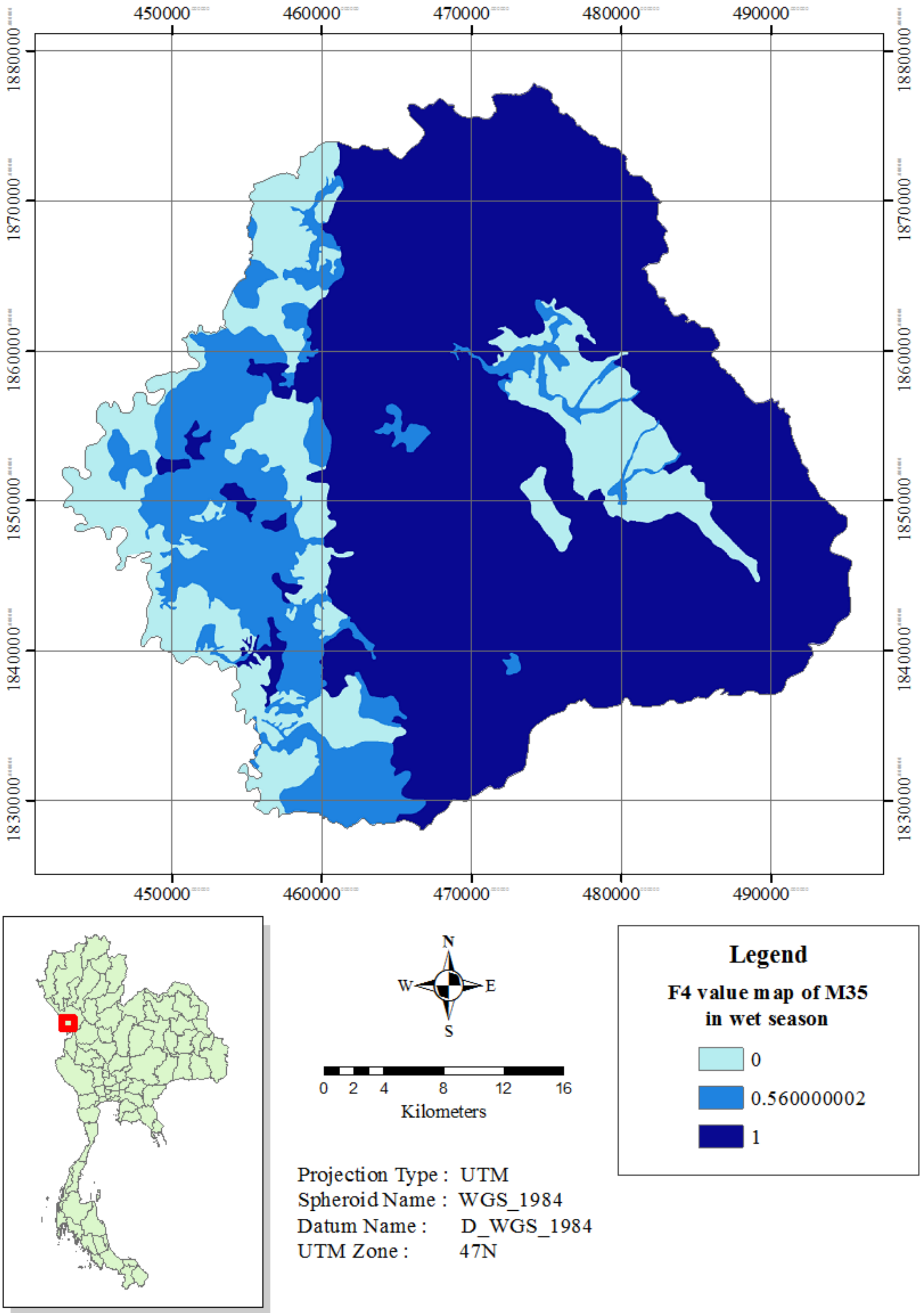



**Figure 4.11b** Soil factor (F4) map for M35 (wet season).

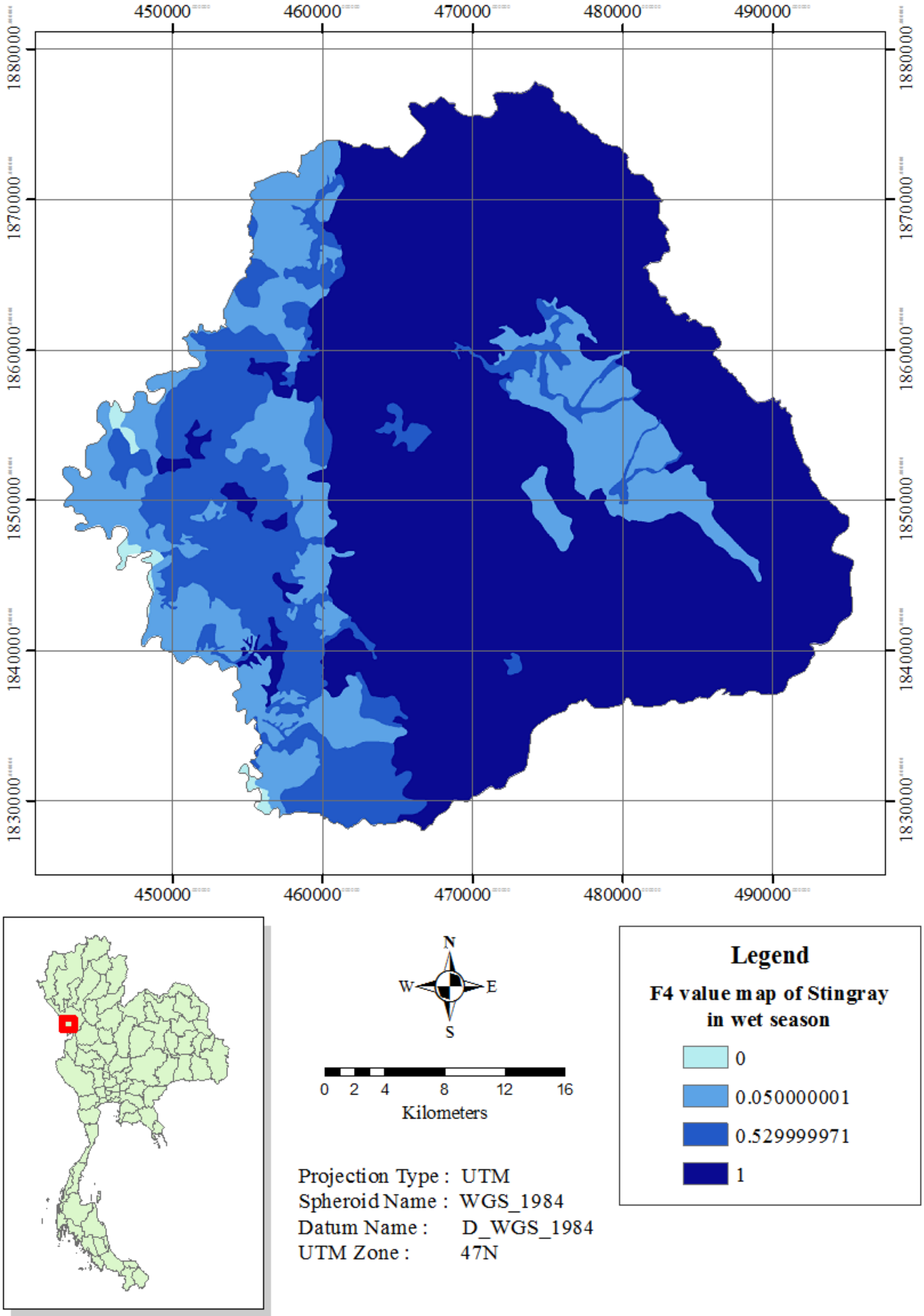



**Figure 4.11c** Soil factor (F4) map for Stingray (wet season).

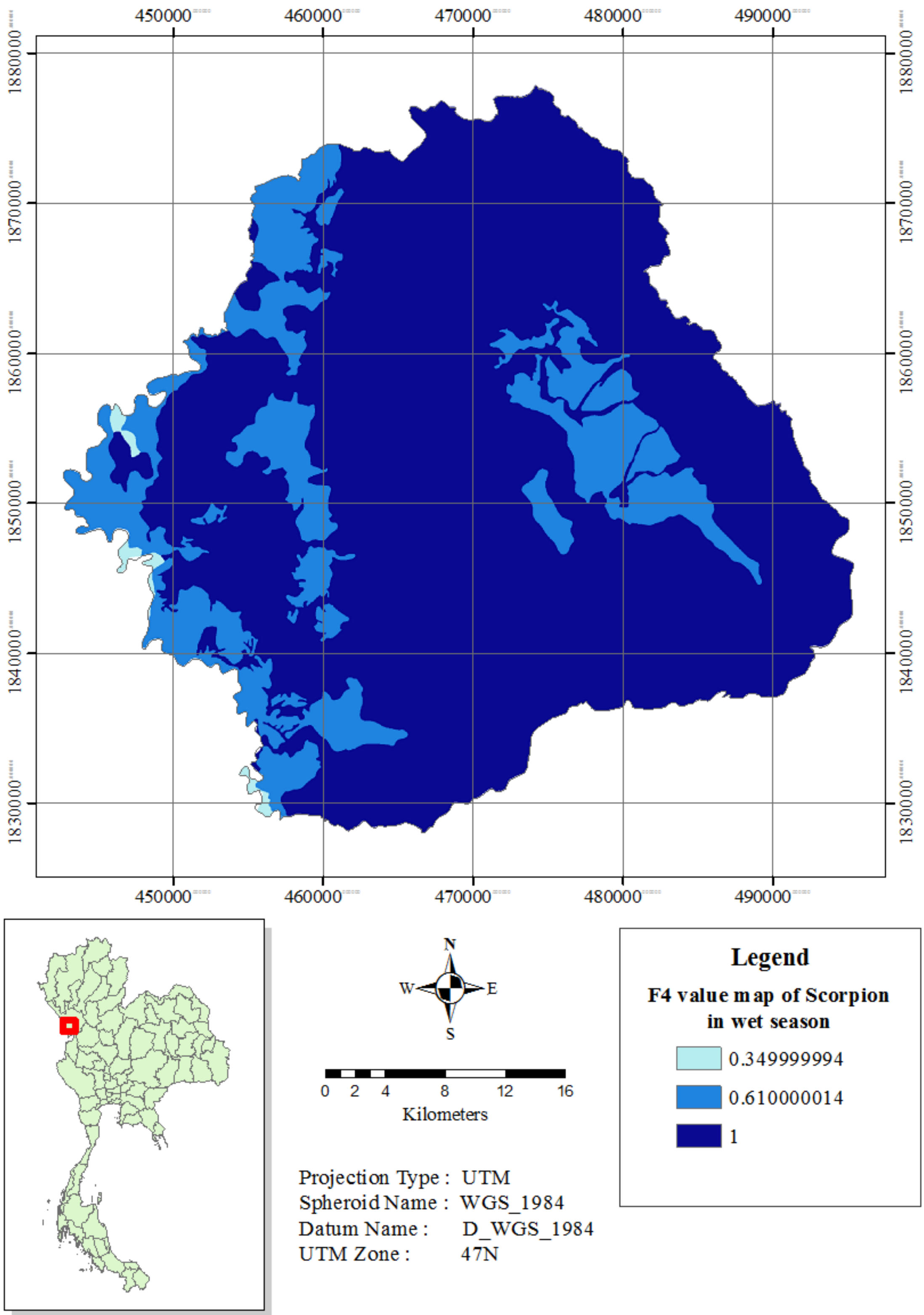



**Figure 4.11d** Soil factor (F4) map for Scorpion (wet season).

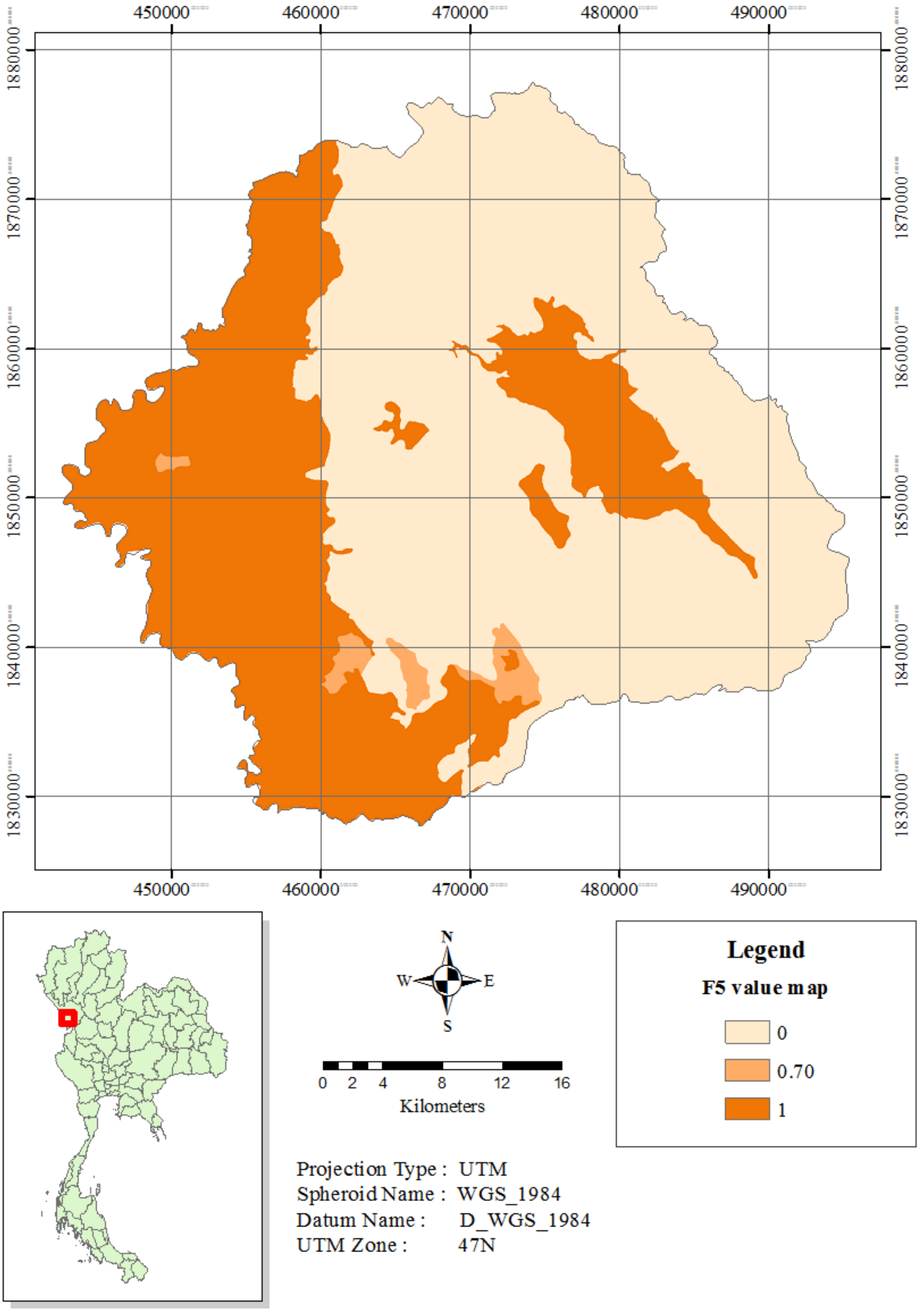



**Figure 4.12** Surface roughness factor (F5) map (for all vehicles).

The surface roughness factor depends on surface materials and its values range at 0 - 1 where a lower value indicates higher impact on the vehicle trafficability over that surface (reducing speed). The F5 values applied in this study are shown in Table 3.9 (and Figure 4.3) while the F5 map (for all studied vehicles) is displayed in Figure 4.12. Here, only three types of the relevant surfaces were identified:

(1) Surface with no roughness effect (F5 = 1) - mostly found on the western side due to the abundance of natural flat terrain;

(2) Stony soil with large rocks (F5 = 0.7) - only few areas found; and

(3) Area of high landslide potential (F5 = 0) - mostly concentrate on the middle and eastern sides of the area which is dominated by the steep mountainous terrain.

## 4.3 Results of the CCM map construction

The obtained maps of the CCM factor for each concerned vehicles and troop unit can be used to create their CCM maps following Eq. 3.1 and results are shown in Figures 4.13 - 4.18 (dry/wet season), respectively. Table 4.5 shows covering area of the three classes of the traficability: No Go (0-1.5 km/hr), Slow Go (1.5 - 30 km/hr), Go (> 30 km/hr), for the chosen troop unit and vehicle types (foot troop, M113, M35, Stingray and Scorpion). It is noted that, the vehicle’s maximum speeds on road (in Table 3.4) were also included in the resulted CCM maps calculated from Eq. 3.1.

### 4.3.1 Standard infantry (foot troops)

For the standard infantry (foot troops), they can move past most terrains well in both dry and wet seasons except over the few specified No Go areas (water body) (Figure 4.13). The standard velocities of the movement are 4 km/hr during daytime and 2 km/hr during nighttime, respectively.

**Table 4.5** The covering area of three traficability classes: Go, Slow Go, No Go.

| Traficability class | Covering area (%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Infantry troop | | M113 | | M35 | | Stingray | | Scorpion | |
| | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet |
| Go | 98.98 | 96.96 | 6.29 | 5.02 | 2.32 | 2.16 | 16.48 | 3.31 | 18.18 | 11.04 |
| Slow Go | – | – | 31.99 | 31.60 | 33.16 | 16.61 | 21.19 | 22.33 | 19.99 | 25.76 |
| No Go | 1.02 | 3.04 | 61.72 | 63.38 | 64.52 | 81.23 | 62.33 | 74.36 | 61.83 | 63.20 |

### 4.3.2 Armored infantry/cavalry (M113)

For M113 (Figures 4.14a and 4.14b), their Go areas were mainly found on the western side of the district due to the rather flat terrain of the area that is suitable for the CCM movement, e.g. area with surface slope of 0 - 3% (Figure 4.2). On the contrary, the No Go areas notably situate within the mountainous region in the middle and eastern parts due to the high surface slope and the proneness to landsliding of the areas. In addition, the Slow Go areas were found distributing in-between the Go and No Go areas. The M113's CCM maps look very similar in both wet and dry seasons with covered area of about 5 - 6% for the Go class, 31 - 32% for the Slow Go class, and 61 - 63% for the No Go class. This indicates that the M113 can travel comparably well in both seasons with the combined Go and Slow Go areas of about 36 - 38%.

### 4.3.3 Mechanized infantry (M35)

For M35 trucks (Figures 4.15a and 4.15b), pattern of their CCM map in dry season is rather similar to that of the M113 map with Go area at about 2.32%, Slow Go area about 33.16% and No Go area about 64.52% (Table 4.5). However, the Slow Go area is dropped significantly to about 16.61% in wet season while the No Go area is increased to be 81.23%. This indicates that the traficability of M35 is quite limited in the wet season compared to dry season with the combined Go and Slow Go areas at about 18.77% of the total study area only.

### 4.3.4 Tank cavalry (Stingray)

For Stingray tank (Figures 4.16a and 4.16b), their GO area in dry season is notably higher than those of the M113 and M35 (about 16.48%) while Slow Go drops to be about 21.19% and the No Go maintains at about 62.33%. However, the Go area is sharply lost to be at 3.31% only in wet season while the Slow Go area is slightly increased to be about 22.33% and the No Go area is arisen to be at about 74.36%. The relatively high Go area in dry season might be due mainly to the maximum road speed of about 69 km/hr of the vehicle (if compared to 48 and 56 km/hr for the M113 and M35, respectively).

### 4.3.5 Reconnaissance cavalry (Scorpion)

For Scorpion tank (Figures 4.17a and 4.17b), their GO, Slow Go, and No Go areas in dry season are comparable to those of the Stingray tank (about 18.18%, 19.99, and 61.83%, respectively). However, the Go area is considerably reduced to be at 11.04% in wet season while the Slow Go area is substantially increased to be about 25.76% and the No Go area is slightly increased to be at about 63.20%. The relatively higher Go area in wet season of the Scorpion when compared to the Stingray might be due to their higher maximum road speed of about 72.4 km/hr and lower VCI values (for both $VCI_1$ and $VCI_{50}$ as seen in Table 3.4)

In conclusion for all considered vehicles, their Go areas dominate on the western side due to the relatively flat terrain. On the contrary, the No Go areas situate mainly within the mountainous region in the middle and eastern parts. In addition, the Slow Go areas were usually found distributing in-between the Go and No Go areas.

The Go areas of most vehicles are notably decreased from dry season to wet season (except M35) and turned into the Slow Go or No Go areas. This is due mainly to the soil strength which is much higher in dry season than in wet season for all the vehicles under consideration (as described in Tables 3.8 and 4.4) and the No Go areas also enlarge during wet season due to the increase of area with moving speed less than 1.5 km/hr. Among the four related vehicles, the Scorpion tank can attain the highest moving speed (regarding to the maximum F1 values) at about 54.29 km/hr, followed by the stingray at 46.0 km/hr, the M113 at 36.0 km/hr, and the M35 at 26.25 km/hr (all speeds are in dry season). Regarding to amount of the Go areas, in dry season, the Scorpion and Stingray tanks are far more effective on CCM activity than other studied vehicles. But in the wet season, the Scorpion tank does best followed by the M113. In addition, the M35 truck performs worst in both wet and dry seasons.

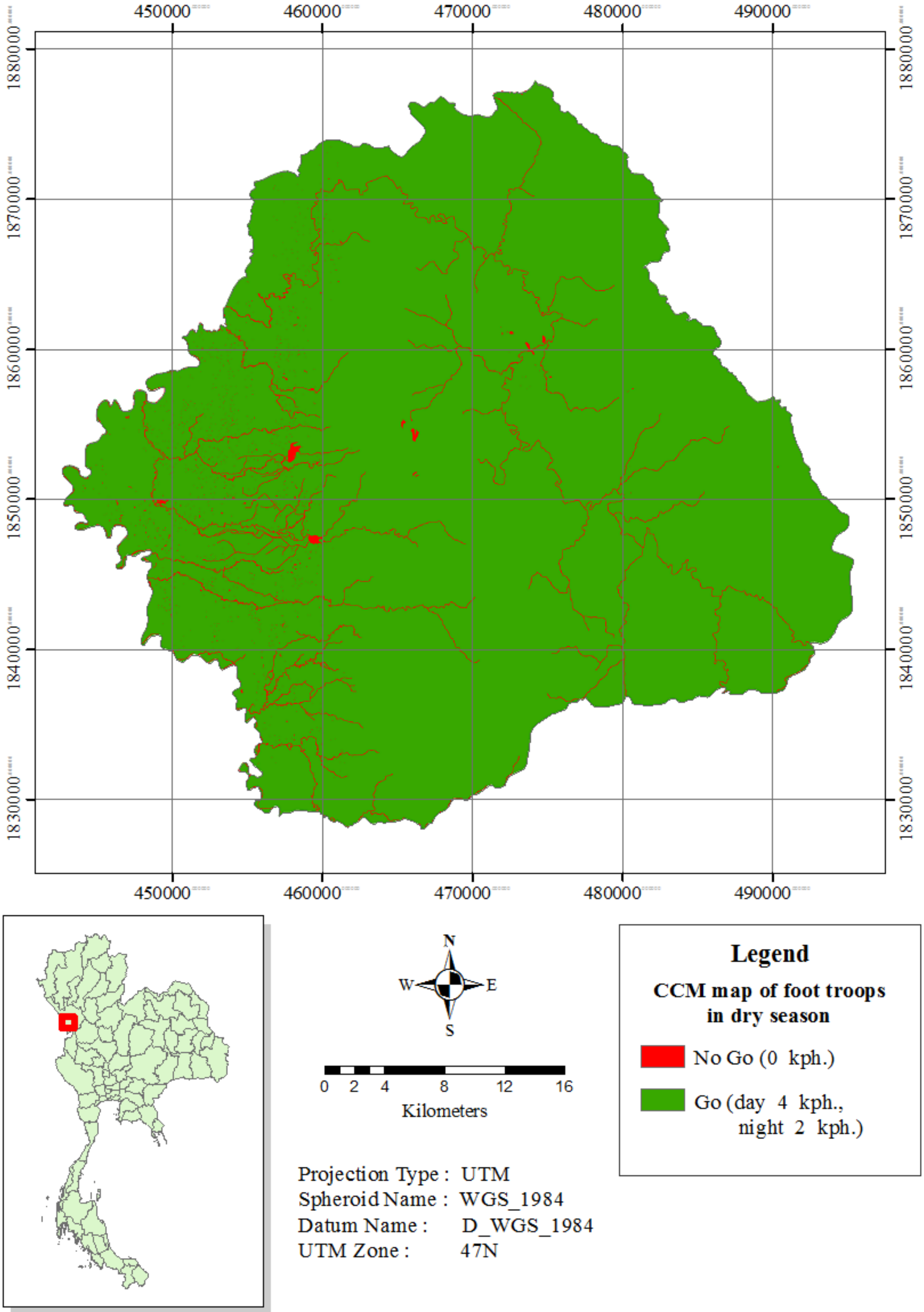



**Figure 4.13a** CCM map for the standard infantry (foot troops) in dry season.

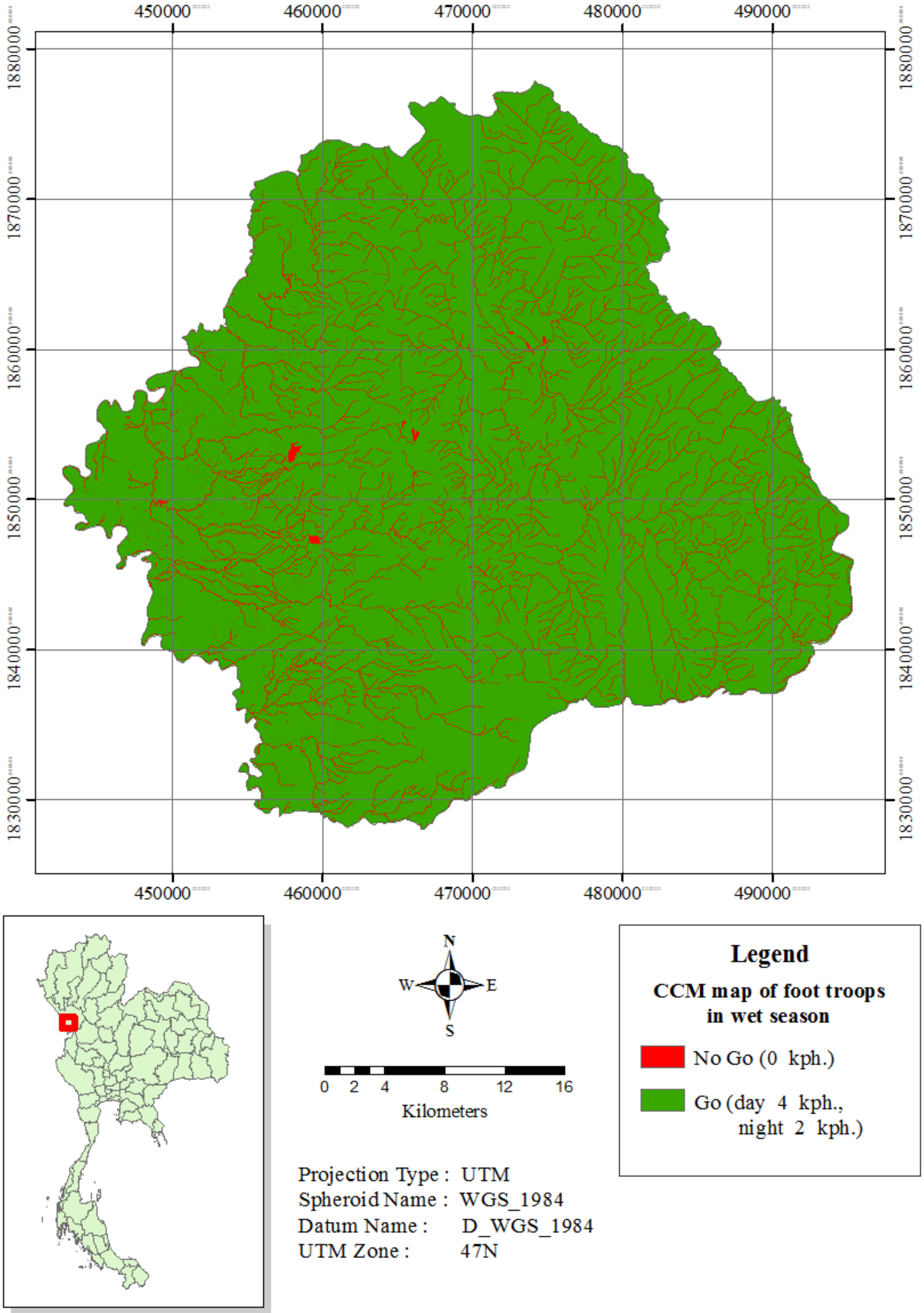



**Figure 4.13b** CCM map for the standard infantry (foot troops) in wet season.

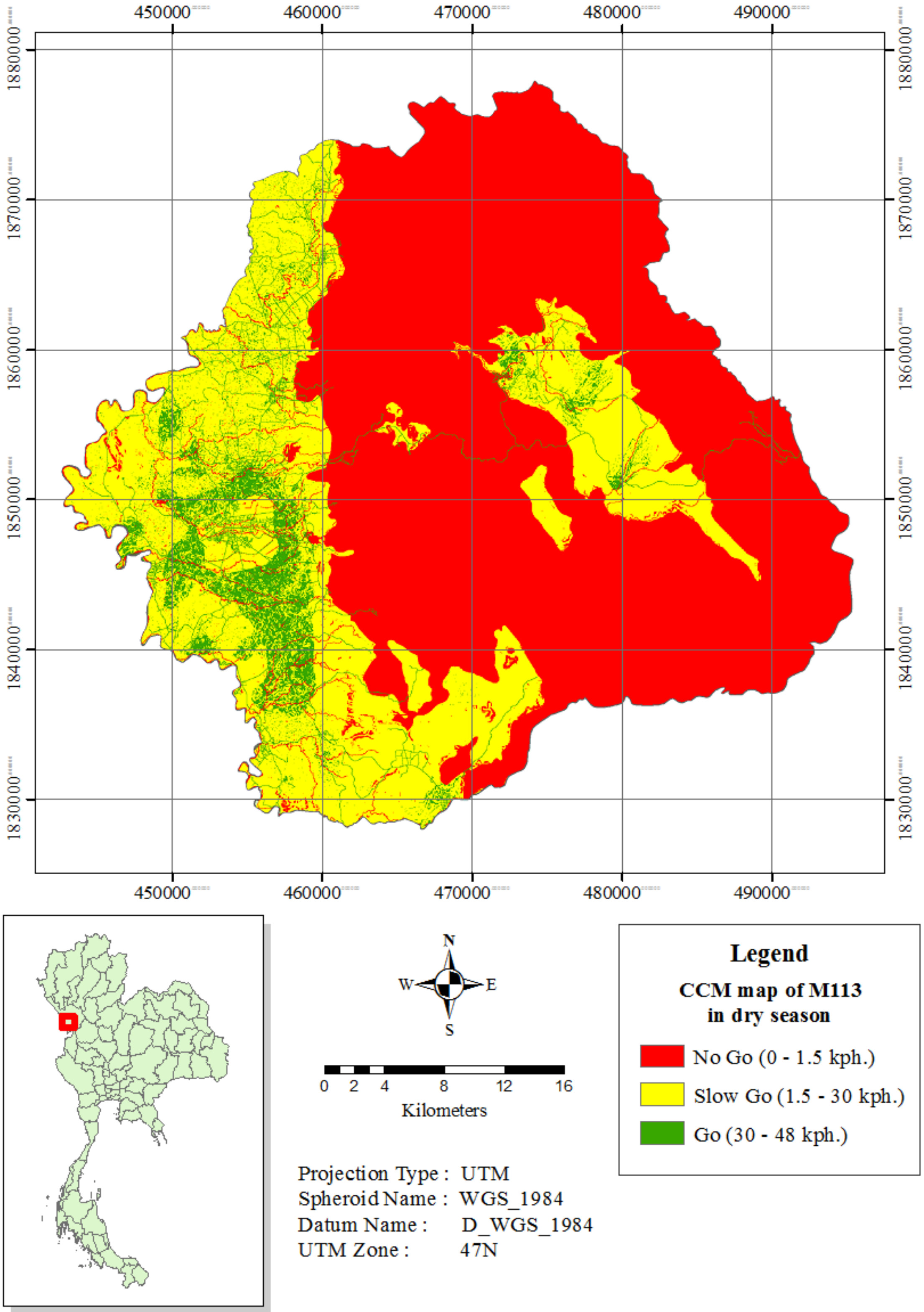



**Figure 4.14a** CCM map for the armored infantry/cavalry (M113) in dry season.

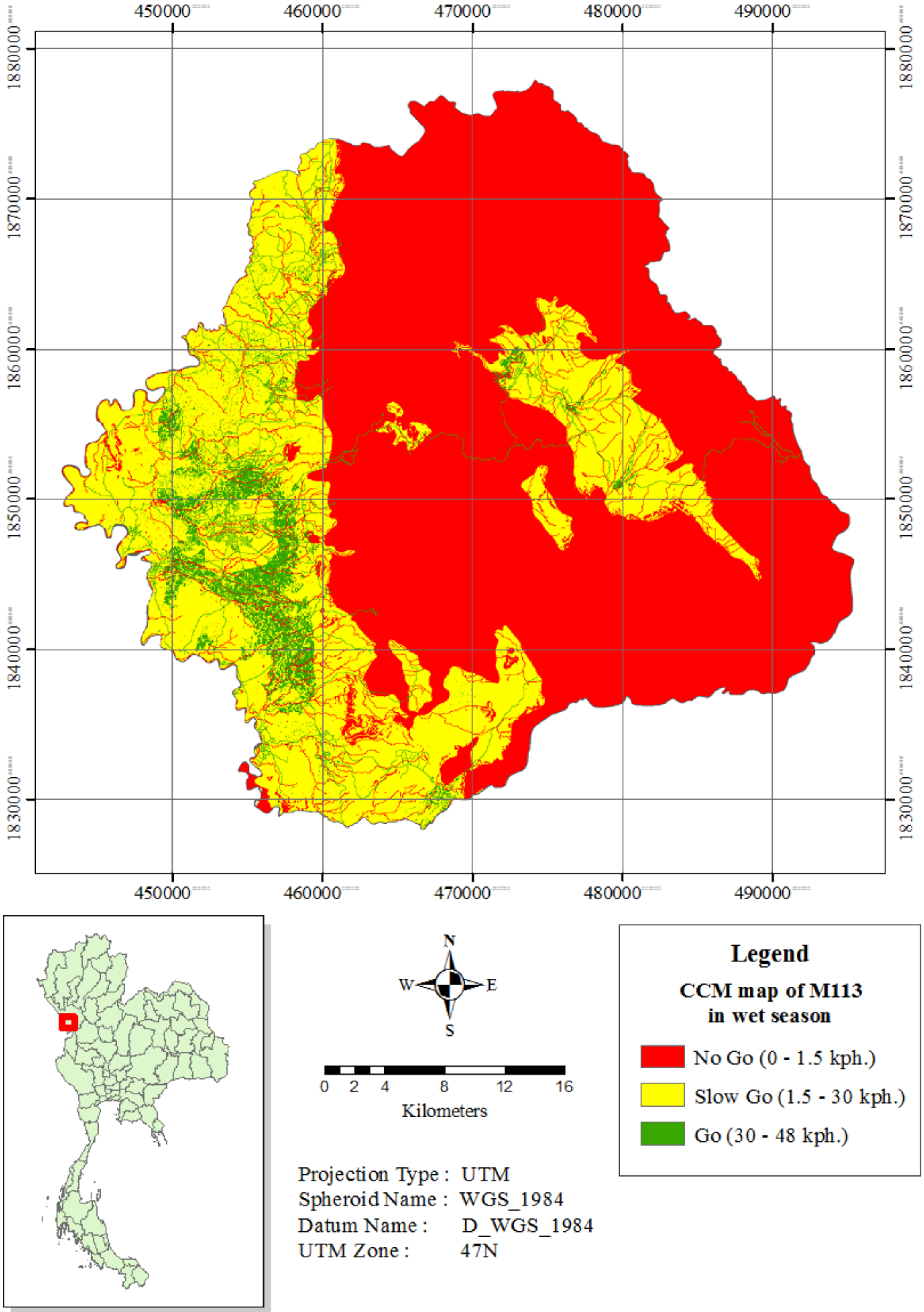



**Figure 4.14b** CCM map for the armored infantry/cavalry (M113) in wet season.

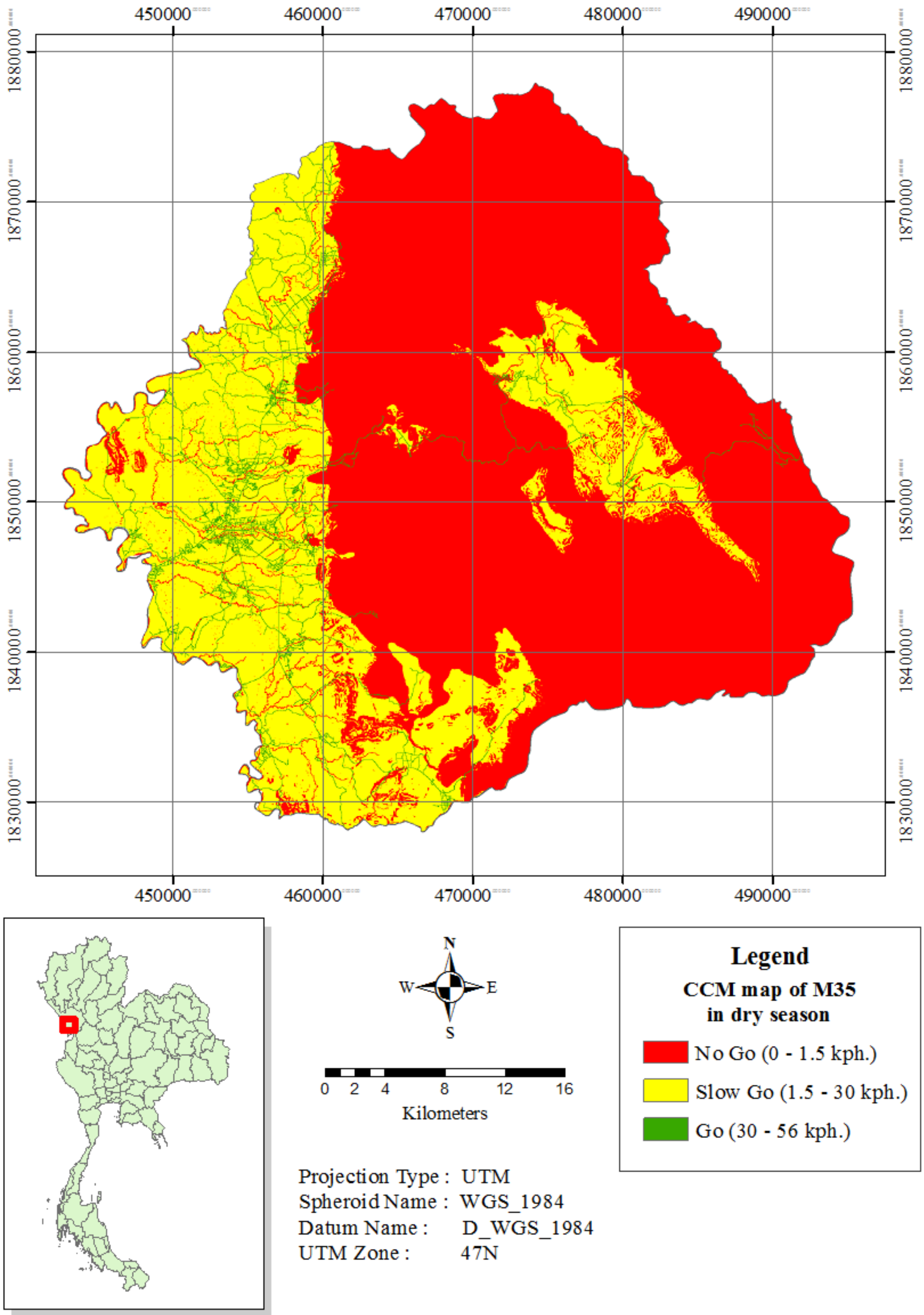



**Figure 4.15a** CCM map for the mechanized infantry (M35) in dry season.

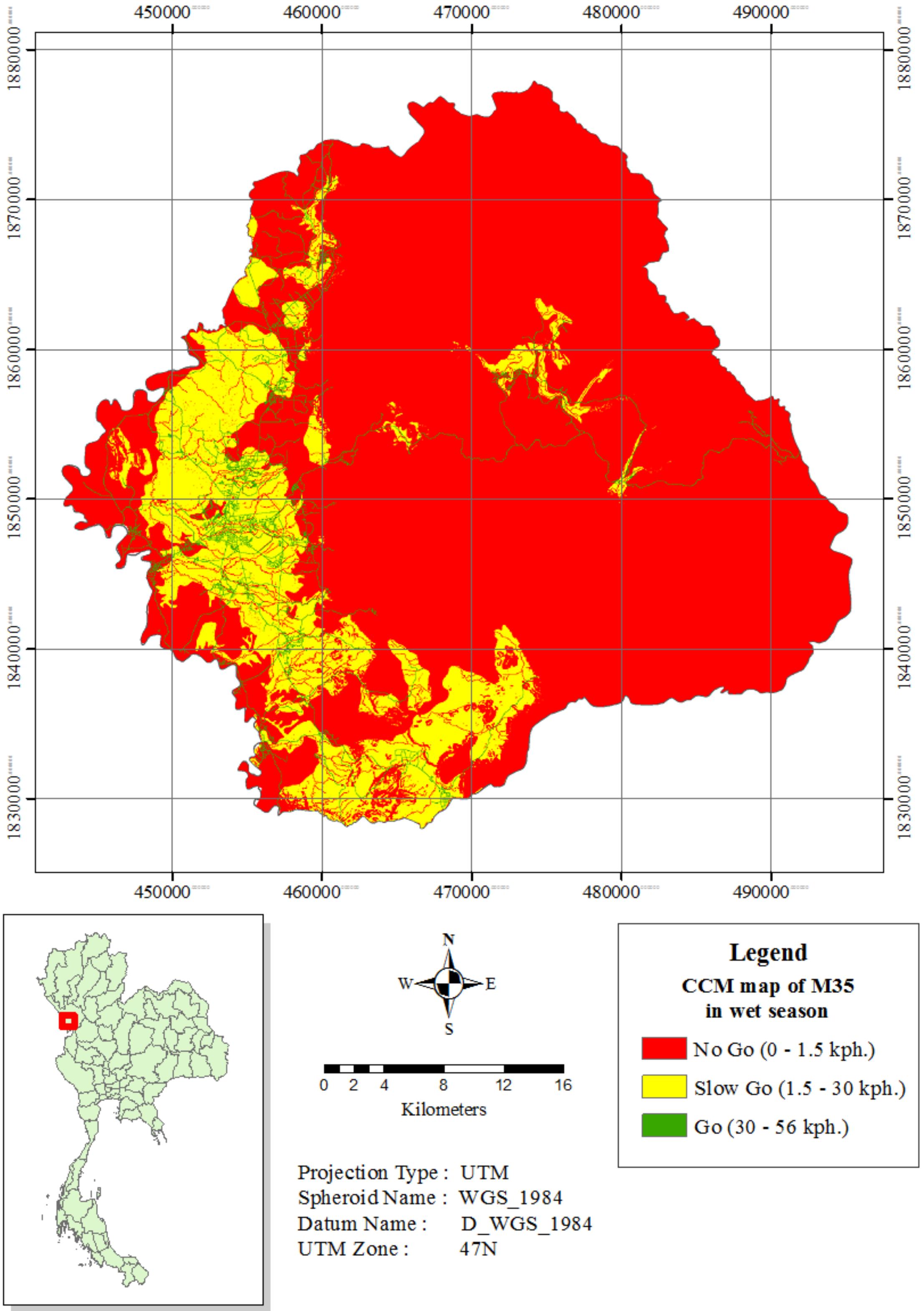



**Figure 4.15b** CCM map for the mechanized infantry (M35) in wet season.

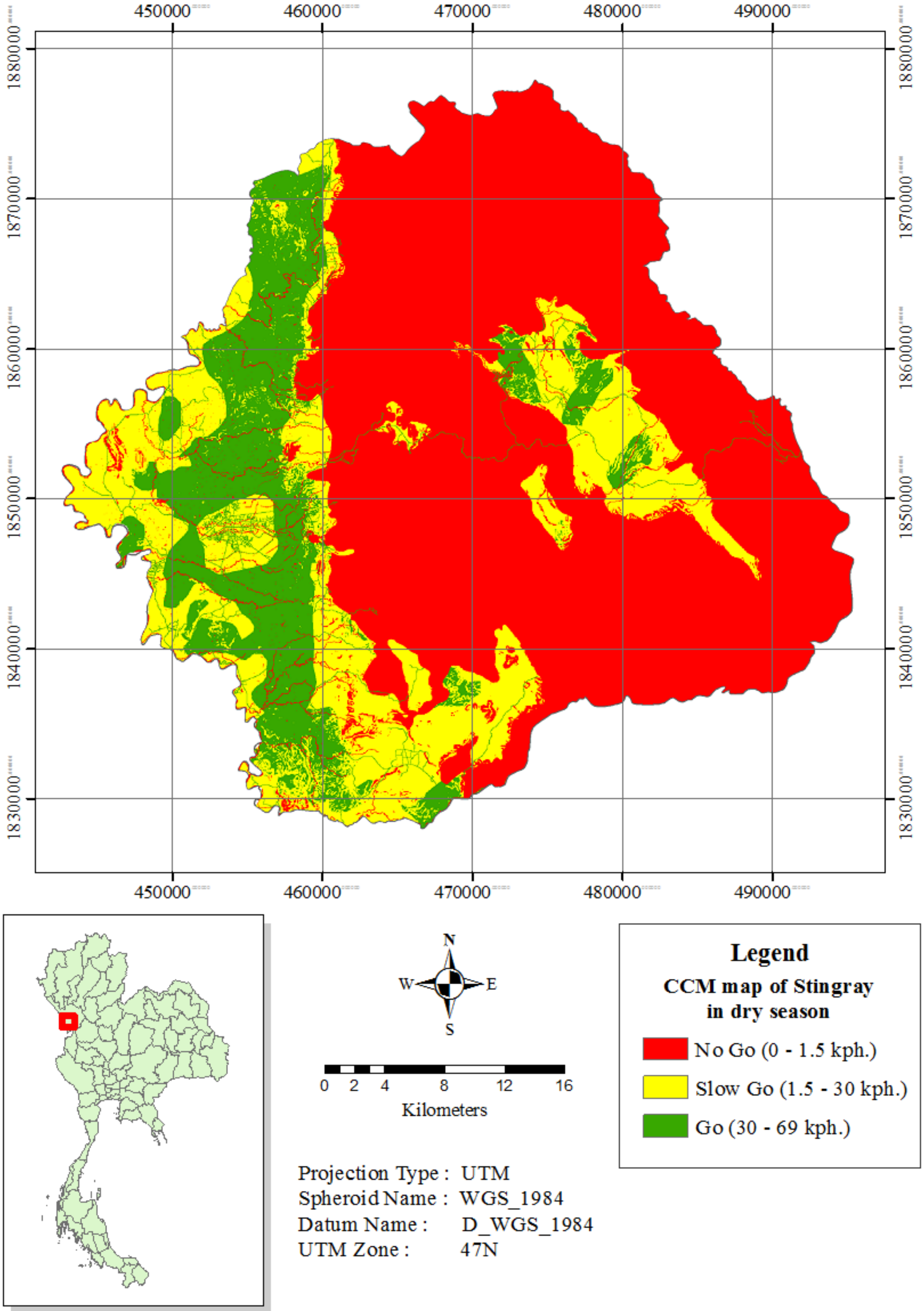



**Figure 4.16a** CCM map for the tank cavalry (Stingray) in dry season.

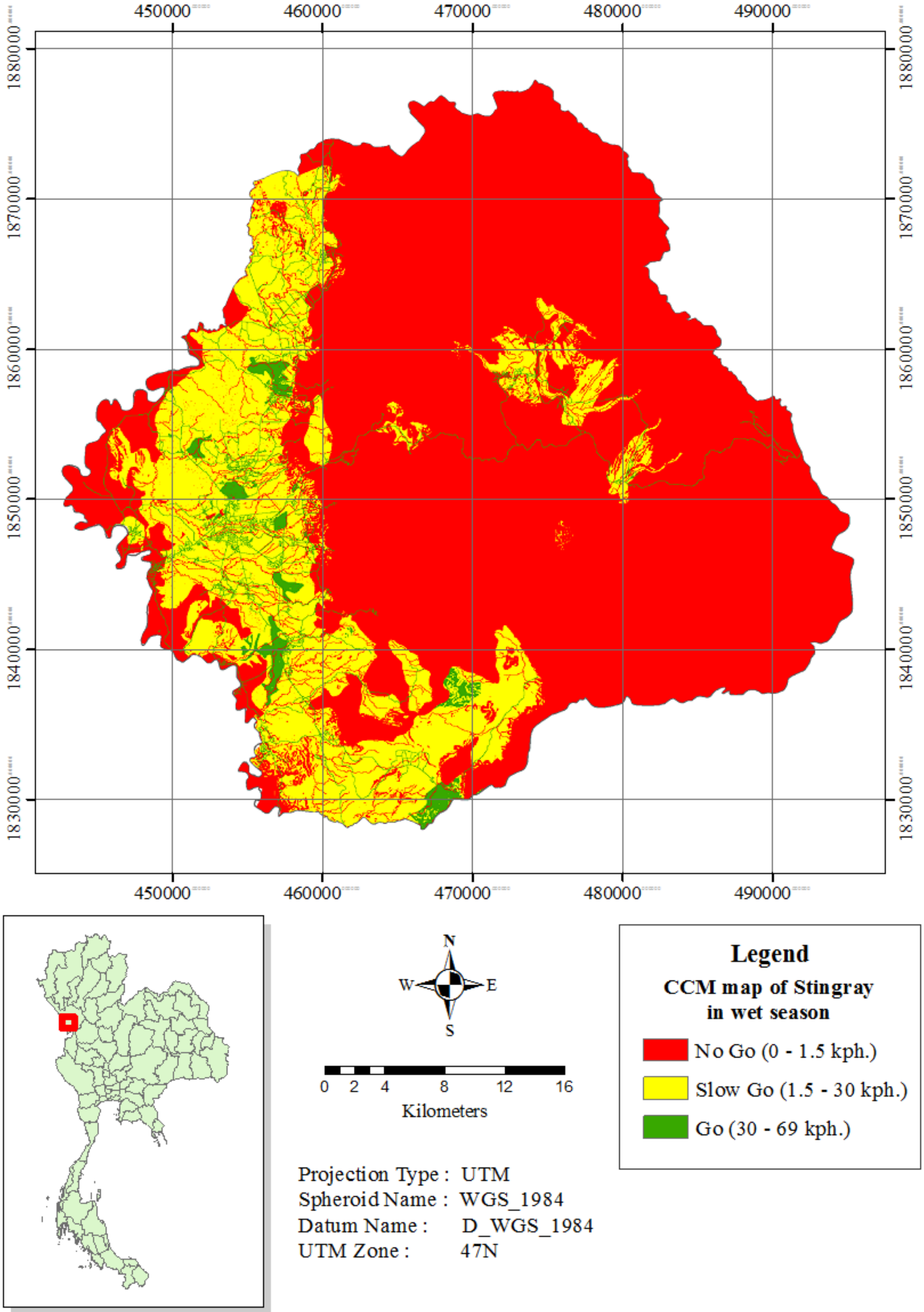



**Figure 4.16b** CCM map for the tank cavalry (Stingray) in wet season.

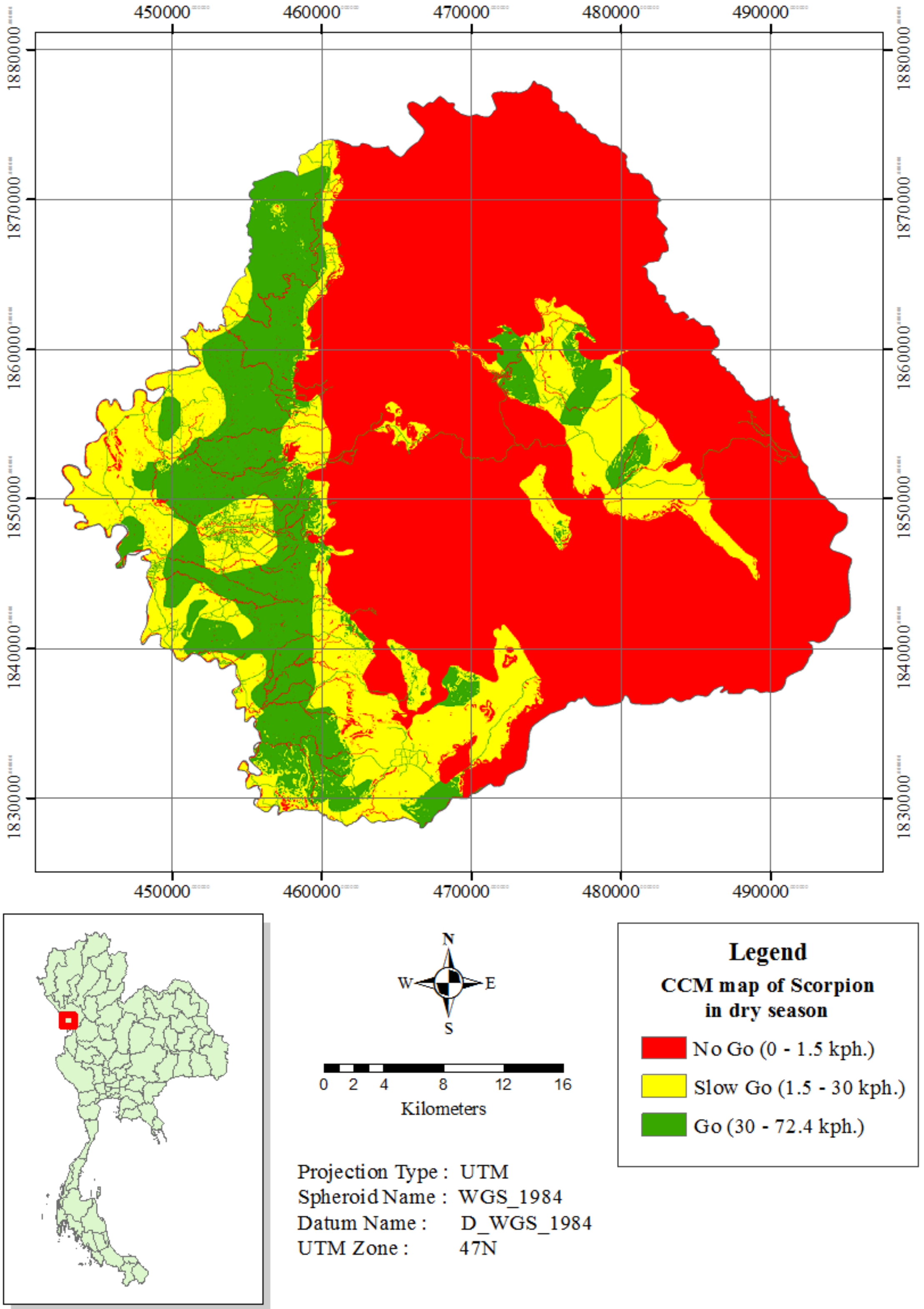



**Figure 4.17a** CCM map for the reconnaissance cavalry (Scorpion) in dry season.

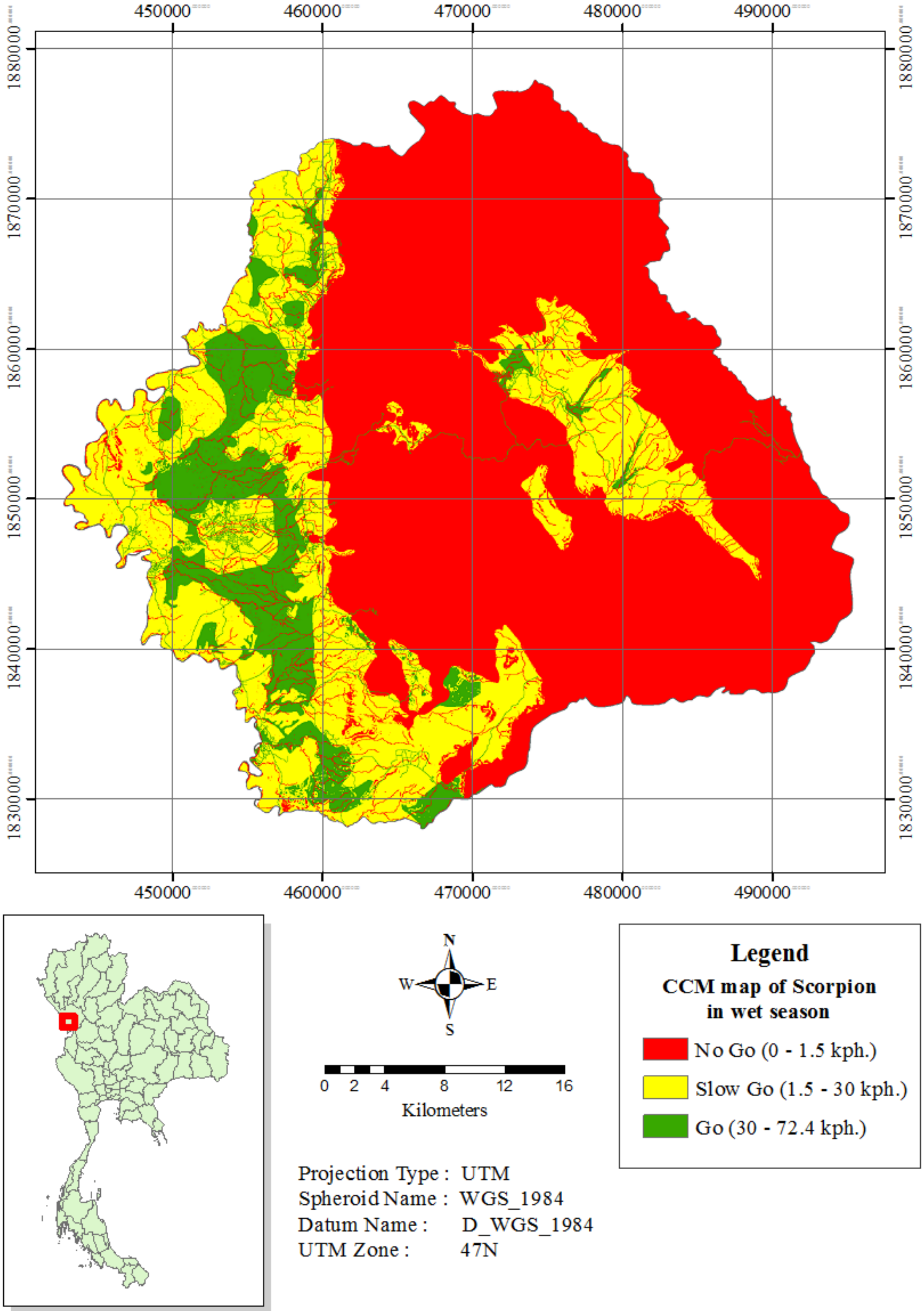



**Figure 4.17b** CCM map for the reconnaissance cavalry (Scorpion) in wet season.

# CHAPTER V

# CCM4CM SYSTEM DEVELOPMENT

This chapter demonstrates the capability of the two chosen search algorithms, breadth first search (BFS) and A-star (A*) search, in the finding of the preferred shortest and fastest paths based on the generated CCM map (under given initial and target states). Operating concepts of both algorithms are given in Chapter 2 and Section 3.4 of Chapter 3 while the relevant source codes are described in Appendix B.

## 5.1 Path finding comparison analysis

To examine the capacity of the BFS and A* search algorithms in the path finding analysis (under shortest/fastest preferences), their performances, or quality indices, were compared (under the same proposed situation) which are: (1) Completeness; (2) Space complexity; (3) Time complexity; and (4) Optimality (as detailed in Table 3.10). To achieve this task, twelve path finding cases were evaluated with the shortest and fastest preferences where two cases each (dry/wet season) were proposed for each troop unit and the concerned vehicle type. The obtained results are reported in Tables 5.1 (shortest path) and 5.2 (fastest path), respectively, while performance comparison for both search algorithms is given in Figure 5.1 and Table 5.3.

**Table 5.1** Results of the path finding analysis (shortest path) of the BFS and A* search algorithm.

| Case | Infantry unit | Start/end point | | Distance (km) | | Processing time | | Memory (Byte) | | Travelling time | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Start point | End point | BFS | A* | BFS | A* | BFS | A* | BFS | A* |
| S1 | Standard infantry (foot troop) (day, dry) | 462915, 1853786 | 466961, 1853421 | 5.72 | 4.23 | 3 hr. 30 m. 36 s. 6 ms. | 15 s. 876 ms. | 1,460,712 | 876,544 | 1 hr. 26 m. 49 s. | 1 hr. 3 m. 26 s. |
| S2 | Standard infantry (foot troop) (night, wet) | 462915, 1853786 | 466961, 1853421 | 5.55 | 4.23 | 35 m. 53 s. 653 ms. | 15 s. 784 ms. | 252,436 | 871,048 | 2 hr. 46 m. 24 s. | 2 hr. 7 m. 52 s. |
| S3 | Armored infantry (M113) (dry) | 453053, 1849103 | 456641, 1849033 | 4.85 | 3.68 | 1 hr. 32 m. 14 s. 166 ms. | 24 s. 20 ms. | 1,339,932 | 1,040,384 | 22 m. 10 s. | 19 m. 45 s. |
| S4 | Armored infantry (M113) (wet) | 453053, 1849103 | 456641, 1849033 | 4.87 | 3.68 | 1 hr. 26 m. 39 s. 951 ms. | 23 s. 794 ms. | 3,872 | 1,048,576 | 25 m. 54 s. | 22 m. 10 s. |
| S5 | Mechanized infantry (M35) (dry) | 450762, 1852567 | 453052, 1852534 | 3.13 | 2.33 | 35 m. 38 s. 459 ms. | 9 s. 451 ms. | 3,965,052 | 483,328 | 9 m. 5 s. | 7 m. 59 s. |
| S6 | Mechanized infantry (M35) (wet) | 450762, 1852567 | 453052, 1852534 | 3.13 | 2.33 | 32 m. 57 s.44 ms. | 9 s.148 ms. | 808,080 | 497,584 | 13 m. 7 s. | 11 m. 49 s. |
| S7 | Tank cavalry (Stingray) (dry) | 453552, 1853911 | 456021, 1853834 | 3.24 | 2.51 | 42 m. 47 s. 842 ms. | 10 s. 994 ms. | 532,700 | 581,632 | 5 m. 25 s. | 4 m. 2 s. |
| S8 | Tank cavalry (Stingray) (wet) | 453552, 1853911 | 456021, 1853834 | 3.24 | 2.51 | 36 m. 51 s. 863 ms. | 11 s. 24 ms. | 5,816 | 565,248 | 1 hr. 26 m. 59 s. | 58 m. 51 s. |
| S9 | Armored cavalry (M113) (dry) | 454648, 1848387 | 458479, 1850571 | 5.23 | 4.83 | 1 hr. 46 m. 5 s. 615 ms. | 2 m. 42 s. 816 ms. | 994,132 | 2,116 | 18 m. 24 s. | 16 m. 13 s. |
| S10 | Armored cavalry (M113) (wet) | 454648, 1848387 | 458479, 1850571 | 5.25 | 4.83 | 2 hr. 49 m. 11 s. 180 ms. | 2 m. 33 s. 442 ms. | 1,567,392 | 17,560 | 22 m. 50 s. | 20 m. 37 s. |
| S11 | Reconnaissance cavalry Scorpion) (dry) | 453246, 1853871 | 457235, 1853081 | 5.24 | 4.34 | 1 hr. 58 m. 6 s. 389 ms. | 24 s. 839 ms. | 784,388 | 1,171,456 | 7 m. 20 s. | 6 m. 52 s. |
| S12 | Reconnaissance cavalry Scorpion) (wet) | 453246, 1853871 | 457235, 1853081 | 5.24 | 4.34 | 1 hr. 35 m. 52 s. 886 ms. | 1 m. 51 s. 744 ms. | 1,236,604 | 866,704 | 12 m. | 8 m. 22 s. |

**Table 5.2** Results of the path finding analysis (fastest path) of the BFS and A* search algorithm.

| Case | Infantry unit | Start/end point | | Distance (km) | | Processing time | | Memory (Byte) | | Travelling time | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Start point | End point | BFS | A* | BFS | A* | BFS | A* | BFS | A* |
| F1 | Standard infantry (foot troop) (day, dry) | 455900, 1850355 | 460788, 1852023 | 6.36 | 5.62 | 1 hr. 1 m. 7 s. 573 ms. | 25 s. 558 ms. | 498,732 | 1,343,488 | 1 hr. 35 m. 26 s. | 1 hr. 24 m. 14 s. |
| F2 | Standard infantry (foot troop) (night, wet) | 455900, 1850355 | 460788, 1852023 | 6.41 | 5.62 | 17 m. 48 s. 820 ms. | 26 s. 189 ms. | 36,120 | 1,326,420 | 3 hr. 12 m. 21 s. | 2 hr. 48 m. 29 s. |
| F3 | Armored infantry (M113) (dry) | 456257, 1861021 | 458874, 1862074 | 3.71 | 3.21 | 42 m. 57 s. 627 ms. | 1 m. 13 s. 24 ms. | 577,400 | 1,279,028 | 8 m. 50 s. | 5 m. 41 s. |
| F4 | Armored infantry (M113) (wet) | 456257, 1861021 | 458874, 1862074 | 3.41 | 3.57 | 44 m. 6 s. 356 ms. | 1 m. 5 s. 276 ms. | 202,688 | 14,336 | 13 m. 22 s. | 5 m. 9 s. |
| F5 | Mechanized infantry (M35) (dry) | 457352, 1840579 | 458977, 1840488 | 2.31 | 2.06 | 20 m. 9 s. 281 ms. | 3 m. 12 s. 20 ms. | 1,076,140 | 901,716 | 6 m. 55 s. | 3 m. 3 s. |
| F6 | Mechanized infantry (M35) (wet) | 457352, 1840579 | 458977, 1840488 | 2.91 | 2.07 | 15 m. 30 s. 939 ms. | 3 m. 47 s. 547 ms. | 22,828 | 140,784 | 9 m. 8 s. | 4 m. 41 s. |
| F7 | Tank cavalry (Stingray) (dry) | 457403, 1851333 | 453139, 1855611 | 7.62 | 9.14 | 2 hr. 41 m. 11 s. 39 ms. | 44 m. 58 s. 892 ms. | 543,792 | 1,440,996 | 14 m. 45 s. | 9 m. 8 s. |
| F8 | Tank cavalry (Stingray) (wet) | 457403, 1851333 | 453139, 1855611 | 7.89 | 9.14 | 3 hr. 7 m. 42 s. 365 ms. | 39 m. 43 s. 797 ms. | 1,419,152 | 764,996 | 2 hr. 59 m. 16 s. | 11 m. 11 s. |
| F9 | Armored cavalry (M113) (dry) | 454648, 1848387 | 458479, 1850571 | 5.23 | 5.5 | 1 hr. 46 m. 5 s. 241 ms. | 2 m. 19 s. 188 ms. | 7,036 | 1,391,760 | 18 m. 24 s. | 8 m. 35 s. |
| F10 | Armored cavalry (M113) (wet) | 454648, 1848387 | 458479, 1850571 | 5.25 | 5.63 | 1 hr. 37 m. 36 s. 224 ms. | 3 m. 14 s. 395 ms. | 1,094,992 | 30,592 | 22 m. 50 s. | 8 m. 6 s. |
| F11 | Reconnaissance cavalry (Scorpion) (dry) | 453246, 1853871 | 457235, 1853081 | 5.24 | 4.34 | 1 hr. 58 m. 6 s. 389 ms. | 24 s. 839 ms. | 784,388 | 1,171,456 | 7 m. 20 s. | 6 m. 52 s. |
| F12 | Reconnaissance cavalry (Scorpion) (wet) | 453246, 1853871 | 457235, 1853081 | 5.24 | 4.34 | 1 hr. 35 m. 52 s. 886 ms. | 1 m. 51 s. 744 ms. | 1,236,604 | 886,704 | 12 m. | 8 m. 22 s. |

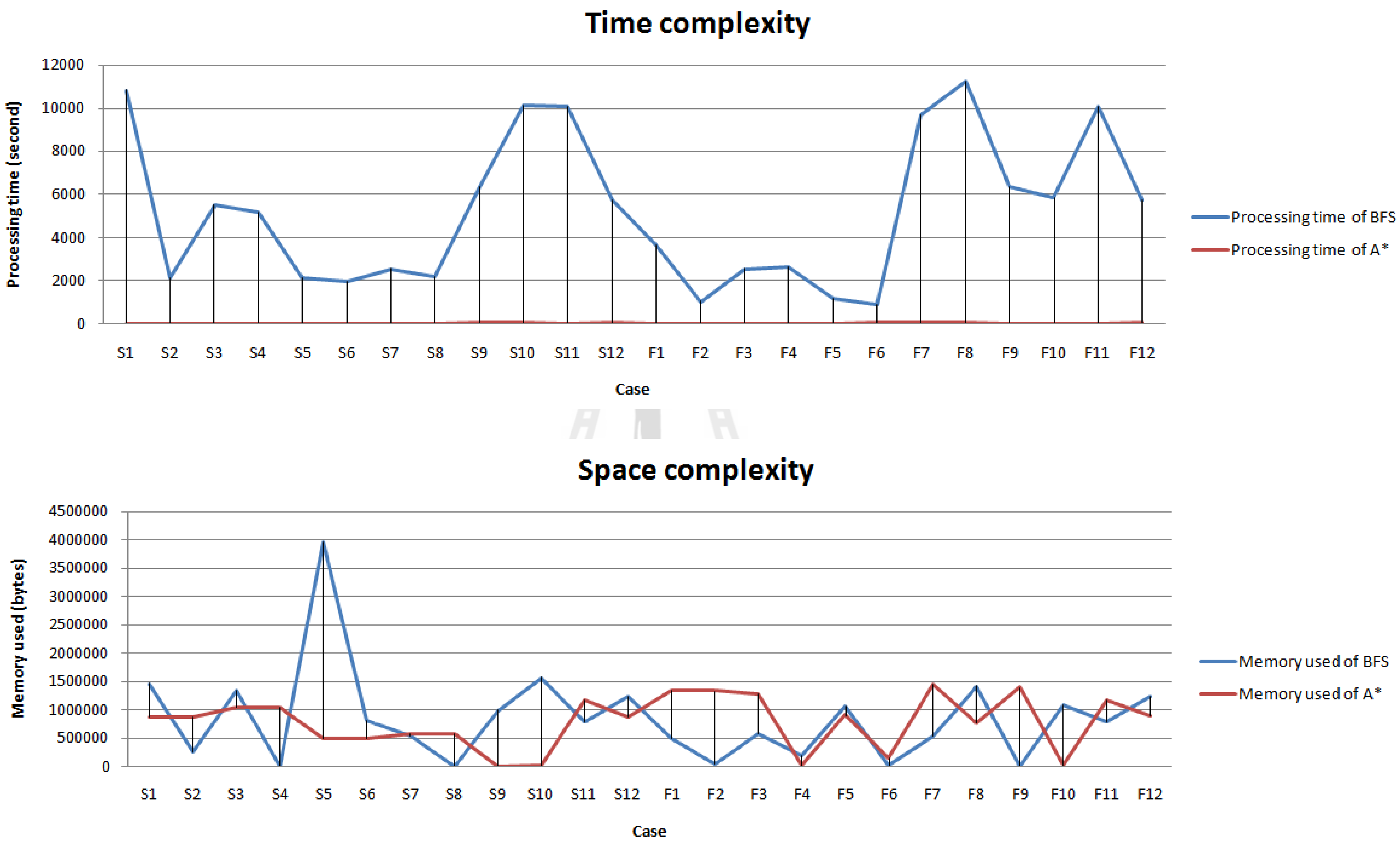


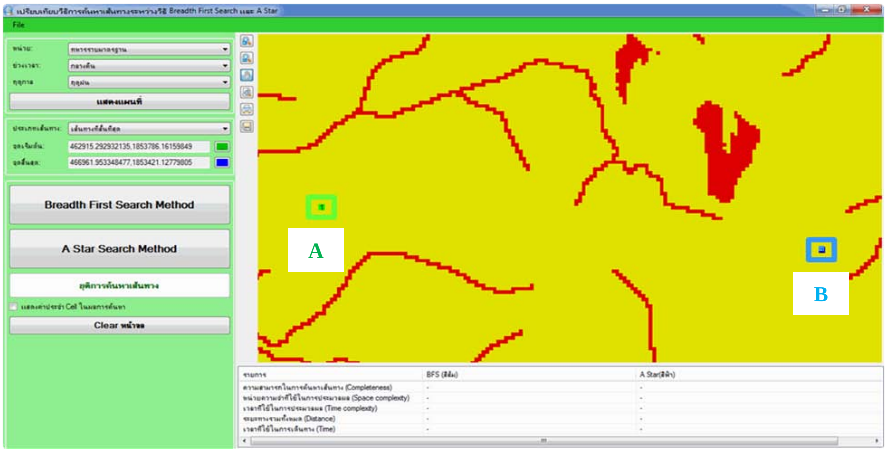

**Figure 5.1** Efficiency comparison between the two methods in terms of time and space complexities (as detailed in Tables 5.1 and 5.2).

**Table 5.3** Performance comparison for the BFS and A* search algorithms.

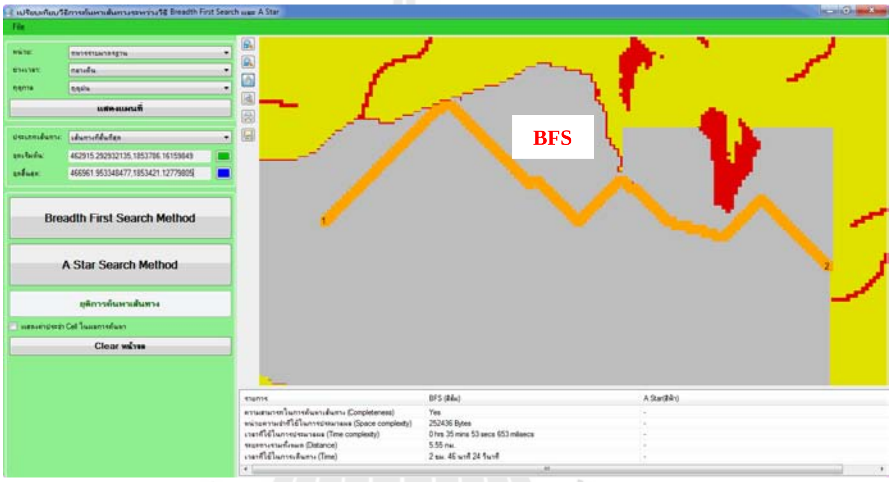
| Performance criteria | Performance comparison | |
|---|---|---|
| | **BFS** | **A*** |
| 1. Completeness | Yes | Yes |
| 2. Space complexity | Uncertain | Uncertain |
| 3. Time complexity | Always worse | Always better |
| 4. Optimality | Always worse | Always better |

From Tables 5.1 and 5.2, it can be primarily concluded here that for all four performance criteria stated in Table 3.10, both algorithms can find the solutions under their own procedures (but not the same one). However, the A* did considerably better than the BFS in terms of processing time and the correct solution found in all cases under consideration (especially the processing time). But in terms of the used memory, it is still uncertain which one is superior. For example, from Table 5.1, the shortest path in dry season found by the BFS for standard infantry troops (daytime) has travel distance of about 5.72 km which takes the processing time of more than 3 hours (1,460,712 bytes of memory in use) while the A* has found the solution of 4.23 km in just less than 1 minute (876,544 bytes of memory in use). Also, for the reconnaissance cavalry in dry season, the BFS found path solution at distance of 5.23 km (using more than 1 hour of the processing time) while the A* found at 4.34 km (with less than 1 minute of processing time). However, the used memory for BFS case is about 784,388 bytes while for the A* case is 1,171,456 bytes.

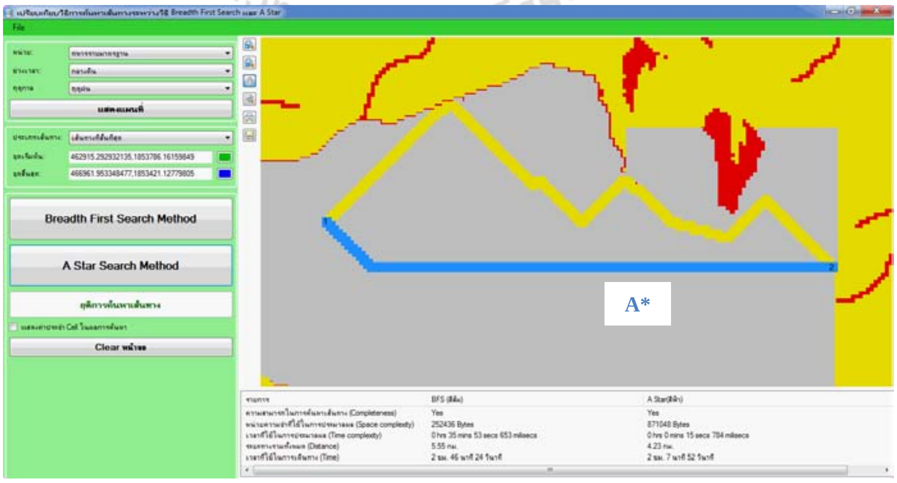
Figures 5.2 - 5.6 illustrate the path solutions found by the BFS and A* search algorithms in some selected cases from Table 5.1 and 5.2.




(a) Start (A) and goal (B) positions.

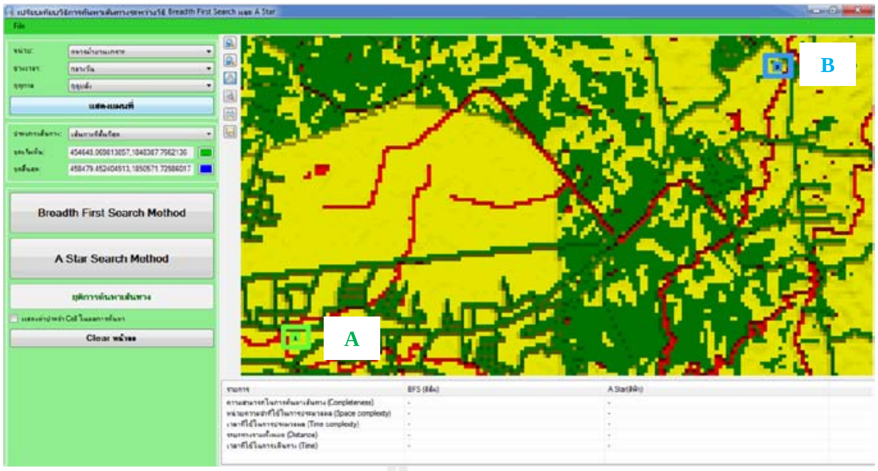



(b) Solution path from the BFS algorithm.

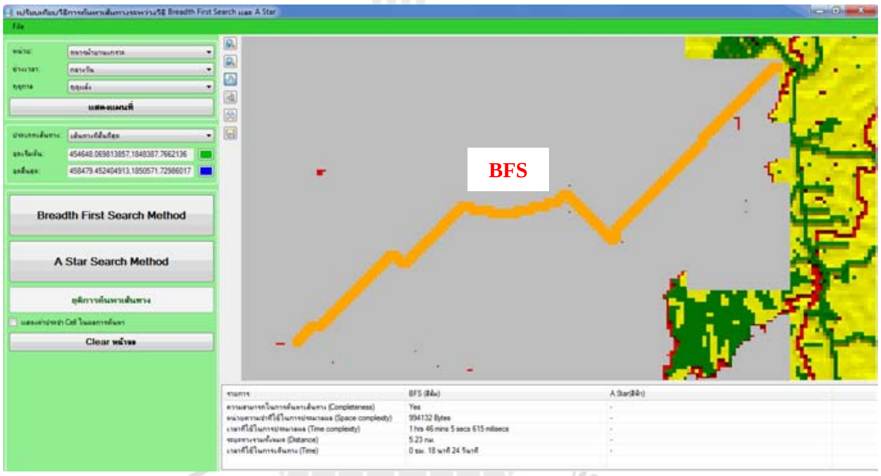



(c) Solution path from the A* algorithm.

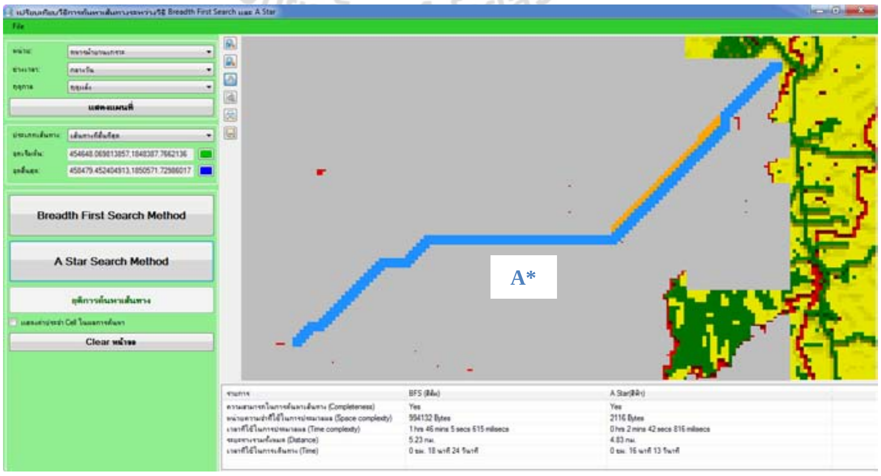
**Figure 5.2** Solutions for the shortest path from point A to B (a) in case S2 (foot troops at nighttime in wet season) as found by (b) BFS and (c) A* search algorithms.




(a) Start (A) and goal (B) positions.

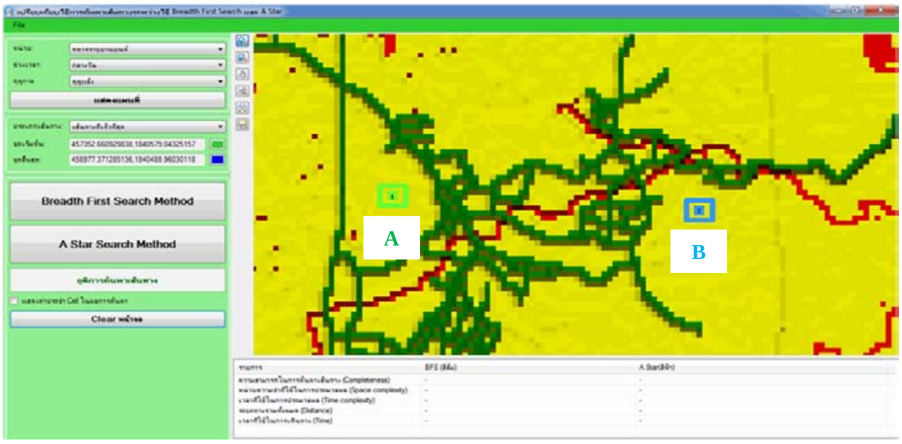



(b) Solution path from the BFS algorithm.




(c) Solution path from the A* algorithm.

**Figure 5.3** Solutions for the shortest path from point A to B (a) in case S9 (M113 in dry season) as found by (b) BFS and (c) A* search algorithms.

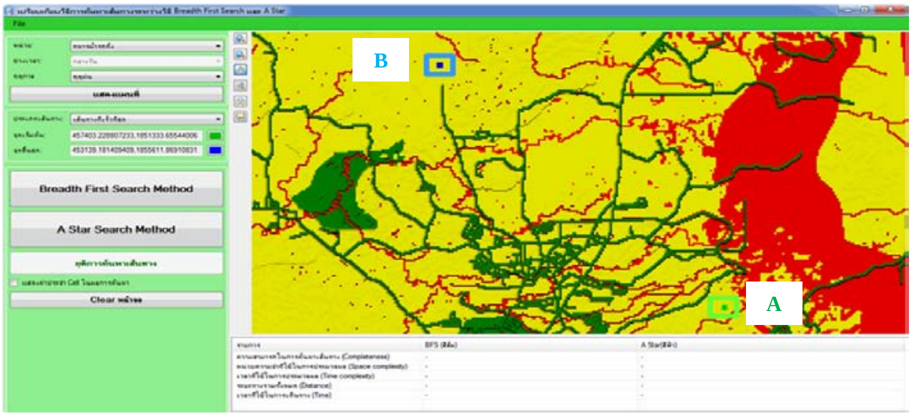



(a) Start (A) and goal (B) positions.

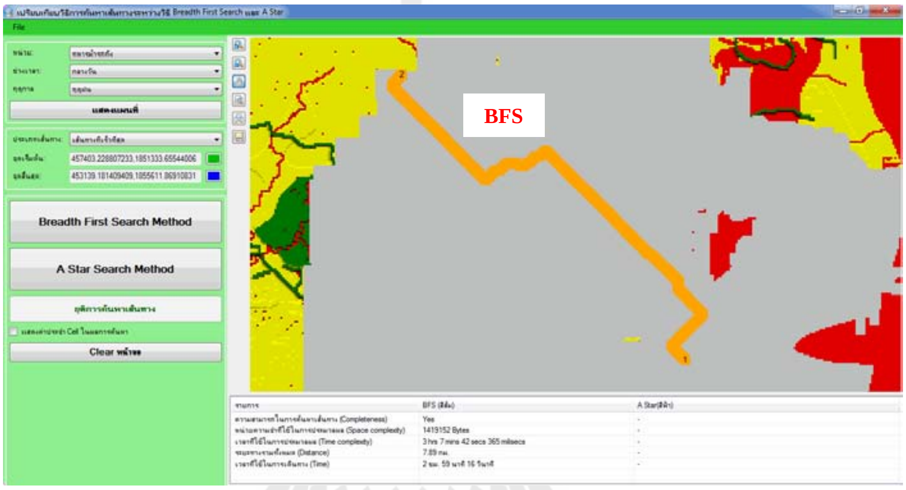

(b) Solution path from the BFS algorithm.


(c) Solution path from the A* algorithm.

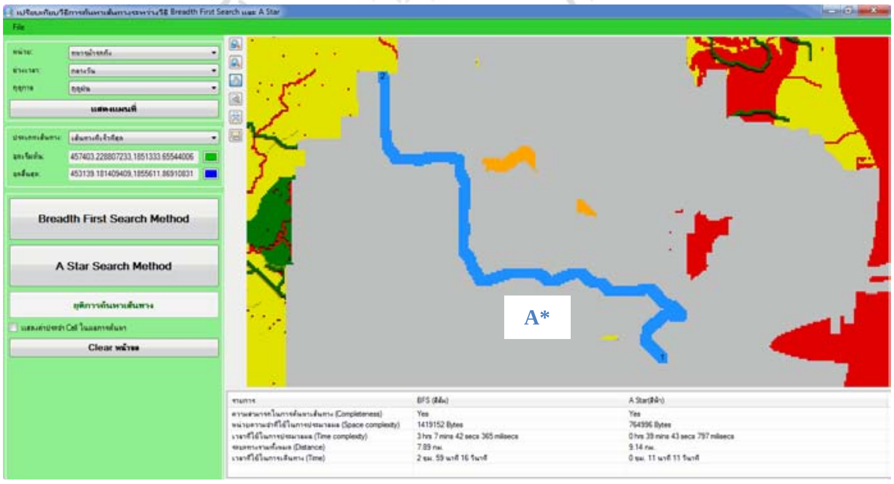
**Figure 5.4** Solutions for the shortest path from point A to B (a) in case S5 (M35 in dry season) as found by (b) BFS and (c) A* search algorithms.




(a) Start (A) and goal (B) positions.

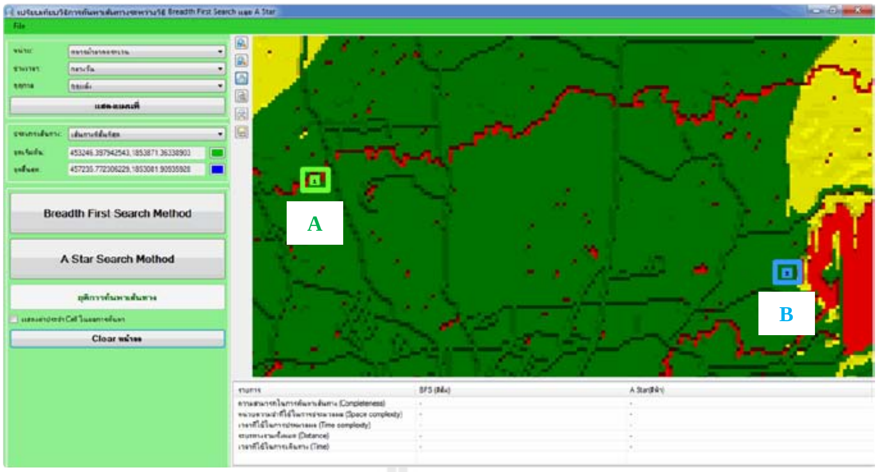



(b) Solution path from the BFS algorithm.

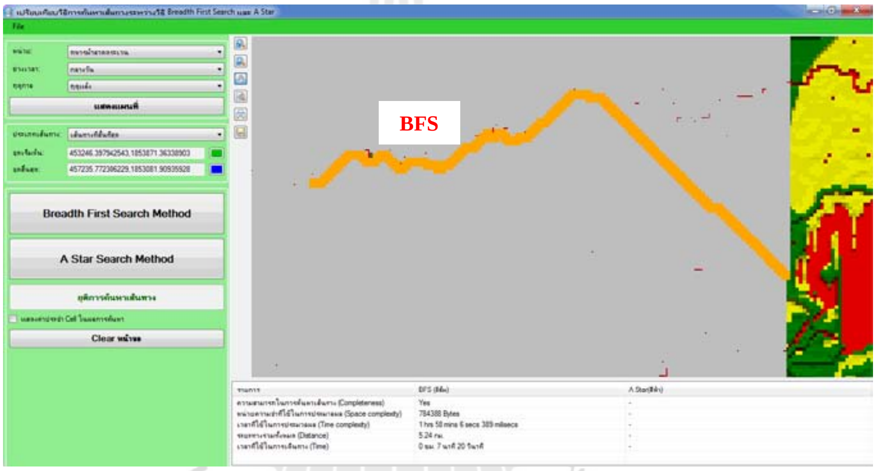



(c) Solution path from the A* algorithm.

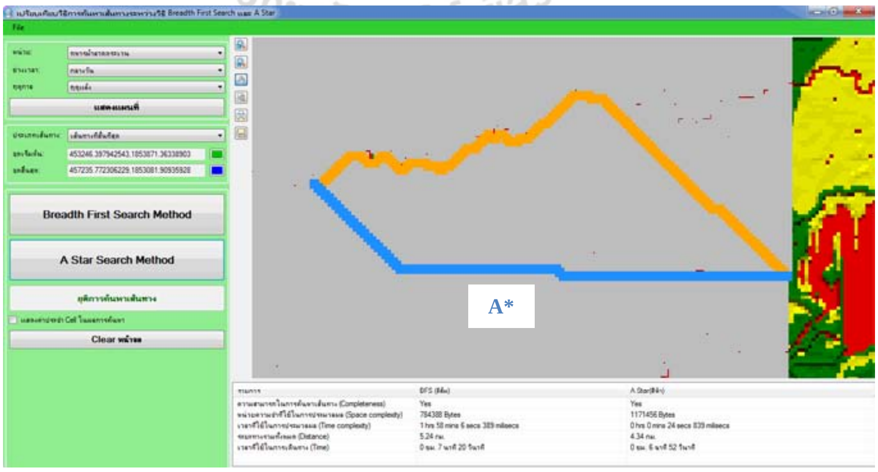
**Figure 5.5** Solutions for the fastest path from point A to B (a) in case F8 (Stringray tank in wet season) as found by (b) BFS and (c) A* search algorithms.




(a) Start (A) and goal (B) positions.




(b) Solution path from the BFS algorithm.




(c) Solution path from the A* algorithm.

**Figure 5.6** Solutions for the fastest path from point A to B (a) in case F11 (Scorpion tank in dry season) as found by (b) BFS and (c) A* search algorithms.

## 5.2 Application for automatic path finding of the CCM4CM system

As the A* algorithm has been found (in Section 5.1) to be notably superior than the BFS in path finding analysis, especially in terms of the better solution and the rapid processing time, therefore, it was chosen for the construction of the automatic path searching system (as described in Section 3.5).

To employ the system, users must access through the accessing interface where their valid account and password are needed (Figure 5.7) and the output interface that gives users opportunities to select initial conditions of the processing of interest (Figure 5.8), for examples, type of the preferred route (shortest/fastest), type of combat unit (as stated in Table 3.1), time (day/night), season (dry/wet), start/end positions. Results of the processing will be reported as continuous lines on map and specific details of the identified routes given in text, e.g. total length, travelling time. The CCM maps needed to assist the path finding analysis can be identified and fed into the system by using the "file" function as shown in Figure 5.9.

The system is able to search for the preferred shortest/fastest routes under given specific pair of the start and end points where two types of searching priorities are available:

(1) Normal search-no extra requirements of the preferred solution needed in the analysis (Figure 5.10); and

(2) Conditional search-some specific conditions are required for the path finding analysis (Figure 5.11). These are:

(a) The preferred path must, or must not, pass some specific locations along the route (Figure 5.12 and 5.13, respectively);

(b) The preferred path must not pass close to some specific locations along the route at some certain distances (Figure 5.14);

(c) The preferred path must, or must not, pass over some specific areas along the route (Figure 5.15 and 5.16, respectively); and

(d) The preferred path must pass the instantly-built bridge along the route (Figure 5.17).

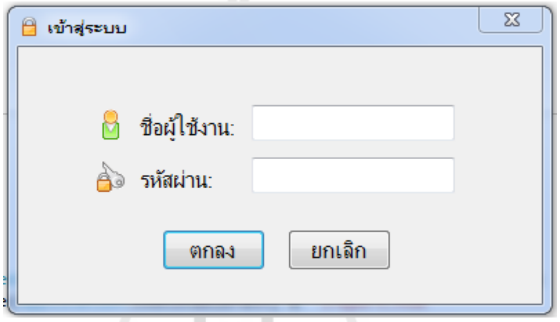



**Figure 5.7** Accessing interface of the system.

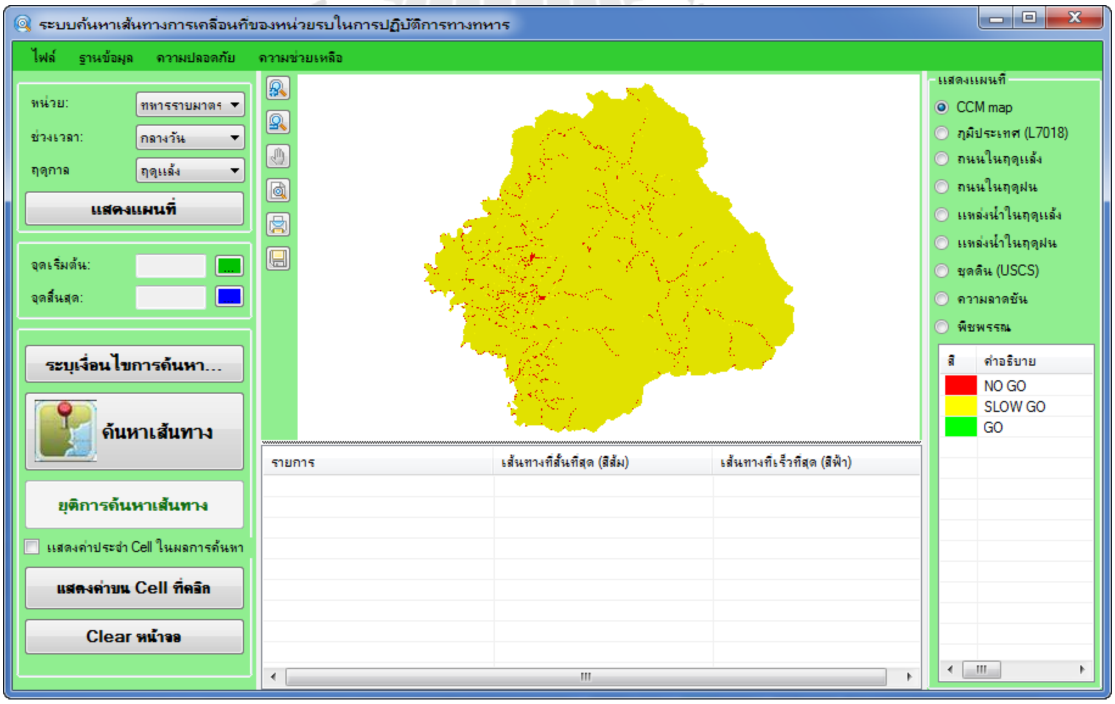



**Figure 5.8** The main graphic user interface of the CCM4CM system.

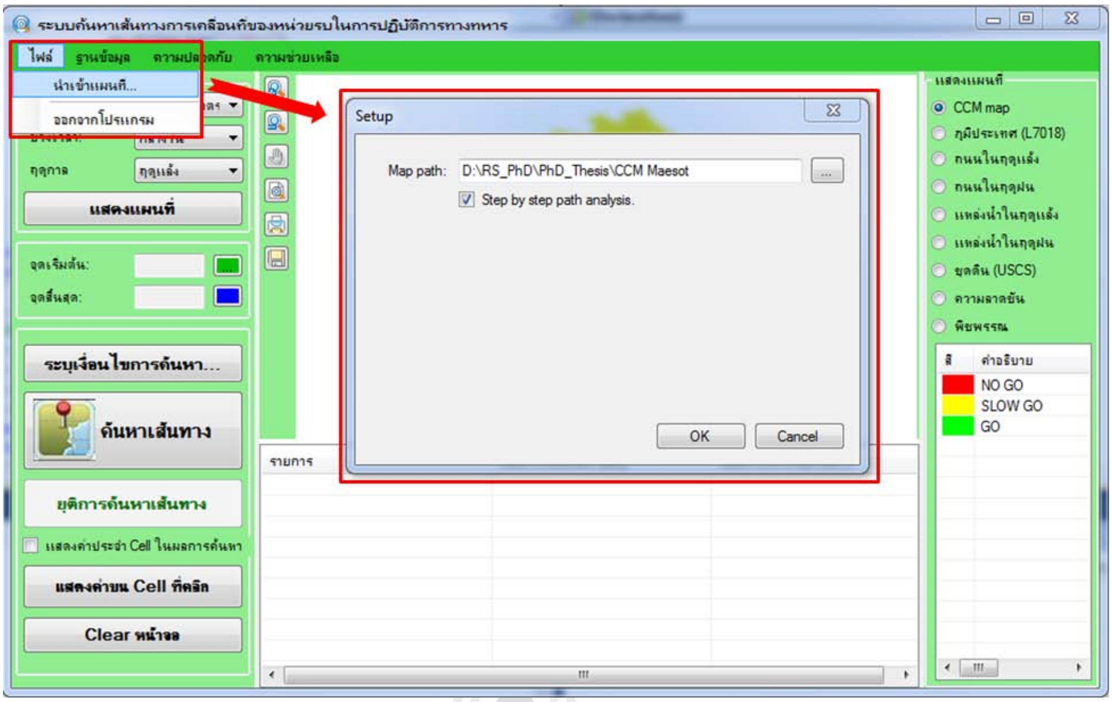



**Figure 5.9** How to introduce the relevant CCM maps into the system.


**Figure 5.10** Example of resulting report of the normal search system (shortest path in orange and fastest path in blue).

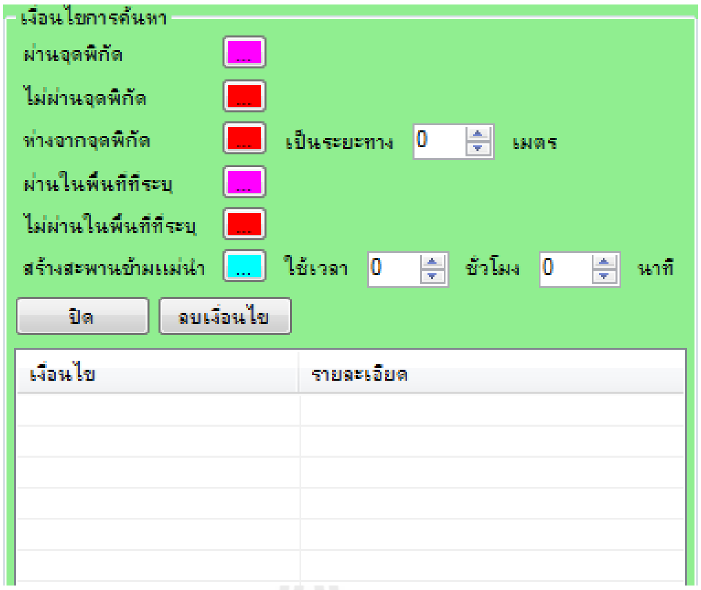
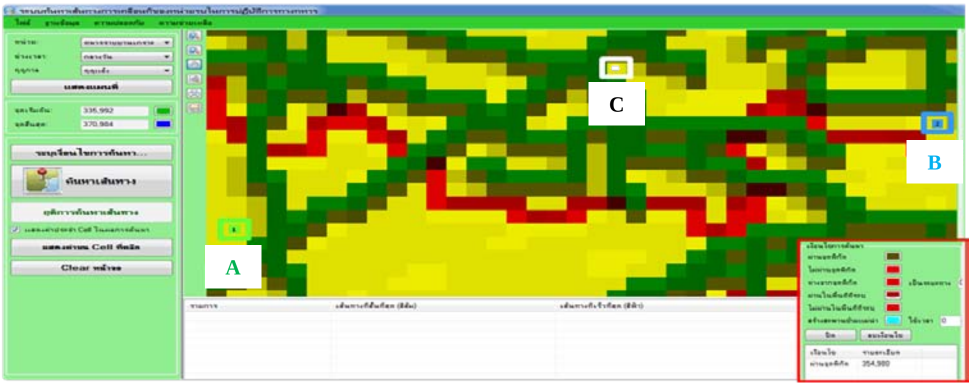
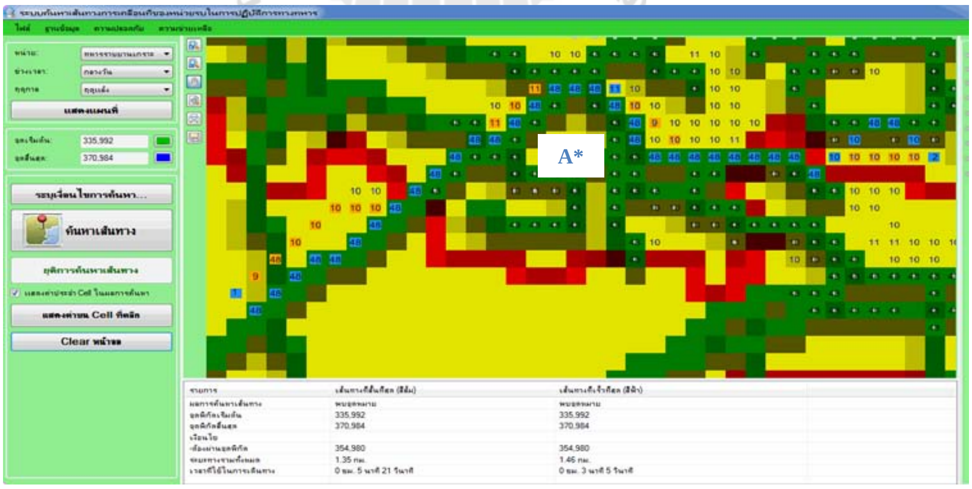



**Figure 5.11** Available requirements offered in the conditional searching mode.



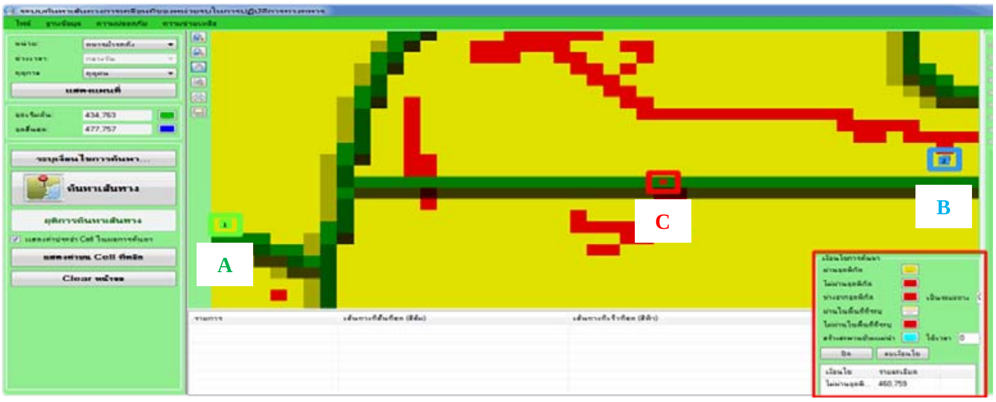

(a) Start (A), goal (B), and must-pass (C) positions.


(b) Solution path from the BFS algorithm.




(c) Solution path from the A* algorithm.

**Figure 5.12** Example of the resulting reports when the "must pass" some specific location requirement is used.



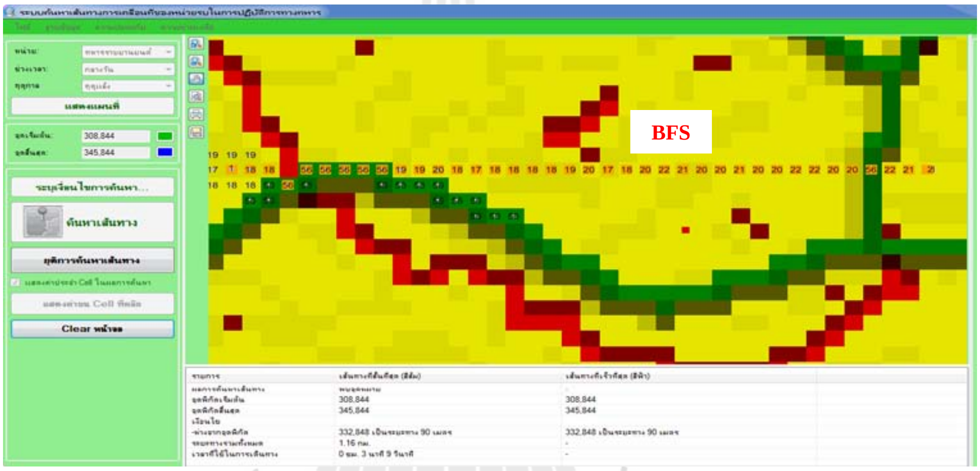

(a) Start (A), goal (B), and must-not-pass (C) positions.


(b) Solution path from the BFS algorithm.

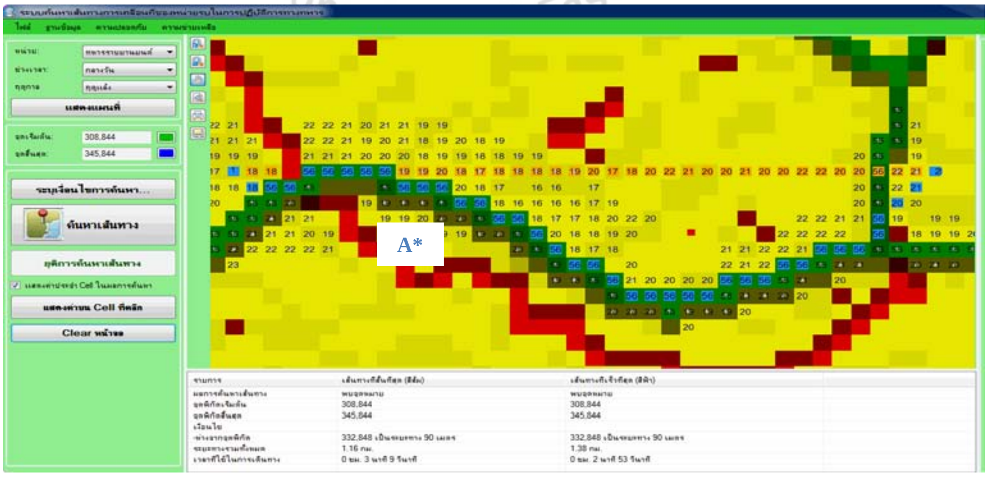

(c) Solution path from the A* algorithm.

**Figure 5.13** Example of the resulting reports when the "must not pass" some specific location requirement is used.


(a) Start (A), goal (B), and must-not-pass-closer-to (C) positions.

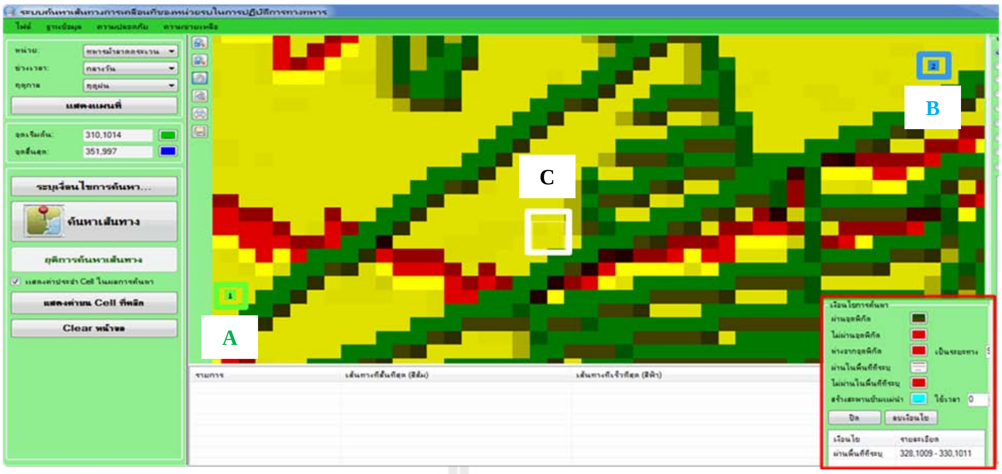



(b) Solution path from the BFS algorithm.



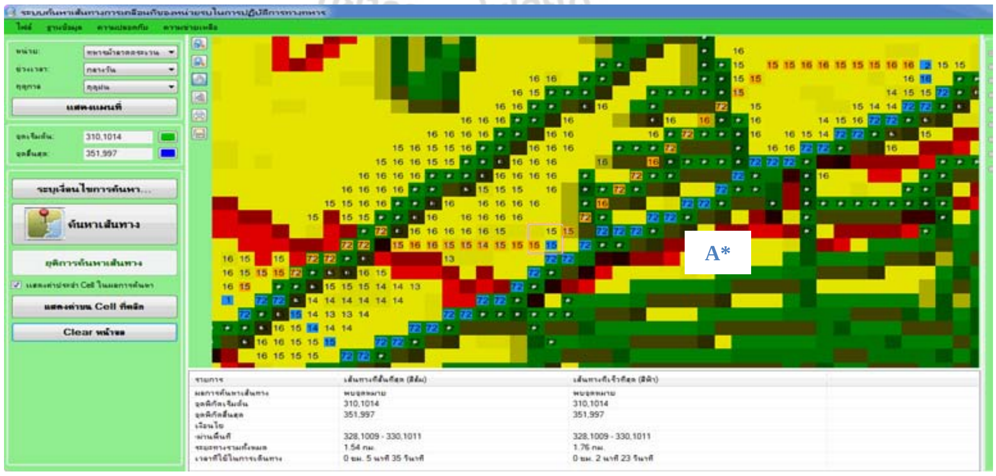

(c) Solution path from the A* algorithm.

**Figure 5.14** Example of the resulting reports when the “must not pass” closer to some specific location at some certain distance requirement is used.



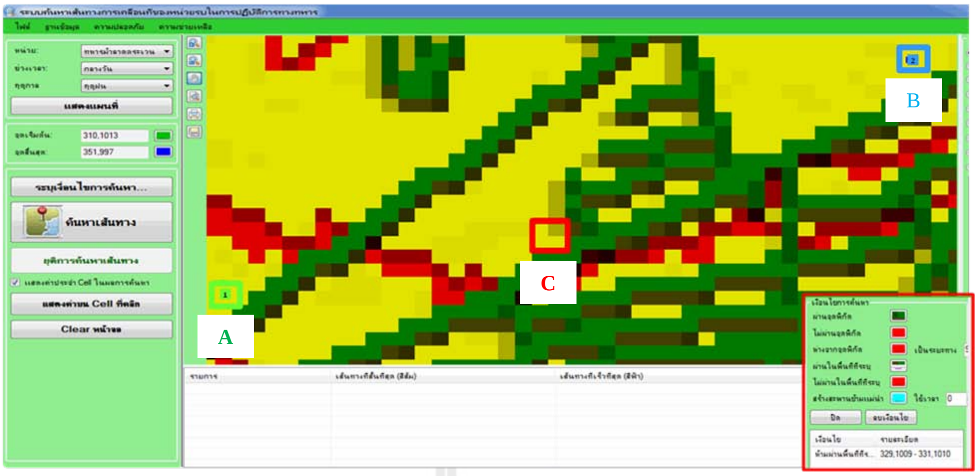

(a) Start (A), goal (B), and must-pass-over (C) positions.


(b) Solution path from the BFS algorithm.




(c) Solution path from the A* algorithm.

**Figure 5.15** Example of the resulting reports when the "must pass" over some specific area requirement is needed.

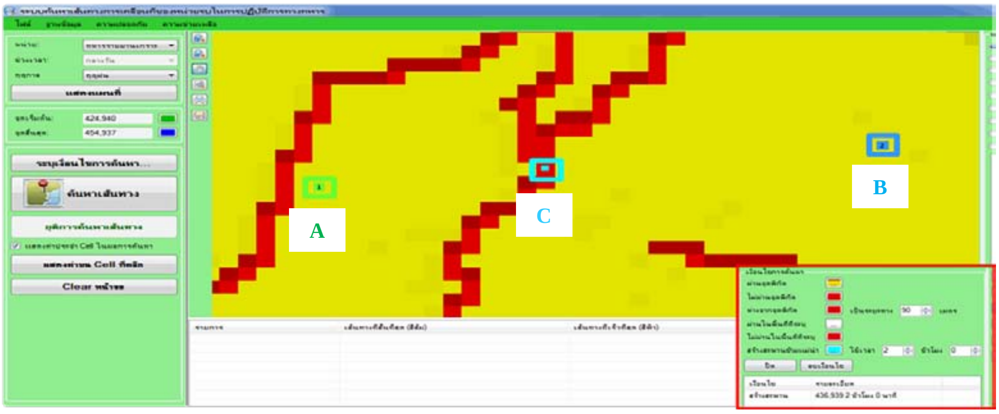



(a) Start (A), goal (B), and must-not-pass-over (C) positions.


(b) Solution path from the BFS algorithm.

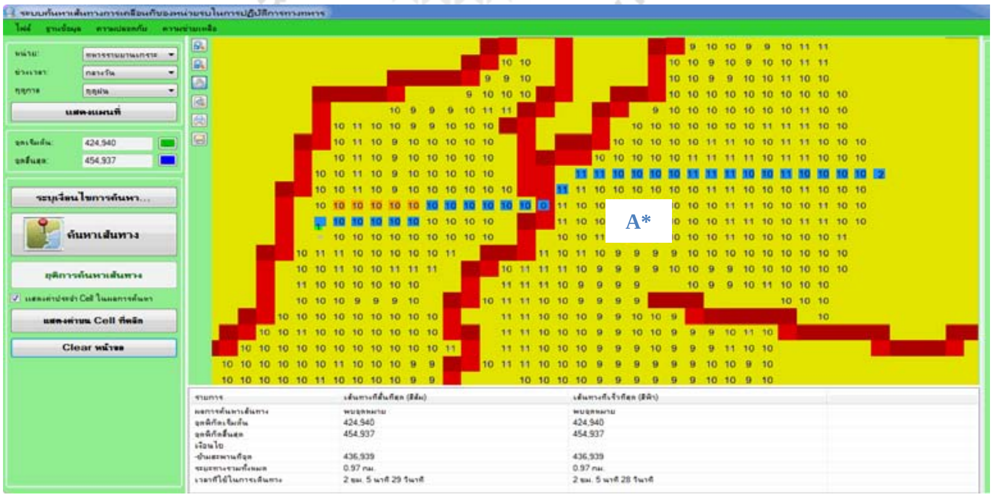

(c) Solution path from the A* algorithm.

**Figure 5.16** Example of the resulting reports when the “must not pass” over some specific area requirement is needed.




(a) Start (A), goal (B), and must-pass instantly-built bridge (C) positions.


(b) Solution path from the BFS algorithm.




(c) Solution path from the A* algorithm.

**Figure 5.17** Example of the resulting reports when the “must pass” some instantly-built bridge requirement is needed.

## 5.3 System evaluation

Evaluation of the system was performed after it was fully developed to gain opinions of the target users on the functionality, capability and limitations of the system that might need adjustment or improvement. To achieve this task, a questionnaire was created and distributed to ten system's users which were divided into two groups: system administrators (5 persons) and data analysts (5 persons). The questionnaire comprises of three main parts:

(1) personal details of the user;

(2) efficiency of the system for the use; and

(3) suggestions and guidelines for the improvement of the system.

For efficiency evaluation, the score range of 1 to 5 was established to reflect the satisfaction level of each participated user from least to most as follows:

| Score | | Satisfaction level |
|---|---|---|
| 1 | = | Least (the system should be tremendously improved); |
| 2 | = | Low (the system should be considerably improved); |
| 3 | = | Moderate (the system still needs some improvements); |
| 4 | = | High (the system is quite satisfied for the use); and |
| 5 | = | Very high (the system is highly satisfied for the use). |

Results gained from the referred questionnaire can be concluded as follows:

User's details (out of 10 persons)

(1) Age;

< 29 years (0),

30 - 39 years (2),

40 - 49 years (6),

50 - 60 years (2).

(2) Sex;

Male (10),

Female (0).

(3) Working status;

System's administrator (5),

Data analysts (5).

**Table 5.4** Results of the system's evaluation in Part 2.

| No. | Evaluated list | Number of persons | | | | | Average | Evaluation result |
|---|---|---|---|---|---|---|---|---|
| | | Very high (5) | High (4) | Moderate (3) | Low (2) | Very low (1) | | |
| 1. | Outputs satisfy needs of users | 4 | 6 | - | - | - | 4.4 | High |
| 2. | System satisfies working procedure of users | - | 10 | - | - | - | 4.2 | High |
| 3. | Outputs benefit works of users | 4 | 6 | - | - | - | 4.4 | High |
| 4. | System is easy to be used | 6 | 4 | - | - | - | 4.6 | Very high |
| 5. | Offered menu and tools are easy to understand for the use | 8 | 2 | - | - | - | 4.8 | Very high |
| 6. | Validity of data processing | - | 8 | 2 | - | - | 3.8 | High |
| 7. | Usefulness level of the system for the military path finding | - | 10 | - | - | - | 4.2 | High |
| 8. | Possibility to apply the system elsewhere | - | 8 | 2 | - | - | 3.8 | High |

Results of the evaluation from Part 3 (about the suggestions and guidelines for the system's further improvement and development) can be concluded as follows:

(1) Administrator;

Application of the system should be implemented in other border areas also apart from those in the 3rd Army Area.

(2) User;

Higher spatial resolution should be done and GIS application on route navigation should be included.

In general, according to the evaluation results from both groups of the system users, the developed system was found to be functioning well and suited for the responsible tasks of the users. It can also respond well to the needs of the users and has convenient user interface as well. The system is hoped to be applied fruitfully in other concerned areas in the future.

# CHAPTER VI

# CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Conclusions

This thesis has two main objectives to be fulfilled. The first goal is to produce CCM maps for the combat units of interest based on the guidelines from the US Army (1990) and the RTSD Map Center (1997). The study area was chosen to be Maesot District, Tak Province, which is key area for transportation and trading hub between Thailand and Myanmar. The results were reported separately between the dry and wet seasons for all concerned combat units in accordance with their main operating vehicles (or troops) chosen for the analysis, which are Standard infantry (Foot troops), Armored infantry (M113), Mechanized infantry (M35 truck), Tank cavalry (Stingray tank), Armored cavalry (M113), and Reconnaissance cavalry (Scorpion tank).

The second goal is to develop the automatic path finding system based on the associated CCM maps obtained from the first objective and the superior path finding algorithm between two candidates, the BFS and A* search algorithms, found in the performance comparing analysis. These two methods work based on rather different concepts from which the first one (BFS) is called uninformed (or blind) search while the second one (A*) is called the informed (or heuristic) search. The path finding capability was focused on two basic preferences: the shortest and the fastest paths (if a pair of start/end positions is given).

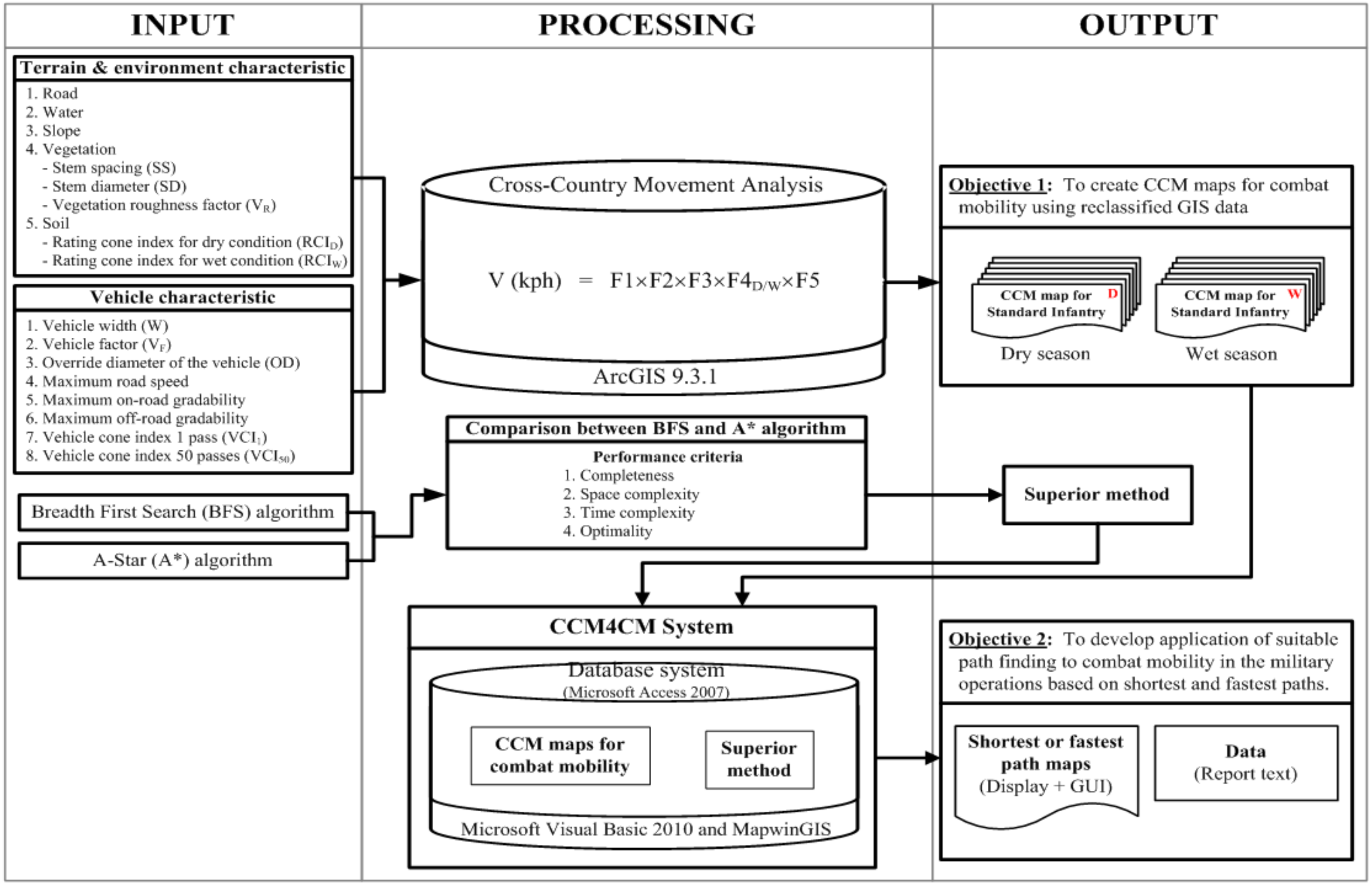



**Figure 6.1** The proposed structure of terrain analysis of cross-country movement for path finding of combat mobility in military operations.

**Construction of the CCM factor**

In the first objective, the CCM maps for each relevant combat unit were derived based on standard formula proposed by the US Army manual (1990):

$$V\ (kph) = F1 \times F2 \times F3 \times F4_{D/W} \times F5, \tag{6.1}$$

where F1 to F5 represent key terrain and environmental characteristics of the study area, F1 is speed/slope factor, F2 is slope-intercept-frequency (SIF) factor, F3 is vegetation factor, F4 is soil factor, and F5 is surface roughness factor.

The obtained F1 values were divided into 3 categories: No Go (0 - 1.5 km/hr), Slow Go (1.5 - 30 km/hr), and Go (> 30 km/hr). It was found that, the Go areas for all listed vehicles mainly dominate on the rather flat portion on the western side of the district, e.g. areas with slope 0 - 3%, while the No Go areas located mainly within the mountainous region on the middle and eastern parts of the district, with the Slow Go areas distributed in-between. Among the four considered vehicles, the Scorpion tank can attain the highest moving speed (regarding to the maximum F1 values) at about 54.29 km/hr, followed by the Stingray at 46.0 km/hr, the M113 at 36.0 km/hr, and the M35 at 26.25 km/hr (all speeds are in dry season). Because M35 cannot move faster than 30 km/hr, therefore, only the No Go and Slow Go categories can be achieved.

The computed F2 (SIF) map for the study area has similar outlook to the F1 map (due to their dependencies on surface slope) in which the high values occur mostly on the western side of the area (due to low slope) and low values appear mostly on the middle and eastern parts of the study area. The vegetation factor (F3) indicates impact of vegetation cover (type, density, or distributing pattern) on the mobility of vehicle movement. It was found that, the F3 values depend significantly on both the preferred vehicle type and the relevant vegetation type. The highest values for all listed vehicles were found at 0.90 (A2/A3 classes) and 0.85 (A1/G2 classes). In general, the M113 has highest F3 values in all other vegetation types and Stingray tank has the lowest.

The soil factor (F4) shows impact of soil characteristics on vehicle’s mobility. The F4 value determines if a particular soil type will support the vehicular movement and to what extent the speed will decrease due to that soil type. In general, dry soil can afford the CCM movement of a vehicle much better than the wet soil. As a result, the F4 values for a chosen vehicle were usually found much higher in dry season than in wet season in almost all soil types. In dry season, rock, sand and gravel can support the CCM movement the best while in wet season, rock and gravel can do the best. The F5 values applied in this study for the map unit 1, 3, 6 were identified (in association with the USCS soil types) as follows:

(1) Surface with no roughness effect (map unit 1: F5 = 1) - mostly found on the western side due to the abundance of natural flat terrain**;**

(2) Stony soil with large rocks (map unit 3: F5 = 0.7) - only few areas found; and

(3) Area of high landslide potential (map unit 6: F5 = 0) - mostly found on the middle and eastern sides of the area (the steep mountainous terrain).

**Construction of the CCM maps**

From results of CCM maps construction, it was found that the standard infantry (foot troops) can move past most terrains well in both dry and wet seasons except at the few specified No Go areas (water body) at standard velocities of 4 km/hr during daytime and 2 km/hr during nighttime, respectively. For all considered vehicles, their Go areas were mainly identified on the western side of the district due to the dominant flat terrain of the area. On the contrary, the No Go areas are notably situated within the mountainous region in the middle and eastern parts of the district due to steep slopes and the proneness to landsliding of the areas. In addition, the Slow Go areas were found distributed around and in-between the Go and No Go areas for most vehicles.

The Go areas of most vehicles often decrease dramatically from dry season to wet season due mainly to the soil strength which is much higher in dry season than in wet season for all the vehicles under consideration. The No Go areas usually enlarge during wet season due to the increase of areas with moving speed less than 1.5 km/hr (especially M35 and Stingray). Regarding to amount of the Go areas in dry season, the Scorpion and Stingray tanks are far more effective on CCM activity than other studied vehicles. But in the wet season, the Scorpion tank does best, followed by the M113. In addition, the M35 truck performs worst in both wet and dry seasons.

**Analysis of the path finding algorithms**

This part demonstrates capability of the two chosen search algorithms, breadth first search (BFS) and A-Star (A*) search, in the finding of the preferred shortest and fastest paths based on the generated CCM map (under given initial and target states). To achieve this objective, their performances were compared (under same conditions) in terms of: (1) completeness; (2) space complexity; (3) time complexity; and (4) optimality. In the process, twelve path finding cases each were evaluated for the shortest and fastest preferences where two cases each (dry/wet season) were assessed for each troop unit and the concerned vehicle type.

Results of the study indicate for all four performance criteria stated earlier, both algorithms can find the solutions under their own procedures (but not the same one).

However, the A* did considerably better than the BFS in terms of processing time and preferred solution found in all considered cases (especially for the processing time). But in term of the used memory, one's superiority is still uncertain.

**Application for automatic searching system**

Eventually, the A* algorithm was chosen to make an automatic path searching system due to its notable several superiority to the BFS technique. In order to gain access to the devised system, users must have valid account and password provided to them by the system's administrator. After logging-in, the system allows general users to select initial conditions of the processing task of their interest, for examples, type of the preferred route (shortest/fastest), type of the combat unit (e.g. standard infantry, armored infantry), time (day/night), season (dry/wet), or start/end positions. Results are reported as continuous lines on the output map and specific details of the identified routes are given in text, e.g. total length, travelling time.

In conclusion, the major advantages and limitations of the developed path finding system are as follows:



**Advantages**

(1) Developed based on the popular Windows platform which is convenient for the study and implementation. The relevant GUI was also constructed based on the user-friendly concept to accommodate all kinds of potential users;

(2) Several types of the search options are available and the output report can be generated and displayed very readily; and

(3) Potentiality to be applicable at other areas of interest is high as fundamental concepts of the system's development were well established.

**Limitations**

(1) Only options of the shortest and fastest paths are available at present. Some other interesting choice, like the safest path, is still not included in the study; and

(2) Some input data (for the calculation of F1 to F5) might be still not sufficiently realistic, e.g. topographic data or soil moisture data. This makes the output CCM maps less credible or less applicability as priorly expected.

## 6.2 Recommendations

From the experiences gained from this study, the recommendations for further study can be as the followings:

(1) Use high capability versions of the preferred software and hardware to speed up the processing time of the system (in the construction of the CCM maps and the developing of the automatic path finding system);

(2) The used mapping freeware MapWinGIS (for displaying and managing CCM map) still has some limitations to fulfill need in the study. It is recommended to try to use the standard licensed Map Object which might give better results;

(3) Information of the selected vehicle specifications in some cases is still quite limited. This makes the obtained results having less credibility as more assumptions or simplifications were needed in the analysis. Details of vehicle specifications should be more completed in the further study; and

(4) The use of more realistic input for calculation of F1 to F5 is recommended. For examples, slope characteristics, e.g. up-slope/down-slop data (for F2), updated soil moisture content, e.g. daily data (for F4), and updated data of vegetation cover, especially in the agricultural area (for F3).

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# REFERENCES


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# APPENDICES

# APPENDIX A

# VEGETATION DATA

## A.1 Notes on DMA Vegetation Codes

The vegetation code is based on DMA vegetation coding standards, in which areas are assigned a 1, 2, or 3 character code. For all codes the first character denotes the general class of vegetation.

Following are the valid 1 character codes:

| | |
|---|---|
| H | Forest Clearing (cutover areas, burns, etc.) |
| J | Marsh/Bog (peat, muskeg, etc.) |
| K | Wetlands (L.S.I., low-lying wet areas) |
| N | Bare Ground |
| W | Open Water |
| X | Built-up Areas (not evaluated) |

Following are the valid codes with exactly 2 characters:

| | |
|---|---|
| A1 | Agriculture (dry crops) |
| A2 | Agriculture (wet crops, rice) |
| A3 | Agriculture (terraced crops, both wet and dry) |
| A4 | Agriculture (shifting cultivation) |
| A5 | Aquaculture (fish ponds, shrimp farms) |
| B1 | Brushland/Scrub (<5m high, nearly open to medium spacing) |
| B2 | Brushland/Scrub (<5m high, medium to dense spacing) |

| | |
|---|---|
| G1 | Grassland, Meadows, Pasture |
| G2 | Grassland with scattered trees, some scrub |
| M0 - M9 | Bamboo forest (second digit indicates height, 0 = height unknown) |
| NE | Not Evaluated |

All other valid codes will have 3 characters, with the following significance:

| 1st char | Vegetation class |
|---|---|
| C | Coniferous/Evergreen Forest |
| D | Deciduous Forest |
| E | Mixed Forest |
| F | Fruit Bearing Trees (Orchard/Plantation) |
| I | Swamp (mangrove, cypress, etc) |
| P | Palm trees (coconut, palm oil, date) |
| R | Rubber tree plantations |

| 2nd char | Canopy closure (%) |
|---|---|
| 1 | 0 - 25 |
| 2 | 25 - 50 |
| 3 | 50 - 75 |
| 4 | 75 - 100 |

| 3rd char | Height (meters) |
|---|---|
| 1 | 0 - 2 |
| 2 | 2 - 5 |
| 3 | 5 - 10 |
| 4 | 10 - 15 |
| 5 | 15 - 20 |
| 6 | 20 - 25 |
| 7 | 25 - 30 |
| 8 | 30 - 35 |
| 9 | > 35 |

**Table A.1** Vegetation data.

| Code | Vegetation description | Stem Diameter (SD) | Stem Spacing (SS) | Vegetation Roughness ($V_R$) |
|---|---|---|---|---|
| A1 | Agriculture (dry crops) | Null | Null | 0.85 |
| A2 | Agriculture (wet crops, rice) | Null | Null | 0.9 |
| A3 | Agriculture (terraced crops, both wet and dry) | Null | Null | Null ** |
| A4 | Agriculture (shifting cultivation) | Null | Null | Null ** |
| A5 | Agriculture (fish ponds, shrimp farms) | Null | Null | 0.2 |
| B1 | Brushland/Scrub (< 5 m, open to medium spacing) | Null | Null | 0.9 |
| B2 | Brushland/Scrub (< 5 m, medium to dense spacing) | Null | Null | 0.85 |
| C11 | Coniferous / Evergreen Forest | 0.01 | 2.5 | 1 |
| C12 | Coniferous / Evergreen Forest | 0.06 | 2.5 | 1 |
| C13 | Coniferous / Evergreen Forest | 0.11 | 3.8 | 1 |
| C14 | Coniferous / Evergreen Forest | 0.16 | 6 | 1 |
| C15 | Coniferous / Evergreen Forest | 0.20 | 10 | 0.7 |
| C16 | Coniferous / Evergreen Forest | 0.27 | 11 | 1 |
| C17 | Coniferous / Evergreen Forest | 0.34 | 14 | 1 |
| C21 | Coniferous / Evergreen Forest | 0.01 | 2 | 1 |
| C22 | Coniferous / Evergreen Forest | 0.06 | 2 | 1 |
| C23 | Coniferous / Evergreen Forest | 0.11 | 2.8 | 1 |
| C24 | Coniferous / Evergreen Forest | 0.16 | 6 | 1 |
| C25 | Coniferous / Evergreen Forest | 0.21 | 6.5 | 1 |
| C26 | Coniferous / Evergreen Forest | 0.27 | 7 | 1 |
| C27 | Coniferous / Evergreen Forest | 0.34 | 7.5 | 1 |
| C31 | Coniferous / Evergreen Forest | 0.01 | 1.5 | 1 |
| C32 | Coniferous / Evergreen Forest | 0.06 | 1.5 | 1 |
| C33 | Coniferous / Evergreen Forest | 0.10 | 1.8 | 1 |
| C34 | Coniferous / Evergreen Forest | 0.13 | 2.5 | 0.2 |
| C35 | Coniferous / Evergreen Forest | 0.20 | 3.7 | 1 |
| C36 | Coniferous / Evergreen Forest | 0.29 | 4.8 | 1 |
| C37 | Coniferous / Evergreen Forest | 0.33 | 5 | 1 |
| C41 | Coniferous / Evergreen Forest | 0.01 | 1 | 1 |

**Table A.1** Vegetation data (Continued).

| Code | Vegetation description | Stem Diameter (SD) | Stem Spacing (SS) | Vegetation Roughness ($V_R$) |
|---|---|---|---|---|
| C42 | Coniferous / Evergreen Forest | 0.06 | 1 | 1 |
| C43 | Coniferous / Evergreen Forest | 0.10 | 1.3 | 1 |
| C44 | Coniferous / Evergreen Forest | 0.15 | 2.5 | 0.1 |
| C45 | Coniferous / Evergreen Forest | 0.17 | 2.7 | 0.1 |
| C46 | Coniferous / Evergreen Forest | 0.26 | 3.2 | 1 |
| C47 | Coniferous / Evergreen Forest | 0.33 | 3.6 | 1 |
| CEM | Cemetary or burial ground | Null | Null | 0 |
| D11 | Deciduous Forest | 0.01 | 2.5 | 1 |
| D12 | Deciduous Forest | 0.04 | 2.5 | 1 |
| D13 | Deciduous Forest | 0.09 | 4 | 1 |
| D14 | Deciduous Forest | 0.22 | 7 | 1 |
| D15 | Deciduous Forest | 0.27 | 9 | 1 |
| D16 | Deciduous Forest | 0.34 | 12 | 1 |
| D17 | Deciduous Forest | 0.40 | 15 | 1 |
| D21 | Deciduous Forest | 0.01 | 2 | 1 |
| D22 | Deciduous Forest | 0.04 | 2 | 1 |
| D23 | Deciduous Forest | 0.09 | 3 | 1 |
| D24 | Deciduous Forest | 0.21 | 4 | 1 |
| D25 | Deciduous Forest | 0.26 | 6 | 1 |
| D26 | Deciduous Forest | 0.34 | 7 | 1 |
| D27 | Deciduous Forest | 0.39 | 8 | 1 |
| D31 | Deciduous Forest | 0.01 | 1.2 | 1 |
| D32 | Deciduous Forest | 0.04 | 1.5 | 1 |
| D33 | Deciduous Forest | 0.08 | 2 | 1 |
| D34 | Deciduous Forest | 0.20 | 2.5 | 1 |
| D35 | Deciduous Forest | 0.25 | 4 | 1 |
| D36 | Deciduous Forest | 0.32 | 5 | 1 |
| D37 | Deciduous Forest | 0.38 | 5.5 | 1 |
| D41 | Deciduous Forest | 0.01 | 1 | 1 |

**Table A.1** Vegetation data (Continued).

| Code | Vegetation description | Stem Diameter (SD) | Stem Spacing (SS) | Vegetation Roughness ($V_R$) |
|---|---|---|---|---|
| D42 | Deciduous Forest | 0.04 | 1 | 1 |
| D43 | Deciduous Forest | 0.08 | 1.5 | 1 |
| D44 | Deciduous Forest | 0.19 | 2 | 1 |
| D45 | Deciduous Forest | 0.24 | 2.5 | 1 |
| D46 | Deciduous Forest | 0.30 | 3.5 | 1 |
| D47 | Deciduous Forest | 0.41 | 5 | 1 |
| E11 | Mixed Forest | 0.0085 | 2.5 | 1 |
| E12 | Mixed Forest | 0.05 | 2.5 | 1 |
| E13 | Mixed Forest | 0.10 | 3.9 | 1 |
| E14 | Mixed Forest | 0.19 | 6.5 | 1 |
| E15 | Mixed Forest | 0.24 | 8.5 | 1 |
| E16 | Mixed Forest | 0.305 | 11.5 | 1 |
| E17 | Mixed Forest | 0.37 | 14.5 | 1 |
| E21 | Mixed Forest | 0.0085 | 2 | 1 |
| E22 | Mixed Forest | 0.05 | 2 | 0.9 |
| E23 | Mixed Forest | 0.10 | 2.9 | 0.8 |
| E24 | Mixed Forest | 0.185 | 4 | 1 |
| E25 | Mixed Forest | 0.235 | 4.8 | 1 |
| E26 | Mixed Forest | 0.305 | 7 | 1 |
| E27 | Mixed Forest | 0.365 | 7.8 | 1 |
| E31 | Mixed Forest | 0.0085 | 1.3 | 1 |
| E32 | Mixed Forest | 0.05 | 1.5 | 0.8 |
| E33 | Mixed Forest | 0.09 | 1.9 | 1 |
| E34 | Mixed Forest | 0.175 | 2.6 | 1 |
| E35 | Mixed Forest | 0.225 | 3.9 | 1 |
| E36 | Mixed Forest | 0.29 | 4.8 | 1 |
| E37 | Mixed Forest | 0.355 | 5.3 | 1 |
| E41 | Mixed Forest | 0.0085 | 0.9 | 1 |
| E42 | Mixed Forest | 0.05 | 1 | 1 |

**Table A.1** Vegetation data (Continued).

| Code | Vegetation description | Stem Diameter (SD) | Stem Spacing (SS) | Vegetation Roughness ($V_R$) |
|---|---|---|---|---|
| E43 | Mixed Forest | 0.09 | 1.4 | 1 |
| E44 | Mixed Forest | 0.17 | 2.1 | 0.7 |
| E45 | Mixed Forest | 0.22 | 2.7 | 1 |
| E46 | Mixed Forest | 0.28 | 3.4 | 1 |
| E47 | Mixed Forest | 0.35 | 4.1 | 1 |
| F12 | Fruit bearing trees (orchard / plantation) | 0.05 | 5.5 | 0.7 |
| F13 | Fruit bearing trees (orchard / plantation) | 0.12 | 7 | 0.9 |
| F21 | Fruit bearing trees (orchard / plantation) | 0.04 | 5 | 1 |
| F22 | Fruit bearing trees (orchard / plantation) | 0.08 | 3 | 0.8 |
| F23 | Fruit bearing trees (orchard / plantation) | 0.12 | 6.5 | 0.8 |
| F24 | Fruit bearing trees (orchard / plantation) | 0.14 | 5.5 | 0.8 |
| F32 | Fruit bearing trees (orchard / plantation) | 0.08 | 3 | 0.8 |
| F33 | Fruit bearing trees (orchard / plantation) | 0.13 | 6 | 0.8 |
| F34 | Fruit bearing trees (orchard / plantation) | 0.14 | 5 | 0.8 |
| F35 | Fruit bearing trees (orchard / plantation) | 0.18 | 10 | 0.9 |
| F43 | Fruit bearing trees (orchard / plantation) | 0.13 | 5.5 | 0.6 |
| F44 | Fruit bearing trees (orchard / plantation) | 0.14 | 4.5 | 0.9 |
| F45 | Fruit bearing trees (orchard / plantation) | 0.18 | 10.5 | 0.9 |
| F46 | Fruit bearing trees (orchard / plantation) | 0.1015 | 18 | 0.8 |
| G1 | Grassland, Meadows, Pasture | Null | Null | 0.95 |
| G2 | Grassland with Scattered Trees, some scrub | Null | Null | 0.85 |
| H | Forest Clearing (cutover areas, burns, etc.) | Null | Null | 0.5 |
| I0 | Swamp (mangrove, cypress. etc.) | Null | Null | 0.1 |
| I1 | Swamp (mangrove, cypress. etc.) | Null | Null | 0.1 |
| I2 | Swamp (mangrove, cypress. etc.) | Null | Null | 0.1 |
| I3 | Swamp (mangrove, cypress. etc.) | Null | Null | 0.1 |
| I4 | Swamp (mangrove, cypress. etc.) | Null | Null | 0.1 |
| J | Marsh / Bag (treeless bogs, muskegs, etc.) | Null | Null | 0.1 |
| K | Wetlands (L.S.I., low-lying wet areas) | Null | Null | 0.3 |

**Table A.1** Vegetation data (Continued).

| Code | Vegetation description | Stem Diameter (SD) | Stem Spacing (SS) | Vegetation Roughness ($V_R$) |
|---|---|---|---|---|
| L | Vineyards / Hops | Null | Null | 0.4 |
| M0 | Bamboo forest, height unknown | Null | Null | Null ** |
| M1 | Bamboo forest, height 0 - 2 m. | Null | Null | Null ** |
| M2 | Bamboo forest, height 2 - 5 m. | Null | Null | Null ** |
| M3 | Bamboo forest, height 5 - 10 m. | Null | Null | Null ** |
| M4 | Bamboo forest, height 10 - 15 m. | Null | Null | Null ** |
| M5 | Bamboo forest, height 15 - 20 m. | Null | Null | Null ** |
| M6 | Bamboo forest, height 20 - 25 m. | Null | Null | Null ** |
| M7 | Bamboo forest, height 25 - 30 m. | Null | Null | Null ** |
| M8 | Bamboo forest, height 30 - 35 m. | Null | Null | Null ** |
| M9 | Bamboo forest, height > 35 m. | Null | Null | Null ** |
| N | Bare Ground | Null | Null | 0.95 |
| NE | Not Evaluated | Null | Null | Null |
| P22 | Palm trees (coconut, palm oil, date) | 0.24 | 7 | 0.8 |
| R22 | Rubber tree plantation | 0.05 | 6 | 0.8 |
| R32 | Rubber tree plantation | 0.06 | 6 | 0.8 |
| W | Open Water | Null | Null | 0 |
| X | Built-up Areas | Null | Null | Null |

**Note**: ** Value not currently available.
Stem Diameter (SD) is thickness of stem (in meters).
Stem Spacing (SS) is distance (in meters) between trees/brush.
Vegetation Roughness ($V_R$) varies between 0 and 1.

# APPENDIX B

# SOURCE CODE

## B.1  The CCM4CM system

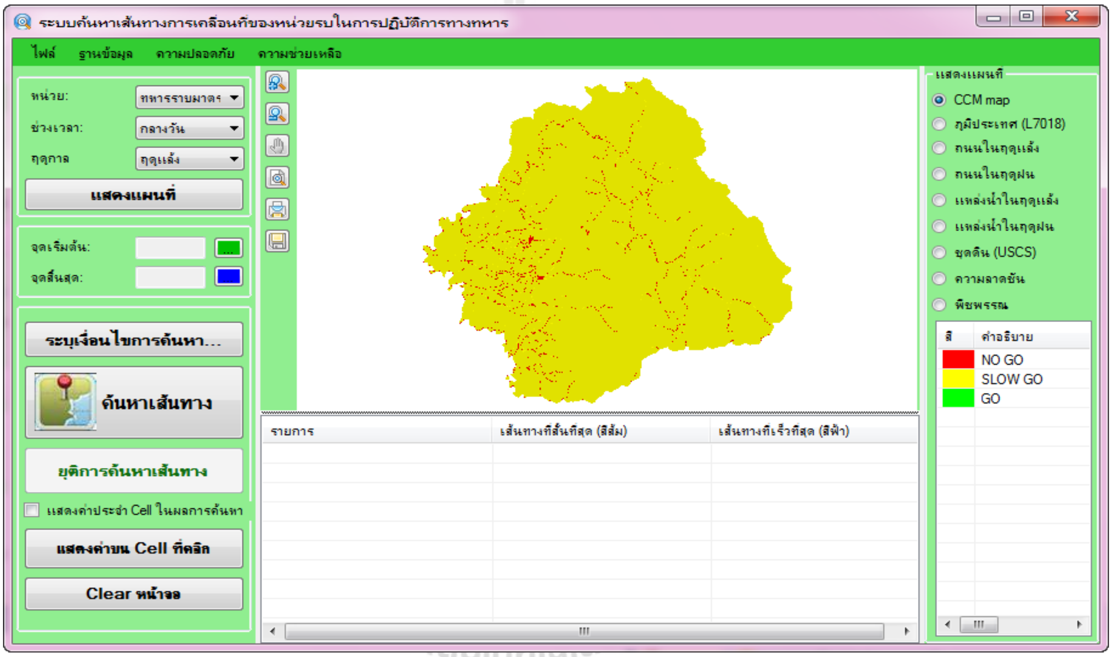



**Figure B.1** The main graphic user interface of CCM4CM system.

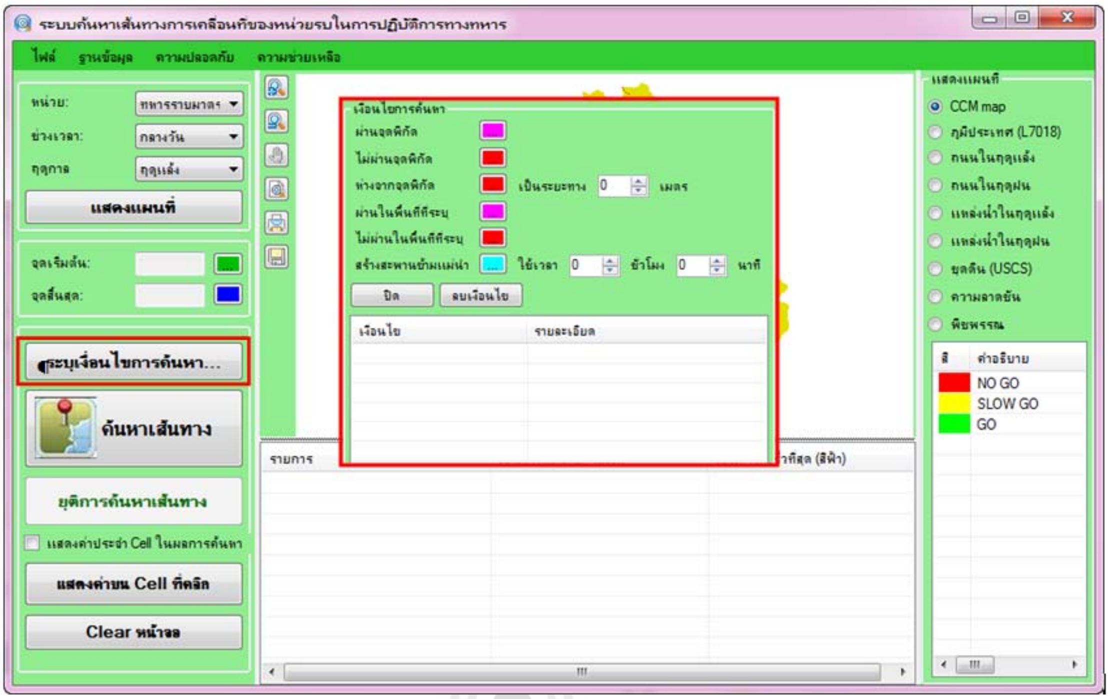



**Figure B.2** Graphic user interface of condition for path finding.

```
Imports WinCCMLib

Public Class frmMain
    'ประกาศตัวแปรเพื่อเก็บข้อมูล Layer
    Private layerData As New CcmDataSet

    'ประกาศตัวแปรเพื่อเก็บข้อมูล Map
    Private ccmLH As Integer
    Private ccmGrid As New MapWinGIS.Grid
    Private ccmGridHeader As MapWinGIS.GridHeader
    Private ccmRaster As New MapWinGIS.Image
    Private curState As CurrentStates
    Private pathDH As Integer
    Private map As MapInterface
    Private astar As New AStar.PathFinder
    Private startWP As New WayPointNode
    Private endWP As New WayPointNode
    Private finalNode As Node
    Private startColor As UInteger = CUInt(RGB(0, 255, 0))
    Private endColor As UInteger = CUInt(RGB(0, 0, 255))
    Private pathsColor As UInteger = CUInt(RGB(190, 190, 190))
    Private finalPathColor() As UInteger =
{System.Convert.ToUInt32(System.Drawing.ColorTranslator.ToOle(System.Drawing.Color.Orange)),
System.Convert.ToUInt32(System.Drawing.ColorTranslator.ToOle(System.Drawing.Color.DodgerBlu
e))}
    Private layerNames As String() = {"CCM", "Maesot_Topo.img", "", "Road30m_Dry.img",
"Road30m_Wet.img", "Water_Dry_NoGo.img", "Water_Wet_NoGo.img", "Soil_30m.img",
"SlopeDEM_30m.img", "VegetRTSD_30m.img"}
    Private layerColors As MapWinGIS.PredefinedColorScheme() =
{MapWinGIS.PredefinedColorScheme.Desert, MapWinGIS.PredefinedColorScheme.Glaciers,
```

```
MapWinGIS.PredefinedColorScheme.Glaciers, MapWinGIS.PredefinedColorScheme.Desert,
MapWinGIS.PredefinedColorScheme.Desert, MapWinGIS.PredefinedColorScheme.Desert,
MapWinGIS.PredefinedColorScheme.Desert, MapWinGIS.PredefinedColorScheme.Desert,
MapWinGIS.PredefinedColorScheme.Desert, MapWinGIS.PredefinedColorScheme.Meadow}
    Private layerLHs As Integer() = {-1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1}
    Private passPointColor As UInteger = CUInt(RGB(255, 0, 255))
    Private notPassPointColor As UInteger = CUInt(RGB(255, 0, 0))
    Private bridgePointColor As UInteger = CUInt(RGB(0, 255, 255))
    Private resultPaths() As Node
    Private waterGrid(1) As MapWinGIS.Grid
    Private valueLableDH As Integer = -1
    Private valueLabelColor As UInteger = CUInt(RGB(255, 255, 255))

    'สถานะของปุ่มจัดการ Map
    Private Enum CurrentStates
        StandBy
        SetStart
        SetStop
        SetOptionPassPoint
        SetOptionNotPassPoint
        SetOptionAwayPoint
        SetOptionPassArea
        SetOptionNotPassArea
        SetOptionBridge
        SetOptionWayPoints
        Test
    End Enum

    Private Sub Logoff()
        Dim ta As New CcmDataSetTableAdapters.USERTableAdapter
        ta.DoLogoff(Now, frmLogin.LoginNo)
        ta.Connection.Close()
        End
    End Sub

    ''' ลบ point สี่เหลี่ยมที่ระบุ
    Private Sub RemoveMarker(ByRef hdraw As Integer)
        If hdraw > -1 Then
            AxMap1.ClearDrawing(hdraw)
            AxMap1.Redraw()
            hdraw = -1
        End If
    End Sub

    Private Sub AddLabel(drawDH As Integer, x As Double, y As Double, label As String, color As
UInteger)
        AxMap1.AddDrawingLabel(drawDH, label, color, x, y, MapWinGIS.tkHJustification.hjCenter)
    End Sub

    Private Sub RemoveLabel(drawDH As Integer)
        AxMap1.ClearDrawingLabels(drawDH)
    End Sub

    Private Function NewDrawingLayer() As Integer
        Return AxMap1.NewDrawing(MapWinGIS.tkDrawReferenceList.dlSpatiallyReferencedList)
    End Function
```

```
''' วาด point สี่เหลี่ยม
Private Sub DrawMarker(handle As Integer, x As Double, y As Double, c As UInteger, size As
Integer)
    Dim TL, BR As MapWinGIS.Point
    TL = New MapWinGIS.Point
    BR = New MapWinGIS.Point
    Dim buffer = 1
    TL.x = x - buffer
    TL.y = y + buffer
    BR.x = x + buffer
    BR.y = y - buffer
    CType(AxMap1.Extents, MapWinGIS.Extents).SetBounds(TL.x, BR.y, 0.0F, BR.x, TL.y, 0.0F)
    AxMap1.DrawPointEx(handle, x, y, size, c)
End Sub

''' วาด point สี่เหลี่ยม
Private Function DrawMarker(x As Double, y As Double, c As UInteger, size As Integer) As Integer
    Dim hdraw =
AxMap1.NewDrawing(MapWinGIS.tkDrawReferenceList.dlSpatiallyReferencedList)
    DrawMarker(hdraw, x, y, c, size)
    Return hdraw
End Function

''' วาดกรอบพื้นที่สี่เหลี่ยม
Private Sub DrawRect(handle As Integer, x0 As Double, y0 As Double, x1 As Double, y1 As
Double, c As UInteger, size As Integer)
    CType(AxMap1.Extents, MapWinGIS.Extents).SetBounds(x0, y0, 0.0F, x1, y1, 0.0F)
    AxMap1.DrawLineEx(handle, x0, y0, x1, y0, size, c)
    AxMap1.DrawLineEx(handle, x1, y0, x1, y1, size, c)
    AxMap1.DrawLineEx(handle, x1, y1, x0, y1, size, c)
    AxMap1.DrawLineEx(handle, x0, y1, x0, y0, size, c)
End Sub

''' วาดกรอบพื้นที่สี่เหลี่ยม
Private Function DrawRect(x0 As Double, y0 As Double, x1 As Double, y1 As Double, c As
UInteger, size As Integer) As Integer
    Dim hdraw =
AxMap1.NewDrawing(MapWinGIS.tkDrawReferenceList.dlSpatiallyReferencedList)
    DrawRect(hdraw, x0, y0, x1, y1, c, size)
    Return hdraw
End Function

''' เพิ่มเงื่อนไขในการค้นหา
Private Sub AddOption(title As String, wp As WayPointNode)
    Dim li = lvOption.Items.Add(title)
    li.SubItems.Add(wp.ToString)
    li.Tag = wp
End Sub

''' ตัวจัดการเหตุการณ์เมื่อคลิกเมาส์บน Map
Private Sub AxMap1_MouseDownEvent(sender As System.Object, e As
AxMapWinGIS._DMapEvents_MouseDownEvent) Handles AxMap1.MouseDownEvent
    If curState = CurrentStates.SetStart Then
        Dim x, y As Double
```

```
    AxMap1.PixelToProj(e.x, e.y, x, y)
    startWP.DrawHandler = DrawMarker(x, y, startColor, 10)
    AddLabel(startWP.DrawHandler, x, y, "1", startColor)
    ccmGrid.ProjToCell(x, y, startWP.X0, startWP.Y0)
    txtStart.Text = startWP.X0 & "," & startWP.Y0
    StopPlotPoint()
ElseIf curState = CurrentStates.SetStop Then
    Dim x, y As Double

    AxMap1.PixelToProj(e.x, e.y, x, y)
    endWP.DrawHandler = DrawMarker(x, y, endColor, 10)
    AddLabel(endWP.DrawHandler, x, y, "2", startColor)
    ccmGrid.ProjToCell(x, y, endWP.X0, endWP.Y0)
    txtStop.Text = endWP.X0 & "," & endWP.Y0
    StopPlotPoint()
ElseIf curState = CurrentStates.SetOptionPassPoint Then
    Dim x, y As Double
    Dim wp As New WayPointNode(WayPointNodeTypes.PassPoint)

    AxMap1.PixelToProj(e.x, e.y, x, y)
    wp.DrawHandler = DrawMarker(x, y, passPointColor, 10)
    ccmGrid.ProjToCell(x, y, wp.X0, wp.Y0)
    StopPlotPoint()

    AddOption("ผ่านจุดพิกัด", wp)
ElseIf curState = CurrentStates.SetOptionNotPassPoint Then
    Dim x, y As Double
    Dim wp As New WayPointNode(WayPointNodeTypes.NotPassPoint)

    AxMap1.PixelToProj(e.x, e.y, x, y)
    wp.DrawHandler = DrawMarker(x, y, notPassPointColor, 10)
    ccmGrid.ProjToCell(x, y, wp.X0, wp.Y0)
    StopPlotPoint()

    AddOption("ไม่ผ่านจุดพิกัด", wp)
ElseIf curState = CurrentStates.SetOptionAwayPoint Then
    Dim x, y As Double
    Dim wp As New WayPointNode(WayPointNodeTypes.FarFromPoint)

    AxMap1.PixelToProj(e.x, e.y, x, y)
    wp.DrawHandler = DrawMarker(x, y, notPassPointColor, 10)
    ccmGrid.ProjToCell(x, y, wp.X0, wp.Y0)
    StopPlotPoint()

    wp.Attributes.Add(numOptDistance.Value)
    AddOption("ห่างจากจุดพิกัด", wp)
ElseIf curState = CurrentStates.SetOptionBridge Then
    Dim x, y As Double
    Dim wp As New WayPointNode(WayPointNodeTypes.Bridge)

    AxMap1.PixelToProj(e.x, e.y, x, y)
    ccmGrid.ProjToCell(x, y, wp.X0, wp.Y0)

    'ตรวจสอบจุดที่คลิกว่าใช้แม่น้ำหรือไม่
    Dim river = waterGrid(cmbSeason.SelectedIndex).Value(wp.X0, wp.Y0)
```

```
        If CInt(river) <> 0 Then
            MsgBox("จุดที่ท่านคลิกไม่ใช่แม่น้ำไม่สามารถสร้างสะพานได้", MsgBoxStyle.Exclamation)
        Else
            wp.DrawHandler = DrawMarker(x, y, bridgePointColor, 10)
            wp.Attributes.Add(CInt(numOptBridgeHour.Value))
            wp.Attributes.Add(CInt(numOptBridgeMinute.Value))
            AddOption("สร้างสะพาน", wp)
        End If

        StopPlotPoint()
    Else
        'TEST
        Dim x, y As Double
        Dim cx, cy As Integer
        AxMap1.PixelToProj(e.x, e.y, x, y)
        ccmGrid.ProjToCell(x, y, cx, cy)

        If valueLableDH = -1 Then
            valueLableDH =
AxMap1.NewDrawing(MapWinGIS.tkDrawReferenceList.dlSpatiallyReferencedList)
        End If

        AddLabel(valueLableDH, x, y, CInt(ccmGrid.Value(cx, cy)).ToString, valueLabelColor)
        'StopPlotPoint()
    End If
End Sub

Private Sub StopPlotPoint()
    rbPan.Checked = True
    AxMap1.CursorMode = MapWinGIS.tkCursorMode.cmPan
    AxMap1.SendMouseDown = False
    curState = CurrentStates.StandBy
End Sub

''' กำหนดจุดเริ่มต้น
Private Sub btnSetStart_Click(sender As System.Object, e As System.EventArgs) Handles
btnSetStart.Click
    RemoveMarker(startWP.DrawHandler)
    RemoveLabel(startWP.DrawHandler)
    curState = CurrentStates.SetStart
    AxMap1.CursorMode = MapWinGIS.tkCursorMode.cmSelection
    AxMap1.SendMouseDown = True
    txtStart.Text = ""
End Sub

''' กำหนดจุดสิ้นสุด
Private Sub btnSetStop_Click(sender As System.Object, e As System.EventArgs) Handles
btnSetStop.Click
    RemoveMarker(endWP.DrawHandler)
    RemoveLabel(endWP.DrawHandler)
    curState = CurrentStates.SetStop
    AxMap1.CursorMode = MapWinGIS.tkCursorMode.cmSelection
    AxMap1.SendMouseDown = True
    txtStop.Text = ""
End Sub
```

```
    ''' เปลี่ยน Map เป็นสถานะ zoom in
    Private Sub rbZoomIn_CheckedChanged(sender As System.Object, e As System.EventArgs) 
Handles rbZoomIn.CheckedChanged
        AxMap1.CursorMode = MapWinGIS.tkCursorMode.cmZoomIn
    End Sub

    ''' เปลี่ยน Map เป็นสถานะ zoom out
    Private Sub rbZoomOut_CheckedChanged(sender As System.Object, e As System.EventArgs) 
Handles rbZoomOut.CheckedChanged
        AxMap1.CursorMode = MapWinGIS.tkCursorMode.cmZoomOut
    End Sub

    ''' เปลี่ยน Map เป็นสถานะ pan
    Private Sub rbPan_CheckedChanged(sender As System.Object, e As System.EventArgs) Handles 
rbPan.CheckedChanged
        Try
            AxMap1.CursorMode = MapWinGIS.tkCursorMode.cmPan
        Catch ex As Exception
        End Try
    End Sub

    ''' แสดงหน้าต่าง About
    Private Sub AboutToolStripMenuItem_Click(sender As System.Object, e As System.EventArgs) 
Handles AboutToolStripMenuItem.Click
        AboutBox.ShowDialog()
    End Sub

    Private Sub frmMain_FormClosed(sender As Object, e As 
System.Windows.Forms.FormClosedEventArgs) Handles Me.FormClosed
        Logoff()
    End Sub

    ''' อ่านข้อมูล Layer ที่ save ไว้ในไฟล์
    Public Sub LoadLayerData()
        Dim filename = GetLayerFileName()
        If System.IO.File.Exists(filename) Then
            layerData.Clear()
            layerData.ReadXml(filename)
        End If
    End Sub

    ''' โหลดข้อมูลเพื่อเตรียมแสดงข้อมูลและ Map
    Private Sub frmMain_Load(sender As System.Object, e As System.EventArgs) Handles 
MyBase.Load
        'แสดงฟอร์มต้อนรับ
        SplashScreen.Show()

        While Not SplashScreen.IsShown
            Application.DoEvents()
        End While

        'โหลดข้อมูลเพื่อแสดงใน combo box
        Me.PATHTYPETableAdapter.Fill(Me.CcmDataSet.PATHTYPE)
        Me.SEASONTableAdapter.Fill(Me.CcmDataSet.SEASON)
```

```
        Me.DURATIONTableAdapter.Fill(Me.CcmDataSet.DURATION)
        Me.COMBATTableAdapter.Fill(Me.CcmDataSet.COMBAT)

        'โหลดข้อมูล Layer ทั้งหมด
        LoadLayerData()

        'โหลด CCM layer แรก
        LoadCcmMap("CCM_TroopsD_D.img")
        layerLHs(0) = ccmLH
        RadioButton1.Checked = True

        'ซ่อนฟอร์มต้อนรับ
        SplashScreen.HideMe = True

        'จัดระเบียบหน้าจอ
        splitMain.SplitterDistance = 200
        gpOptions.Dock = DockStyle.Fill

        'ซ่อนเมนู Security และ Database หากไม่ใช่ admin
        If frmLogin.Permission <> 1 Then
            mnuSecurity.Visible = False
            mnuDatabase.Visible = False
        End If

        'แสดงคำอธิบายของ Layer แรกสุด
        ShowLayer(0)
    End Sub

    ''' โหลดไฟล์แผนที่ CCM ในรูปแบบ Grid
    Private Sub LoadCcmMap(filename As String)
        Try
            Me.Cursor = Cursors.WaitCursor
            ccmGrid.Close()
            ccmGrid.Open(My.Settings.MapPath & "\" & filename)
            ccmGridHeader = ccmGrid.Header

            Dim colorSchema As New MapWinGIS.GridColorScheme
            colorSchema.NoDataColor =
System.Convert.ToUInt32(System.Drawing.ColorTranslator.ToOle(System.Drawing.Color.White))

            Dim b0 As New MapWinGIS.GridColorBreak
            b0.LowValue = 0
            b0.LowColor =
System.Convert.ToUInt32(System.Drawing.ColorTranslator.ToOle(System.Drawing.Color.Red))
            b0.HighValue = 1.5
            b0.HighColor =
System.Convert.ToUInt32(System.Drawing.ColorTranslator.ToOle(System.Drawing.Color.Red))
            colorSchema.InsertBreak(b0)

            Dim b1 As New MapWinGIS.GridColorBreak
            b1.LowValue = 1.5
            b1.LowColor =
System.Convert.ToUInt32(System.Drawing.ColorTranslator.ToOle(System.Drawing.Color.Yellow))
            b1.HighValue = 30
```

```
        b1.HighColor =
System.Convert.ToUInt32(System.Drawing.ColorTranslator.ToOle(System.Drawing.Color.Yellow))
        colorSchema.InsertBreak(b1)

        Dim b2 As New MapWinGIS.GridColorBreak
        b2.LowValue = 30
        b2.LowColor =
System.Convert.ToUInt32(System.Drawing.ColorTranslator.ToOle(System.Drawing.Color.Green))
        b2.HighValue = Double.MaxValue
        b2.HighColor =
System.Convert.ToUInt32(System.Drawing.ColorTranslator.ToOle(System.Drawing.Color.Green))
        colorSchema.InsertBreak(b2)

        Dim utils As New MapWinGIS.Utils
        ccmRaster = utils.GridToImage(ccmGrid, colorSchema, Nothing)
        ccmRaster.DownsamplingMode = MapWinGIS.tkInterpolationMode.imNone
        ccmRaster.UpsamplingMode = MapWinGIS.tkInterpolationMode.imNone

        AxMap1.RemoveLayer(ccmLH)
        ccmLH = AxMap1.AddLayer(ccmRaster, True)
        AxMap1.MoveLayerBottom(AxMap1.get_LayerPosition(ccmLH))

        'clear ภาพ point เริ่มต้น สิ้นสุด และ path ที่ค้นหาพบทั้งหมด
        RemoveMarker(startWP.DrawHandler)
        RemoveMarker(endWP.DrawHandler)
        RemoveMarker(pathDH)
        startWP.DrawHandler = -1
        endWP.DrawHandler = -1
        pathDH = -1

        'เตรียม map และอัลกอริทึมค้นหา
        map = New MapInterface(ccmGrid)
        astar.SetMap(map)
      Catch ex As Exception
        MsgBox(ex.Message, MsgBoxStyle.Critical, "Error")
      Finally
        Me.Cursor = Cursors.Default
      End Try
    End Sub

    ''' โหลดไฟล์ภาพแล้วเพิ่มเป็น layer ใหม่ใน map
    Private Function LoadImageMap(filename As String) As Integer
      If String.IsNullOrEmpty(filename) Then Return -1

      Me.Cursor = Cursors.WaitCursor

      Try
        Dim g As New MapWinGIS.Grid
        g.Open(My.Settings.MapPath & "\" & filename)
        Dim gHeader = ccmGrid.Header

        Dim colorSchema As New MapWinGIS.GridColorScheme
        colorSchema.NoDataColor =
System.Convert.ToUInt32(System.Drawing.ColorTranslator.ToOle(System.Drawing.Color.White))
```

```
        'แสดงสีจากข้อมูล layer ที่กำหนดไว้
        Dim layer = GetLayerData(filename)

        If layer IsNot Nothing Then
            Dim items = layer.GetLayerDescItemRows

            For i = 0 To items.Length - 1
                Dim b0 As New MapWinGIS.GridColorBreak

                If i = 0 Then
                    b0.LowValue = 0
                Else
                    b0.LowValue = items(i - 1).PixelValue
                End If

                b0.LowColor =
System.Convert.ToUInt32(System.Drawing.ColorTranslator.ToOle(System.Drawing.Color.FromArgb(
items(i).Color)))
                b0.HighValue = items(i).PixelValue
                b0.HighColor =
System.Convert.ToUInt32(System.Drawing.ColorTranslator.ToOle(System.Drawing.Color.FromArgb(
items(i).Color)))
                colorSchema.InsertBreak(b0)
            Next
        Else
            colorSchema.UsePredefined(CType(g.Minimum, Double), CType(g.Maximum, Double),
MapWinGIS.PredefinedColorScheme.Desert)
        End If

        Dim utils As New MapWinGIS.Utils
        Dim r = utils.GridToImage(g, colorSchema, Nothing)
        r.DownsamplingMode = MapWinGIS.tkInterpolationMode.imNone
        r.UpsamplingMode = MapWinGIS.tkInterpolationMode.imNone

        Return AxMap1.AddLayer(r, True)
    Catch ex As Exception
        MsgBox(ex.Message, MsgBoxStyle.Critical, "Error")
        Return 0
    Finally
        Me.Cursor = Cursors.Default
    End Try
End Function

Private Sub LoadImageGrid(filename As String, ByRef g As MapWinGIS.Grid)
    If String.IsNullOrEmpty(filename) Then Exit Sub

    Me.Cursor = Cursors.WaitCursor

    Try
        g = New MapWinGIS.Grid
        g.Open(My.Settings.MapPath & "\" & filename)
    Catch ex As Exception
        MsgBox(ex.Message, MsgBoxStyle.Critical, "Error")
    Finally
        Me.Cursor = Cursors.Default
    End Try
End Sub
```

```
    ''' โหลด Map
    Private Sub btnLoadMap_Click(sender As System.Object, e As System.EventArgs) Handles
btnLoadMap.Click
        Select Case cmbCombat.SelectedIndex
            Case 0
                Select Case cmbSeason.SelectedIndex
                    Case 0
                        If cmbDuration.SelectedIndex = 0 Then
                            LoadCcmMap("CCM_TroopsD_D.img")
                        Else
                            LoadCcmMap("CCM_TroopsD_N.img")
                        End If
                    Case 1
                        If cmbDuration.SelectedIndex = 0 Then
                            LoadCcmMap("CCM_TroopsW_D.img")
                        Else
                            LoadCcmMap("CCM_TroopsW_N.img")
                        End If
                End Select
            Case 1
                Select Case cmbSeason.SelectedIndex
                    Case 0
                        LoadCcmMap("CCM_M113D.img")
                    Case 1
                        LoadCcmMap("CCM_M113W.img")
                End Select
            Case 2
                Select Case cmbSeason.SelectedIndex
                    Case 0
                        LoadCcmMap("CCM_M35D.img")
                    Case 1
                        LoadCcmMap("CCM_M35W.img")
                End Select
            Case 3
                Select Case cmbSeason.SelectedIndex
                    Case 0
                        LoadCcmMap("CCM_StingrayD.img")
                    Case 1
                        LoadCcmMap("CCM_StingrayW.img")
                End Select
            Case 4
                Select Case cmbSeason.SelectedIndex
                    Case 0
                        LoadCcmMap("CCM_M113D.img")
                    Case 1
                        LoadCcmMap("CCM_M113W.img")
                End Select
            Case 5
                Select Case cmbSeason.SelectedIndex
                    Case 0
                        LoadCcmMap("CCM_ScorpionD.img")
                    Case 1
                        LoadCcmMap("CCM_ScorpionW.img")
                End Select
        End Select
    End Sub
```

```
    Private Sub ToolStripMenuItem1_Click(sender As System.Object, e As System.EventArgs) Handles
ToolStripMenuItem1.Click
        frnSetup.ShowDialog()
    End Sub

    Private Sub DisableControls()
        'ปิดการทำงานของ controls ที่สำคัญ
        mnuMain.Enabled = False
        cmbCombat.Enabled = False
        cmbDuration.Enabled = False
        cmbSeason.Enabled = False
        btnLoadMap.Enabled = False
        btnOption.Enabled = False
        btnSetStart.Enabled = False
        btnSetStop.Enabled = False
        btnStart.Enabled = False
        btnStop.Enabled = True
        GroupBox4.Enabled = False
        chkShowValue.Enabled = False
        btnTestCell.Enabled = False
    End Sub

    ''' เก็บเงื่อนไขการค้นหา
    Private _wps As New List(Of WayPointNode)
    Private _startReportLine As Integer

    ''' เริ่มทำการค้นหาเมื่อคลิกปุ่มนี้
    Private Sub Button2_Click(sender As System.Object, e As System.EventArgs) Handles
btnStart.Click
        If String.IsNullOrEmpty(txtStart.Text) OrElse String.IsNullOrEmpty(txtStop.Text) Then
            MsgBox("โปรดระบุจุดเริ่มต้นและจุดสิ้นสุดก่อน", MsgBoxStyle.Exclamation)
            Exit Sub
        End If

        'ปิดการใช้งาน control ชั่วคราว
        DisableControls()

        'ลบเส้นทางการค้นหาเดิม
        RemoveMarker(pathDH)

        'เตรียมการวาดจุดที่ค้นหา
        pathDH = NewDrawingLayer()

        'กำหนด waypoint
        _wps.Clear()

        'เพิ่มจุดเริ่มต้น
        _wps.Add(startWP)

        'เพิ่มจุดตามเงื่อนไขการค้นหา (ถ้ามี)
        Dim li As ListViewItem

        For Each li In lvOption.Items
            Dim wp = CType(li.Tag, WayPointNode)
```

```
        If wp.Type = WayPointNodeTypes.Bridge Then
            'เก็บค่าเดิมบนแม่น้ำ
            wp.OldValue = CDbl(ccmGrid.Value(wp.X0, wp.Y0))

            'หาค่าเวลาสร้างสะพานเป็นนาที แล้วนำไปคำนวณหาความเร็วที่ได้
            Dim speed = (30.0 / (CDbl(wp.Attributes(0)) + CDbl(wp.Attributes(1)) / 60.0)) / 1000.0

            'กำหนดค่าผ่านทางบนแม่น้ำ
            ccmGrid.Value(wp.X0, wp.Y0) = speed
        End If

        _wps.Add(wp)
    Next

    'เพิ่มจุดสิ้นสุด
    _wps.Add(endWP)

    'ล้างหน้าจอรายงาน
    lvOutput.Items.Clear()

    'สร้างแบบรายงานผลเปล่าๆ
    li = lvOutput.Items.Add("ผลการค้นหาเส้นทาง")
    li.SubItems.Add("-")
    li.SubItems.Add("-")

    li = lvOutput.Items.Add("จุดพิกัดเริ่มต้น")
    li.SubItems.Add(txtStart.Text)
    li.SubItems.Add(txtStart.Text)

    li = lvOutput.Items.Add("จุดพิกัดสิ้นสุด")
    li.SubItems.Add(txtStop.Text)
    li.SubItems.Add(txtStop.Text)

    _startReportLine = lvOutput.Items.Count - 2

    li = lvOutput.Items.Add("เงื่อนไข")
    li.SubItems.Add("")
    li.SubItems.Add("")

    For Each li In lvOption.Items
        With CType(li.Tag, WayPointNode)
            If .Type = WayPointNodeTypes.PassPoint Then
                li = lvOutput.Items.Add("-ต้องผ่านจุดพิกัด ")
                li.SubItems.Add(.X0 & "," & .Y0)
                li.SubItems.Add(.X0 & "," & .Y0)
            ElseIf .Type = WayPointNodeTypes.NotPassPoint Then
                li = lvOutput.Items.Add("-ห้ามผ่านจุดพิกัด ")
                li.SubItems.Add(.X0 & "," & .Y0)
                li.SubItems.Add(.X0 & "," & .Y0)
            ElseIf .Type = WayPointNodeTypes.FarFromPoint Then
                li = lvOutput.Items.Add("-ห่างจากจุดพิกัด ")
```

```
          li.SubItems.Add(.X0 & "," & .Y0 & " เป็นระยะทาง " & CInt(.Attributes(0)) & " เมตร")
          li.SubItems.Add(.X0 & "," & .Y0 & " เป็นระยะทาง " & CInt(.Attributes(0)) & " เมตร")
        ElseIf .Type = WayPointNodeTypes.PassArea Then
          li = lvOutput.Items.Add("-ผ่านพื้นที่ ")
          li.SubItems.Add(.X0 & "," & .Y0 & " - " & .X1 & "," & .Y1)
          li.SubItems.Add(.X0 & "," & .Y0 & " - " & .X1 & "," & .Y1)
        ElseIf .Type = WayPointNodeTypes.NotPassArea Then
          li = lvOutput.Items.Add("-ห้ามผ่านพื้นที่ ")
          li.SubItems.Add(.X0 & "," & .Y0 & " - " & .X1 & "," & .Y1)
          li.SubItems.Add(.X0 & "," & .Y0 & " - " & .X1 & "," & .Y1)
        ElseIf .Type = WayPointNodeTypes.Bridge Then
          li = lvOutput.Items.Add("-ข้ามสะพานที่จุด ")
          li.SubItems.Add(.X0 & "," & .Y0)
          li.SubItems.Add(.X0 & "," & .Y0)
        End If
      End With
    Next

    li = lvOutput.Items.Add("ระยะทางรวมทั้งหมด")
    li.SubItems.Add("-")
    li.SubItems.Add("-")

    li = lvOutput.Items.Add("เวลาที่ใช้ในการเดินทาง")
    li.SubItems.Add("-")
    li.SubItems.Add("-")

    'ล้างค่า Label
    If valueLableDH > -1 Then
      RemoveLabel(valueLableDH)
      valueLableDH = -1
    End If

    If chkShowValue.Checked Then
      valueLableDH =
AxMap1.NewDrawing(MapWinGIS.tkDrawReferenceList.dlSpatiallyReferencedList)
    End If

    'เริ่มการค้นหาแบบสั้นที่สุดก่อน
    astar.SearchMode = SearchTypes.Shortest
    _colIndex = 1
    DoSearch()

    'ทำการค้นหาแบบเร็วที่สุดต่อ
    If Not My.Settings.PathStep Then
      _colIndex = 2
      astar.SearchMode = SearchTypes.Fastest
      DoSearch()

      'เปิดการใช้งาน controls
      EnableControls()
    End If
  End Sub
```

```
''' ทำการค้นหา
Private Sub DoSearch()
    If My.Settings.PathStep Then
        'ทำการค้นหาโดยแสดงที่ละ step
        astar.XPrepare(_wps)
        tmPathStep.Start()
    Else
        'ทำการค้นหาและแสดงผลทีเดียว
        astar.XPrepare(_wps)

        While astar.XGetNode(AddressOf DebugSub)
        End While

        SearchSuccess()
    End If
End Sub

''' วาดเส้นทางที่พบโดยการกำหนดสีเฉพาะลงไป
Private Sub DrawFinalPath()
    resultPaths = astar.GetResult.ToArray
    Dim x, y As Double

    For Each p In resultPaths
        ccmGrid.CellToProj(p.X, p.Y, x, y)
        DrawMarker(pathDH, x, y, finalPathColor(astar.SearchMode), 15)

        'เพิ่มแสดงค่าตัวเลขใน cell ที่พบด้วย
        If valueLableDH > -1 Then
            AddLabel(valueLableDH, x, y, CInt(ccmGrid.Value(p.X, p.Y)).ToString, valueLabelColor)
        End If

        If My.Settings.PathStep Then
            Threading.Thread.Sleep(100)
            Application.DoEvents()
        End If
    Next
End Sub

Public Sub DebugSub(row As Integer, col As Integer)
    Dim x, y As Double
    ccmGrid.CellToProj(row, col, x, y)
    DrawMarker(pathDH, x, y, pathsColor, 5)

    'แสดงค่าประจำ cell ที่ผ่าน
    AddLabel(valueLableDH, x, y, CInt(ccmGrid.Value(row, col)).ToString, valueLabelColor)
End Sub

Private Sub tmPathStep_Tick(sender As System.Object, e As System.EventArgs) Handles
tmPathStep.Tick
    If Not astar.XGetNode(AddressOf DebugSub) Then
        tmPathStep.Stop()
        SearchSuccess()

        'ทำการค้นหาแบบเร็วที่สุดต่อ
        If astar.SearchMode = SearchTypes.Shortest Then
```

```
            _colIndex = 2
            astar.SearchMode = SearchTypes.Fastest
            DoSearch()
        Else
            'ทำการค้นหาแบบเร็วเสร็จสิ้น
            'เปิดการใช้งาน controls
            EnableControls()
        End If
    End If
End Sub

Private Sub WriteOutput(rowIndex As Integer, colIndex As Integer, value As String)
    lvOutput.Items(rowIndex).SubItems(colIndex).Text = value
End Sub

Private _colIndex As Integer

''' ประมวลผลเส้นทางเป้าหมาย
Private Sub SearchSuccess()
    astar.XFinalize()

    If astar.IsFound Then
        DrawFinalPath()

        WriteOutput(0, _colIndex, "พบจุดหมาย")

        'หาค่าระยะทางกับเวลาที่ใช้ในการเดินทาง
        Dim distance = 0.0
        Dim time = 0.0
        Dim prevWp As WinCCMLib.Node = Nothing
        Dim dst As Double

        For Each wp In resultPaths
            dst = 30.0

            'ตรวจสอบว่าเดินทางเปนเส้นทแยงมุมหรือไม่
            If prevWp IsNot Nothing Then
                If (wp.X - prevWp.X) <> 0 AndAlso (wp.Y - prevWp.Y) <> 0 Then
                    dst = 42.43
                End If
            End If

            distance += dst
            time += (60 / (wp.Speed * 1000)) * dst
            prevWp = wp
        Next

        Dim h = (CInt(time) \ 60)
        Dim m = CInt(time) - (h * 60)
        Dim xs = CStr(time)
        Dim ss = ""

        Dim xn = xs.IndexOf(".")
        If xn > 0 Then
            Dim tmp = CDbl(Mid(xs, xn + 1))
```

```
          ss = CStr(Math.Round(tmp * 60.0, 0))
        End If

        WriteOutput(lvOutput.Items.Count - 2, _colIndex, Math.Round(distance / 1000, 2) & " กม.")
        WriteOutput(lvOutput.Items.Count - 1, _colIndex, h & " ชม. " & m & " นาที " & ss & " วินาที")
      Else
        WriteOutput(0, _colIndex, "ไม่พบจุดหมาย!")
      End If
    End Sub

    Private Sub EnableControls()
      mnuMain.Enabled = True
      cmbCombat.Enabled = True
      cmbDuration.Enabled = True
      cmbSeason.Enabled = True
      btnLoadMap.Enabled = True
      btnOption.Enabled = True
      btnSetStart.Enabled = True
      btnSetStop.Enabled = True
      btnStart.Enabled = True
      btnStop.Enabled = False
      GroupBox4.Enabled = True
      chkShowValue.Enabled = True
      btnTestCell.Enabled = True
    End Sub

    Private Sub btnStop_Click(sender As System.Object, e As System.EventArgs) Handles
btnStop.Click
      'เปิดการทำงานของ controls ที่สำคัญ
      'astar.StopSearch()
      tmPathStep.Stop()
      EnableControls()
    End Sub

    ''' ซ่อน/แสดง Layer ที่เลือก
    Private Sub chkLayers_ItemCheck(sender As Object, e As
System.Windows.Forms.ItemCheckEventArgs)
      'ซ่อนแสดง layer
      If layerLHs(e.Index) <> -1 Then
        AxMap1.set_LayerVisible(layerLHs(e.Index), e.NewValue = CheckState.Checked)
      End If
    End Sub

    Private Sub ExitToolStripMenuItem_Click(sender As System.Object, e As System.EventArgs)
Handles ExitToolStripMenuItem.Click
      Logoff()
    End Sub

    Private Sub SettingsToolStripMenuItem_Click(sender As System.Object, e As System.EventArgs)
Handles SettingsToolStripMenuItem.Click
      frnSetup.ShowDialog()
    End Sub

    Private Sub AboutToolStripMenuItem1_Click(sender As System.Object, e As System.EventArgs)
Handles AboutToolStripMenuItem1.Click
```

```
        AboutBox.ShowDialog()
    End Sub

    Private Sub btnOption_Click(sender As System.Object, e As System.EventArgs) Handles
btnOption.Click
        gpOptions.Visible = True
    End Sub

    Private Sub Button2_Click_1(sender As System.Object, e As System.EventArgs) Handles
Button2.Click
        gpOptions.Visible = False
    End Sub

    Private Sub btnOptionPassPoint_Click(sender As System.Object, e As System.EventArgs) Handles
btnOptPassPoint.Click
        curState = CurrentStates.SetOptionPassPoint
        AxMap1.CursorMode = MapWinGIS.tkCursorMode.cmSelection
        AxMap1.SendMouseDown = True
    End Sub

    Private Sub btnOption1_Click(sender As System.Object, e As System.EventArgs) Handles
btnOption1.Click
        curState = CurrentStates.SetOptionNotPassPoint
        AxMap1.CursorMode = MapWinGIS.tkCursorMode.cmSelection
        AxMap1.SendMouseDown = True
    End Sub

    Private Sub btnOption2_Click(sender As System.Object, e As System.EventArgs) Handles
btnOption2.Click
        If numOptDistance.Value = 0 Then
            MsgBox("โปรดระบุระยะทางก่อน", MsgBoxStyle.Exclamation)
        Else
            curState = CurrentStates.SetOptionAwayPoint
            AxMap1.CursorMode = MapWinGIS.tkCursorMode.cmSelection
            AxMap1.SendMouseDown = True
        End If
    End Sub

    'กำหนดพื้นที่ที่ต้องแวะ
    Private Sub btnOption3_Click(sender As System.Object, e As System.EventArgs) Handles
btnOption3.Click
        curState = CurrentStates.SetOptionPassArea
        AxMap1.CursorMode = MapWinGIS.tkCursorMode.cmSelection
        AxMap1.SendSelectBoxFinal = True
    End Sub

    Private Sub AxMap1_SelectBoxFinal(sender As Object, e As
AxMapWinGIS._DMapEvents_SelectBoxFinalEvent) Handles AxMap1.SelectBoxFinal
        If curState = CurrentStates.SetOptionPassArea Then
            Dim x0, y0, x1, y1 As Double
            Dim wp As New WayPointNode(WayPointNodeTypes.PassArea)

            AxMap1.PixelToProj(e.left, e.top, x0, y0)
            AxMap1.PixelToProj(e.right, e.bottom, x1, y1)
            wp.DrawHandler = DrawRect(x0, y0, x1, y1, passPointColor, 1)
            ccmGrid.ProjToCell(x0, y0, wp.X0, wp.Y0)
            ccmGrid.ProjToCell(x1, y1, wp.X1, wp.Y1)
```

```
            AddOption("ผ่านพื้นที่ที่ระบุ", wp)
        ElseIf curState = CurrentStates.SetOptionNotPassArea Then
            Dim x0, y0, x1, y1 As Double
            Dim wp As New WayPointNode(WayPointNodeTypes.NotPassArea)

            AxMap1.PixelToProj(e.left, e.top, x0, y0)
            AxMap1.PixelToProj(e.right, e.bottom, x1, y1)
            wp.DrawHandler = DrawRect(x0, y0, x1, y1, notPassPointColor, 1)
            ccmGrid.ProjToCell(x0, y0, wp.X0, wp.Y0)
            ccmGrid.ProjToCell(x1, y1, wp.X1, wp.Y1)

            AddOption("ห้ามผ่านพื้นที่ที่ระบุ", wp)
        End If

        rbPan.Checked = True
        AxMap1.CursorMode = MapWinGIS.tkCursorMode.cmPan
        AxMap1.SendSelectBoxFinal = False
        curState = CurrentStates.StandBy
    End Sub

    ''' กำหนดพื้นที่ห้ามผ่าน
    Private Sub btnOption4_Click(sender As System.Object, e As System.EventArgs) Handles
btnOption4.Click
        curState = CurrentStates.SetOptionNotPassArea
        AxMap1.CursorMode = MapWinGIS.tkCursorMode.cmSelection
        AxMap1.SendSelectBoxFinal = True
    End Sub

    ''' กำหนดจุดที่สร้างสะพาน
    Private Sub btnOption5_Click(sender As System.Object, e As System.EventArgs) Handles
btnOption5.Click
        If numOptBridgeHour.Value = 0 AndAlso numOptBridgeMinute.Value = 0 Then
            MsgBox("โปรดระบุเวลาที่ใช้สร้างสะพานก่อน", MsgBoxStyle.Exclamation)
        Else
            If cmbSeason.SelectedIndex = 0 Then
                'โหลด grid แม่น้ำหน้าแล้ง
                If waterGrid(0) Is Nothing Then
                    LoadImageGrid("Stream_Dry30m.img", waterGrid(0))
                End If
            Else
                'โหลด grid แม่น้ำหน้าฝน
                If waterGrid(1) Is Nothing Then
                    LoadImageGrid("Stream_Wet30m.img", waterGrid(1))
                End If
            End If

            curState = CurrentStates.SetOptionBridge
            AxMap1.CursorMode = MapWinGIS.tkCursorMode.cmSelection
            AxMap1.SendMouseDown = True
        End If
    End Sub
```

```
    Private Sub ขอมลหนวยToolStripMenuItem_Click(sender As System.Object, e As System.EventArgs)
Handles ขอมลหนวยToolStripMenuItem.Click
        frmDbCombat.ShowDialog()
    End Sub

    Private Sub ขอมลแผนทToolStripMenuItem_Click(sender As System.Object, e As System.EventArgs)
Handles ขอมลแผนทToolStripMenuItem.Click
        frmDbMap.ShowDialog()
    End Sub

    Private Sub ขอมลชวงเวลาToolStripMenuItem_Click(sender As System.Object, e As
System.EventArgs) Handles ขอมลชวงเวลาToolStripMenuItem.Click
        frmDbDuration.ShowDialog()
    End Sub

    Private Sub ขอมลฤดกาลToolStripMenuItem_Click(sender As System.Object, e As System.EventArgs)
Handles ขอมลฤดกาลToolStripMenuItem.Click
        frmDbCondition.ShowDialog()
    End Sub

    Private Sub ขอมลประเภทเสนทางToolStripMenuItem_Click(sender As System.Object, e As
System.EventArgs) Handles ขอมลประเภทเสนทางToolStripMenuItem.Click
        frmDbPathType.ShowDialog()
    End Sub

    Private Sub ขอมลยศToolStripMenuItem_Click(sender As System.Object, e As System.EventArgs)
Handles ขอมลยศToolStripMenuItem.Click
        frmDbRank.ShowDialog()
    End Sub

    Private Sub ขอมลผใชงานToolStripMenuItem1_Click(sender As System.Object, e As
System.EventArgs) Handles ขอมลผใชงานToolStripMenuItem1.Click
        frmDbUser.ShowDialog()
    End Sub

    Private Sub ขอมลการใชงานระบบToolStripMenuItem1_Click(sender As System.Object, e As
System.EventArgs) Handles ขอมลการใชงานระบบToolStripMenuItem1.Click
        frmDbLogin.ShowDialog()
    End Sub

    Private Sub ขอมลระดบสทธToolStripMenuItem1_Click(sender As System.Object, e As
System.EventArgs) Handles ขอมลระดบสทธToolStripMenuItem1.Click
        frmDbPermission.ShowDialog()
    End Sub

    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles btnTestCell.Click
        If curState <> CurrentStates.Test Then
            curState = CurrentStates.Test
            AxMap1.CursorMode = MapWinGIS.tkCursorMode.cmSelection
```

```
            AxMap1.SendMouseDown = True
        Else
            StopPlotPoint()
        End If
    End Sub

    Private Sub HideAllLayer(exception As Integer)
        For i = 0 To layerLHs.Length - 1
            If i <> exception AndAlso layerLHs(i) > -1 Then
                AxMap1.set_LayerVisible(layerLHs(i), False)
            End If
        Next
    End Sub

    Private Function GetLayerData(mapFilename As String) As CcmDataSet.LayerDescRow
        For i = 0 To layerData.LayerDesc.Rows.Count - 1
            If layerData.LayerDesc(i).MapFileName = mapFilename Then
                Dim layer = layerData.LayerDesc.FindByID(layerData.LayerDesc(i).ID)
                Return layer
            End If
        Next

        Return Nothing
    End Function

    Private Sub ShowLayer(index As Integer)
        If layerNames(index) <> "" Then
            HideAllLayer(index)

            If layerLHs(index) = -1 Then
                layerLHs(index) = LoadImageMap(layerNames(index))
            Else
                AxMap1.set_LayerVisible(layerLHs(index), True)
            End If

            'แสดงคำอธิบาย layer ข้อมูล
            Dim layer = GetLayerData(layerNames(index))

            If layer IsNot Nothing Then
                lvInfo.Items.Clear()

                Dim descs = layer.GetLayerDescItemRows

                For Each item In descs
                    Dim li = lvInfo.Items.Add("")
                    li.UseItemStyleForSubItems = False
                    li.SubItems(0).BackColor = Color.FromArgb(item.Color)
                    li.SubItems.Add(item.Title)
                Next
            End If
        End If
    End Sub

    Private Sub RadioButton2_CheckedChanged(sender As System.Object, e As System.EventArgs)
Handles RadioButton2.CheckedChanged
        If RadioButton2.Checked Then ShowLayer(1)
    End Sub
```

```
    Private Sub RadioButton1_CheckedChanged(sender As System.Object, e As System.EventArgs)
Handles RadioButton1.CheckedChanged
        If RadioButton1.Checked Then ShowLayer(0)
    End Sub

    Private Sub RadioButton4_CheckedChanged(sender As System.Object, e As System.EventArgs)
Handles RadioButton4.CheckedChanged
        If RadioButton4.Checked Then ShowLayer(3)
    End Sub

    Private Sub RadioButton5_CheckedChanged(sender As System.Object, e As System.EventArgs)
Handles RadioButton5.CheckedChanged
        If RadioButton5.Checked Then ShowLayer(4)
    End Sub

    Private Sub RadioButton6_CheckedChanged(sender As System.Object, e As System.EventArgs)
Handles RadioButton6.CheckedChanged
        If RadioButton6.Checked Then ShowLayer(5)
    End Sub

    Private Sub RadioButton7_CheckedChanged(sender As System.Object, e As System.EventArgs)
Handles RadioButton7.CheckedChanged
        If RadioButton7.Checked Then ShowLayer(6)
    End Sub

    Private Sub RadioButton8_CheckedChanged(sender As System.Object, e As System.EventArgs)
Handles RadioButton8.CheckedChanged
        If RadioButton8.Checked Then ShowLayer(7)
    End Sub

    Private Sub RadioButton9_CheckedChanged(sender As System.Object, e As System.EventArgs)
Handles RadioButton9.CheckedChanged
        If RadioButton9.Checked Then ShowLayer(8)
    End Sub

    ''' แสดงชั้นของพืชพรรณ
    Private Sub RadioButton10_CheckedChanged(sender As System.Object, e As System.EventArgs)
Handles RadioButton10.CheckedChanged
        If RadioButton10.Checked Then ShowLayer(9)
    End Sub

    ''' ลบเงื่อนไขที่เลือกออกจากรายการเงื่อนไข
    Private Sub Button3_Click(sender As System.Object, e As System.EventArgs) Handles
Button3.Click
        For Each li As ListViewItem In lvOption.SelectedItems
            Dim wp = CType(li.Tag, WayPointNode)

            RemoveMarker(wp.DrawHandler)

            'คืนค่าสะพาน
            If wp.Type = WayPointNodeTypes.Bridge Then
                ccmGrid.Value(wp.X0, wp.Y0) = wp.OldValue
            End If

            li.Remove()
        Next
```

```
    End Sub

    ''' ดูรายงานสรุป
    Private Sub btnReportPreview_Click(sender As System.Object, e As System.EventArgs) Handles
btnReportPreview.Click
        Dim htmlFilename = System.IO.Path.GetDirectoryName(Application.ExecutablePath) &
"\report.htm"
        CreateReport(htmlFilename)
        frmReport.RunForm(htmlFilename)
    End Sub

    Private Sub CreateReport(htmlFilename As String)
        'บันทึกภาพแผนที่
        Dim image As New MapWinGIS.Image
        Dim extents As MapWinGIS.Extents
        extents = CType(AxMap1.Extents, MapWinGIS.Extents)
        image = CType(AxMap1.SnapShot(extents), MapWinGIS.Image)

        Dim imgFilename = htmlFilename & ".gif"

        If Not image.Save(imgFilename, False, MapWinGIS.ImageType.GIF_FILE) Then
            MsgBox("ไม่สามารถบันทึกไฟล์ภาพแผนที่ได้", MsgBoxStyle.Critical)
        Else
            'สร้างไฟล์รายงานแบบ HTML
            Dim sw As New System.IO.StreamWriter(htmlFilename, False, System.Text.Encoding.UTF8)

            Try
                sw.WriteLine("<html>")
                sw.WriteLine("<head>")
                sw.WriteLine("<title>WinCCM - รายงานผลการค้นหาเส้นทาง</title")
                sw.WriteLine("</head>")
                sw.WriteLine("<body><center>")
                sw.WriteLine("<h2>รายงานผลการค้นหาเส้นทาง</h2>")
                sw.WriteLine("<h3>ภาพแผนที่การค้นหา</h3>")
                sw.WriteLine("<p><img src=""" & IO.Path.GetFileName(imgFilename) & """ border=""1""
/></p>")
                sw.WriteLine("<h3>สรุปผลการค้นหาเส้นทางที่ของหน่วย (" & cmbCombat.Text & ")</h3>")
                sw.WriteLine("<table border=""1"" cellpadding=""4"" cellspacing=""0"" style=""boder-
collapse: collapse"">")
                sw.WriteLine("<tr style=""font-weight:bold"">")

                For Each col As ColumnHeader In lvOutput.Columns
                    sw.WriteLine("<td>" & col.Text & "</td>")
                Next

                sw.WriteLine("</tr>")

                For Each li As ListViewItem In lvOutput.Items
                    sw.WriteLine("<tr>")
                    sw.WriteLine("<td>" & li.Text & "</td>")
                    sw.WriteLine("<td>" & li.SubItems(1).Text & "</td>")
                    sw.WriteLine("<td>" & li.SubItems(2).Text & "</td>")
                    sw.WriteLine("</tr>")
                Next
```

```
            sw.WriteLine("</table>")
            sw.WriteLine("</center></body>")
            sw.WriteLine("</html>")
        Catch ex As Exception
            MsgBox("เกิดข้อผิดพลาด: " & ex.Message, MsgBoxStyle.Critical)
        Finally
            sw.Close()
        End Try
    End If
End Sub

''' พิมพ์ผลการค้นหาออกทางเครื่องพิมพ์
Private Sub btnReportPrint_Click(sender As System.Object, e As System.EventArgs) Handles
btnReportPrint.Click
    Dim htmlFilename = System.IO.Path.GetDirectoryName(Application.ExecutablePath) &
"\report.htm"
    CreateReport(htmlFilename)
    frmReport.RunForm(htmlFilename, True)
End Sub

''' บันทึกผลการค้นหาเป็นไฟล์ HTML
Private Sub btnReportSave_Click(sender As System.Object, e As System.EventArgs) Handles
btnReportSave.Click
    SaveFileDialog1.Filter = "*.htm|*.htm"

    If SaveFileDialog1.ShowDialog = Windows.Forms.DialogResult.OK Then
        CreateReport(SaveFileDialog1.FileName)
        MsgBox("ทำการบันทึกไฟล์รายงาน '" & SaveFileDialog1.FileName & "' เรียบร้อยแล้ว",
MsgBoxStyle.Information)
    End If
End Sub

Private Sub cmbCombat_SelectedIndexChanged(ByVal sender As Object, ByVal e As
System.EventArgs) Handles cmbCombat.SelectedIndexChanged
    If cmbCombat.SelectedIndex = 0 Then
        cmbDuration.Enabled = True
    Else
        cmbDuration.Enabled = False
    End If
End Sub

Public Function GetLayerFileName() As String
    Dim sPath As String
    Dim nIndex As Integer
    sPath = Trim(System.Reflection.Assembly.GetExecutingAssembly().Location)
    nIndex = sPath.LastIndexOf("\")
    sPath = sPath.Substring(0, nIndex)

    Return sPath & "\layer_desc.xml"
End Function

Private Sub แกไขคำอธบายชนขอมลToolStripMenuItem_Click(sender As System.Object, e As
System.EventArgs) Handles แกไขคำอธบายชนขอมลToolStripMenuItem.Click
    frmLayerEditor.ShowDialog()
End Sub
```

```
    ''' Clear หน้าจอ+
    Private Sub Button1_Click_1(sender As System.Object, e As System.EventArgs) Handles
Button1.Click
        ClearAllMarkers()
    End Sub

    ''' ล้างจุดที่แสดงบนแผนที่ทั้งหมด
    Private Sub ClearAllMarkers()
        RemoveMarker(startWP.DrawHandler)
        RemoveMarker(endWP.DrawHandler)
        RemoveMarker(pathDH)
        RemoveMarker(valueLableDH)

        startWP.DrawHandler = -1
        endWP.DrawHandler = -1
        pathDH = -1
        valueLableDH = -1

       lvOutput.Items.Clear()

        For Each li As ListViewItem In lvOption.SelectedItems
            Dim wp = CType(li.Tag, WayPointNode)
            RemoveMarker(wp.DrawHandler)
        Next
    End Sub
End Class
```

## B.2 A Star Search (A*)

```
Imports System.Drawing
Namespace AStar
    Public Class PathFinder
        Implements IPathFinder

        ''' Defines map offsets and movement cost for nodes adjacent to
        ''' another node.
        Private Structure AdjacentNode
            ''' The relative position of the adjacent node.

            Public Offset As Point
            ''' The cost of moving to the adjacent node.
            Public Cost As Double
        End Structure

        ''' The map used for pathfinding.
        Private Map As IMap

        ''' Set of nodes adjacent to any given node.
        ''' The cost of moving along a diagonal is defined as 1.4 times the
        ''' cost of moving horizontally or vertically.
        Private AdjacentNodes As AdjacentNode()

        ''' Collection of all of the nodes used for pathfinding.
        Private PathMap As PathNode(,)
```

```
''' List of nodes making up a particular path.
Private Path As Stack(Of Node)

''' Gets or sets a open list of path nodes.
Private OpenList As OpenList
Private _wayPoints As New List(Of WayPointNode)
Private _startWayPoint As WayPointNode
Private _endWayPoint As WayPointNode
Private _currWayPoint As Integer
Private _finalNode As PathNode

''' Creates a new PathFinder object.
Sub New()
   ReDim AdjacentNodes(7)

   AdjacentNodes(0) = New AdjacentNode
   AdjacentNodes(0).Offset = New Point(-1, -1)
   AdjacentNodes(0).Cost = 14

   AdjacentNodes(1) = New AdjacentNode
   AdjacentNodes(1).Offset = New Point(0, -1)
   AdjacentNodes(1).Cost = 10

   AdjacentNodes(2) = New AdjacentNode
   AdjacentNodes(2).Offset = New Point(1, -1)
   AdjacentNodes(2).Cost = 14

   AdjacentNodes(3) = New AdjacentNode
   AdjacentNodes(3).Offset = New Point(-1, 0)
   AdjacentNodes(3).Cost = 10

   AdjacentNodes(4) = New AdjacentNode
   AdjacentNodes(4).Offset = New Point(1, 0)
   AdjacentNodes(4).Cost = 10

   AdjacentNodes(5) = New AdjacentNode
   AdjacentNodes(5).Offset = New Point(-1, 1)
   AdjacentNodes(5).Cost = 14

   AdjacentNodes(6) = New AdjacentNode
   AdjacentNodes(6).Offset = New Point(0, 1)
   AdjacentNodes(6).Cost = 10

   AdjacentNodes(7) = New AdjacentNode
   AdjacentNodes(7).Offset = New Point(1, 1)
   AdjacentNodes(7).Cost = 14
End Sub

''' Reset all data structures used for pathfinding.
Private Sub Reset()
   'ยกเลิก node ที่ถูกค้นหาไปแล้ว
   OpenList.Clear()

   'reset สถานะ node การค้นหาทั้งหมด
   For Each node In PathMap
      node.Reset()
   Next
```

```
        'ทำการหา waypoint ที่ไม่ให้ผ่านแล้วเพิ่มลงใน map
        For Each wp In _wayPoints
            If wp.Type = WayPointNodeTypes.NotPassPoint Then
                'กำหนดจุดที่ห้ามผ่าน
                PathMap(wp.X0, wp.Y0).Status = NodeStatus.Closed
            ElseIf wp.Type = WayPointNodeTypes.FarFromPoint Then
                'กำหนดจุดที่ห้ามผ่านแบบเว้นระยะห่าง
                Dim half = (CInt(wp.Attributes(0)) \ 2) \ 30 'หารด้วย 30 เนื่องจาก 1 จุดมีค่า 30 เมตร

                For x = wp.X0 - half To wp.X0 + half
                    For y = wp.Y0 - half To wp.Y0 + half
                        PathMap(x, y).Status = NodeStatus.Closed
                    Next
                Next
            ElseIf wp.Type = WayPointNodeTypes.NotPassArea Then
                'กำหนดพื้นที่ห้ามผ่าน
                For x = wp.X0 To wp.X1
                    For y = wp.Y0 To wp.Y1
                        PathMap(x, y).Status = NodeStatus.Closed
                    Next
                Next
            End If
        Next

        'กำหนดสถานะว่ายังหาไม่เจอ
        _isFound = False
    End Sub

    Public Function GetResult() As System.Collections.Generic.List(Of Node) Implements
IPathFinder.GetResult
        Return Path.ToList
    End Function

    ''' จัดเก็บเส้นทางที่ไปถึงเป้ามายไว้ใน stack
    Public Sub XFinalize() Implements IPathFinder.XFinalize
        Do
            Path.Push(_finalNode)
            _finalNode = _finalNode.Parent
        Loop While _finalNode IsNot Nothing
    End Sub

    ''' ทำการค้นหา
    Public Function XGetNode(debugSub As DebugPath) As Boolean Implements
IPathFinder.XGetNode
        'Get the node that we think is closest to the destination.
        Dim node = OpenList.GetBestOpenNode

        If node Is Nothing Then
            'No path is found, so stay at start location.
            PathMap(_startWayPoint.X0, _startWayPoint.Y0).AddToOpenList()
            node = OpenList.GetBestOpenNode()
            Path.Push(CType(node, PathNode))
            _isFound = False
            _finalNode = node
```

```
    Return False
End If

Dim x, y As Integer

'Have we found our destination?
If Not (node.X = _endWayPoint.X0 AndAlso node.Y = _endWayPoint.Y0) Then
    'Search each adjacent node.
    For index = 0 To AdjacentNodes.Length - 1
        x = node.X + AdjacentNodes(index).Offset.X
        y = node.Y + AdjacentNodes(index).Offset.Y

        If ((x >= 0) AndAlso (x < Map.Width) AndAlso (y >= 0) AndAlso (y < Map.Height))
Then
            Dim newNode = PathMap(x, y)
            newNode.Speed = Map.Speed(x, y)

            If Not newNode.IsClosed AndAlso Map.IsTileClear(x, y) Then
                Dim costFromStart As Double

                If _searchMode = SearchTypes.Shortest Then
                    costFromStart = node.CostFromStart + AdjacentNodes(index).Cost
                Else
                    'TODO: นำเอาความเร็วไปลบเพื่อให้ node นี้มีค่า cost น้อยลง
                    costFromStart = node.CostFromStart + AdjacentNodes(index).Cost + (_maxSpeed
- newNode.Speed)
                End If

                If Not newNode.IsOpen Then
                    'Add the node to the open list.
                    Dim tmpX = _endWayPoint.X0 - x
                    Dim tmpY = _endWayPoint.Y0 - y
                    Dim distanceFromDestination = 10 * (Math.Abs(tmpX) + Math.Abs(tmpY))

                    newNode.AddToOpenList(node, costFromStart, distanceFromDestination)
                    debugSub(node.X, node.Y)
                ElseIf costFromStart < newNode.CostFromStart Then
                    'This path is faster than the previous one
                    'found for this node, so update it.
                    newNode.UpdateOpenNode(node, costFromStart)
                    debugSub(node.X, node.Y)
                End If
            End If
        End If
    Next
End If

_finalNode = node

If Not (node.X = _endWayPoint.X0 AndAlso node.Y = _endWayPoint.Y0) Then
    'ไปตรวจสอบใน node ถัดไป
    Return True
Else
    'พบปลายทางแล้ว
    'ไปยัง waypoint ถัดไป
    'จุดเริ่มต้นที่ waypoint ล่าสุด
```

```
        _startWayPoint = _endWayPoint
        _endWayPoint = GetNextWaypoint()

        If _endWayPoint Is Nothing Then
            'ไม่มี waypoint เหลือแล้วให้ยุติการค้นหา
            'ถึงเป้าหมายแล้ว
            _isFound = True
            Return False
        Else
            'เก็บผลการค้นหามายังเป้าหมายนี้
            Do
                Path.Push(_finalNode)
                _finalNode = _finalNode.Parent
            Loop While _finalNode IsNot Nothing

            'เตรียมการค้นหาไปยังเป้าหมายถัดไป
            Reset()

            'กำหนด node เริ่มต้นให้เปิดไว้
            PathMap(_startWayPoint.X0, _startWayPoint.Y0).AddToOpenList()
        End If

        Return True
    End If
End Function

Private _maxSpeed As Double

''' เตรียมการค้นหา
Public Sub XPrepare(waypoints As List(Of WayPointNode)) Implements IPathFinder.XPrepare
    'กำหนดจุดเงื่อนไขต่างๆ
    _wayPoints = waypoints

    'ล้างผลลัพธ์ที่เก็บไว้จากการค้นหาก่อนหน้า
    Path.Clear()

    'เริ่มจาก waypoint แรก ต้องเป็นจุด start เสมอ
    _startWayPoint = _wayPoints(0)

    'หา waypoint เป้าหมายแรก
    _currWayPoint = 0
    _endWayPoint = GetNextWaypoint()

    'Reset current path, open list, and status of every node.
    Reset()

    'หาค่า max speed
    _maxSpeed = Map.MaxSpeed

    'เพิ่มจุดเริ่มต้น
    PathMap(_startWayPoint.X0, _startWayPoint.Y0).AddToOpenList()
End Sub
```

```
        Private Function GetNextWaypoint() As WayPointNode
            Dim wp As WayPointNode = Nothing

            For i = _currWayPoint + 1 To _wayPoints.Count - 1
                If _wayPoints(i).Type = WayPointNodeTypes.PassPoint Then
                    'พบจุดแรกที่ต้องผ่าน
                    wp = _wayPoints(i)
                    _currWayPoint = i
                    Exit For
                ElseIf _wayPoints(i).Type = WayPointNodeTypes.PassArea Then
                    'พบพื้นที่แรกที่ต้องผ่าน หาจุดศูนย์กลางของพื้นที่นั้นๆ
                    wp = New WayPointNode
                    wp.X0 = CInt(_wayPoints(i).X0 + ((_wayPoints(i).X1 - _wayPoints(i).X0) / 2))
                    wp.Y0 = CInt(_wayPoints(i).Y0 + ((_wayPoints(i).Y1 - _wayPoints(i).Y0) / 2))
                    _currWayPoint = i
                    Exit For
                End If
            Next

            Return wp
        End Function

        Private _isFound As Boolean
        Public ReadOnly Property IsFound As Boolean Implements IPathFinder.IsFound
            Get
                Return _isFound
            End Get
        End Property

        Private _searchMode As SearchTypes
        Public Property SearchMode As SearchTypes Implements IPathFinder.SearchMode
            Get
                Return _searchMode
            End Get
            Set(value As SearchTypes)
                _searchMode = value
            End Set
        End Property

        Public Sub SetMap(map As IMap) Implements IPathFinder.SetMap
            Me.Map = map
            OpenList = New OpenList()
            Path = New Stack(Of Node)(map.Width * map.Height)
            ReDim PathMap(map.Width - 1, map.Height - 1)

            For x = 0 To map.Width - 1
                For y = 0 To map.Height - 1
                    PathMap(x, y) = New PathNode(OpenList, x, y)
                Next
            Next
        End Sub

    End Class
End Namespace
```

## B.3 Breadth First Search (BFS)

```
Imports System.Drawing

Namespace Bfs
  Public Class PathFinder
    Implements IPathFinder

    Private Map As IMap
    Private AdjacentNodes As Point()
    Private PathMap As PathNode(,)
    Private _waypoints As List(Of WayPointNode)
    Private _startWayPoint As WayPointNode
    Private _endWayPoint As WayPointNode
    Private _currWayPoint As Integer
    Private _result As New List(Of Node)

    Sub New()
      ReDim AdjacentNodes(7)
      AdjacentNodes(0) = New Point(-1, -1)
      AdjacentNodes(1) = New Point(0, -1)
      AdjacentNodes(2) = New Point(1, -1)
      AdjacentNodes(3) = New Point(-1, 0)
      AdjacentNodes(4) = New Point(1, 0)
      AdjacentNodes(5) = New Point(-1, 1)
      AdjacentNodes(6) = New Point(0, 1)
      AdjacentNodes(7) = New Point(1, 1)
    End Sub

    Private Sub Reset()
      _queue.Clear()

      For Each p In PathMap
        p.IsVisited = False
        p.Parent = Nothing
      Next

      'ทำการหา waypoint ที่ไม่ให้ผ่านแล้วเพิ่มลงใน map
      For Each wp In _waypoints
        If wp.Type = WayPointNodeTypes.NotPassPoint Then
          'กำหนดจุดที่ห้ามผ่าน
          PathMap(wp.X0, wp.Y0).IsVisited = True
        ElseIf wp.Type = WayPointNodeTypes.FarFromPoint Then
          'กำหนดจุดที่ห้ามผ่านแบบเว้นระยะห่าง
          Dim half = (CInt(wp.Attributes(0)) \ 2) \ 30 'หารด้วย 30 เนื่องจาก 1 จุดมีค่า 30 เมตร

          For x = wp.X0 - half To wp.X0 + half
            For y = wp.Y0 - half To wp.Y0 + half
              PathMap(x, y).IsVisited = True
            Next
          Next
        ElseIf wp.Type = WayPointNodeTypes.NotPassArea Then
          'กำหนดพื้นที่ห้ามผ่าน
          For x = wp.X0 To wp.X1
            For y = wp.Y0 To wp.Y1
```

```
                PathMap(x, y).IsVisited = True
              Next
            Next
          End If
        Next
      End Sub

      Public Function GetResult() As System.Collections.Generic.List(Of Node) Implements
IPathFinder.GetResult
        Return _result
      End Function

      Private _isFound As Boolean
      Public ReadOnly Property IsFound As Boolean Implements IPathFinder.IsFound
        Get
          Return _isFound
        End Get
      End Property

      Private _searchMode As SearchTypes
      Public Property SearchMode As SearchTypes Implements IPathFinder.SearchMode
        Get
          Return _searchMode
        End Get
        Set(value As SearchTypes)
          _searchMode = value
        End Set
      End Property

      Public Sub SetMap(map As IMap) Implements IPathFinder.SetMap
        Me.Map = map
        ReDim PathMap(map.Width - 1, map.Height - 1)

        For x = 0 To map.Width - 1
          For y = 0 To map.Height - 1
            PathMap(x, y) = New PathNode(x, y)
          Next
        Next
      End Sub

      Public Sub XFinalize() Implements IPathFinder.XFinalize

      End Sub

      Private Shared Function comparer(x As PathNode, y As PathNode) As Integer
        If x.Speed > y.Speed Then
          Return -1
        ElseIf x.Speed < y.Speed Then
          Return 1
        Else
          Return 0
        End If
      End Function

      Public Function XGetNode(debugSub As DebugPath) As Boolean Implements
IPathFinder.XGetNode
        Dim u = _queue.Dequeue
        If u Is Nothing Then
```

```
    'ไม่มีข้อมูลให้ค้นหาแล้ว
    'สิ้นสุดการค้นหา
    Return False
End If

'กำหนด cost และกำหนดว่า node นี้ได้ถูกตรวจสอบแล้ว
u.Speed = Map.Speed(u.X, u.Y)
u.IsVisited = True

Dim x, y As Integer
Dim finalNode, fastestNode As PathNode
Dim speed As Double

'เปรียบเทียบกับ node ข้างเคียงทั้ง 8 ทิศ
For index = 0 To AdjacentNodes.Length - 1
    x = u.X + AdjacentNodes(index).X
    y = u.Y + AdjacentNodes(index).Y

    If ((x >= 0) AndAlso (x < Map.Width) AndAlso (y >= 0) AndAlso (y < Map.Height)) Then
        If Not PathMap(x, y).IsVisited Then
            If Map.IsTileClear(x, y) Then
                speed = Map.Speed(x, y)
                PathMap(x, y).Speed = speed
                PathMap(x, y).Parent = u
                PathMap(x, y).IsVisited = True

                If x = _endWayPoint.X0 AndAlso y = _endWayPoint.Y0 Then
                    'ถึงจุดหมายแล้ว
                    finalNode = PathMap(x, y)

                    'ไปยัง waypoint ถัดไป
                    GoTo next_waypoint
                Else
                    _queue.Enqueue(PathMap(x, y))
                    debugSub(x, y)
                    'End If
                End If
        End If
        End If
    End If
Next

Return True

next_waypoint:
'พบเป้าหมายแล้ว
'จัดเก็บ path ที่พบไว้ใน list
Dim node = finalNode
_result.Add(node)

While node.Parent IsNot Nothing
    _result.Add(node.Parent)
    node = node.Parent
End While
```

```
    'ทำการเลือก waypoint ถัดไป
    _startWayPoint = _endWayPoint
    _endWayPoint = GetNextWaypoint()

    If _endWayPoint IsNot Nothing Then
        'เตรียมการค้นหาไปยังเป้าหมายถัดไป
        Reset()
        _queue.Enqueue(PathMap(_startWayPoint.X0, _startWayPoint.Y0))
        Return True
    Else
        'สิ้นสุดการค้นหา
        _isFound = True
        Return False
    End If
End Function

Private _queue As New Queue(Of PathNode)

Public Sub XPrepare(waypoints As List(Of WayPointNode)) Implements IPathFinder.XPrepare
    'กำหนดจุดเงื่อนไขต่างๆ
    _waypoints = waypoints

    'ล้างผลลัพธ์ที่เก็บไว้จากการค้นหาก่อนหน้า
    _result.Clear()
    _isFound = False

    'เริ่มจาก waypoint แรก ต้องเป็นจุด start เสมอ
    _startWayPoint = _waypoints(0)

    'หา waypoint เป้าหมายแรก
    _currWayPoint = 0
    _endWayPoint = GetNextWaypoint()

    'Reset current path, open list, and status of every node.
    Reset()

    'กำหนดจุดเริ่มต้น
    _queue.Enqueue(PathMap(_startWayPoint.X0, _startWayPoint.Y0))
End Sub

Private Function GetNextWaypoint() As WayPointNode
    Dim wp As WayPointNode = Nothing

    For i = _currWayPoint + 1 To _waypoints.Count - 1
        If _waypoints(i).Type = WayPointNodeTypes.PassPoint Then
            'พบจุดแรกที่ต้องผ่าน
            wp = _waypoints(i)
            _currWayPoint = i
            Exit For
        ElseIf _waypoints(i).Type = WayPointNodeTypes.PassArea Then
            'พบพื้นที่แรกที่ต้องผ่าน หาจุดศูนย์กลางของพื้นที่นั้นๆ
            wp = New WayPointNode
            wp.X0 = CInt(_waypoints(i).X0 + ((_waypoints(i).X1 - _waypoints(i).X0) / 2))
            wp.Y0 = CInt(_waypoints(i).Y0 + ((_waypoints(i).Y1 - _waypoints(i).Y0) / 2))
```

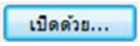
```
                _currWayPoint = i
                Exit For
            End If
        Next

        Return wp
    End Function
End Class
End
```

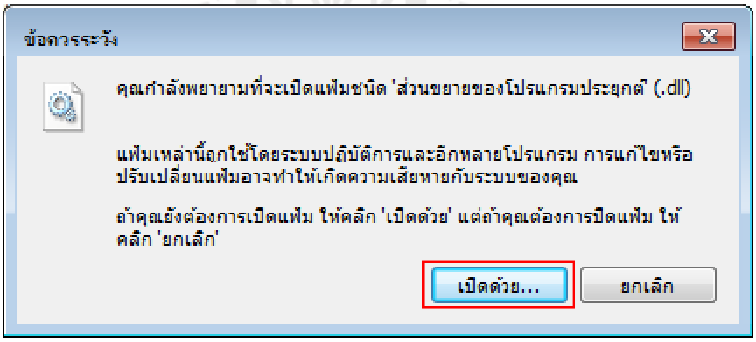
# APPENDIX C

# USER MANUAL

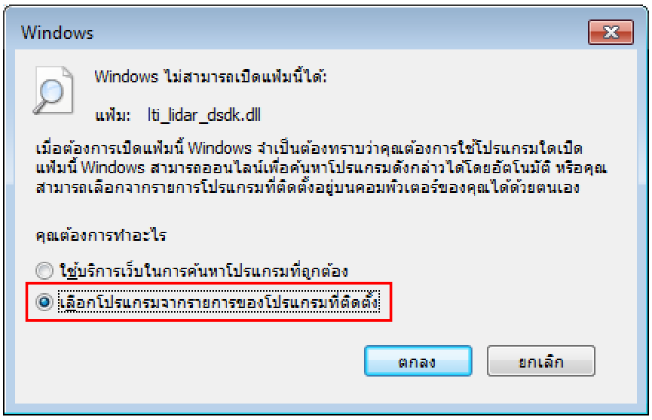
## C.1 การติดตั้งโปรแกรม

### C.1.1 การติดตั้งโปรแกรม MapWindowGIS

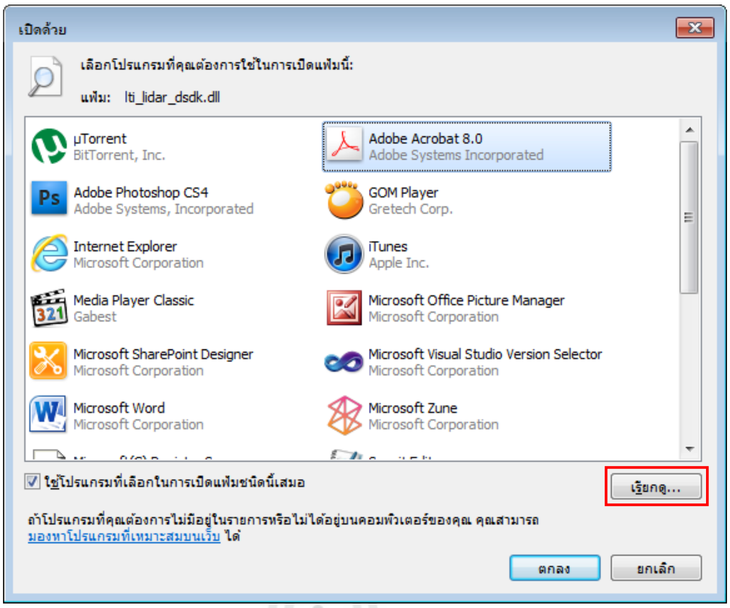
1. เข้าไปในแฟ้ม Software
2. ทำการ Double Click โปรแกรม MapWinGIS-only-v4.8RC3-installer.exe
3. ทำตามขั้นตอนการติดตั้งตามปกติ
4. เปิดโปรแกรม Windows Explorer แล้วเข้าไปในแฟ้ม C:\dev\MapWinGIS
5. ทำการ Double Click ไฟล์ MapWinGIS.ocx
6. ที่หน้าต่าง ข้อควรระวัง ให้คลิกปุ่ม 

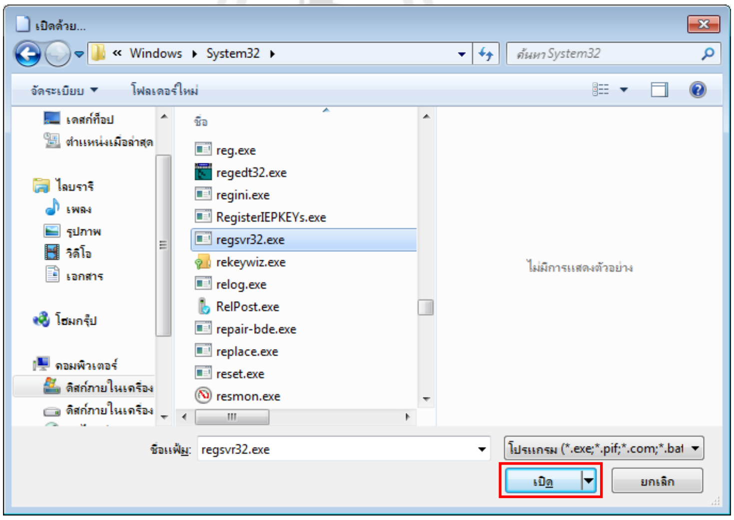

7. เลือกหัวข้อ **เลือกโปรแกรมจากรายการของโปรแกรมที่ติดตั้ง**



8. คลิกปุ่ม 

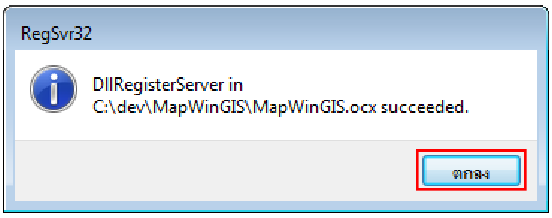




9. ไปที่แฟ้ม **C:\Windows\System32** แล้วเลือกไฟล์ **regsvr32.exe** แล้วคลิกปุ่ม 


10. จะมีหน้าต่างแสดงผลลัพธ์การติดตั้ง MapWinGIS.ocx ดังภาพด้านล่าง

11. คลิกปุ่ม 

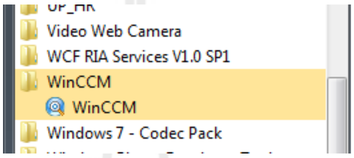



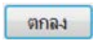
### C.1.2 การติดตั้งโปรแกรม CCM4CM

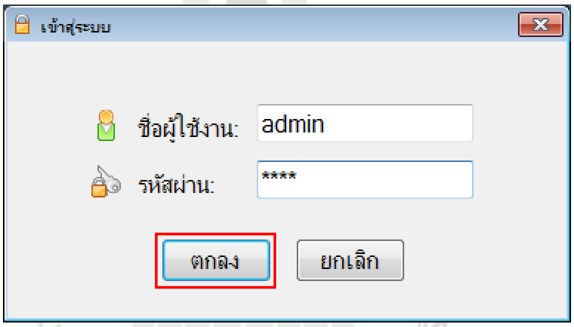
1. เข้าไปในแฟ้ม Publish
2. ทำการ Double Click ไฟล์ setup.exe
3. ดำเนินการตามขั้นตอนการติดตั้งจนแล้วเสร็จ

## C.2 การเข้าสู่โปรแกรม

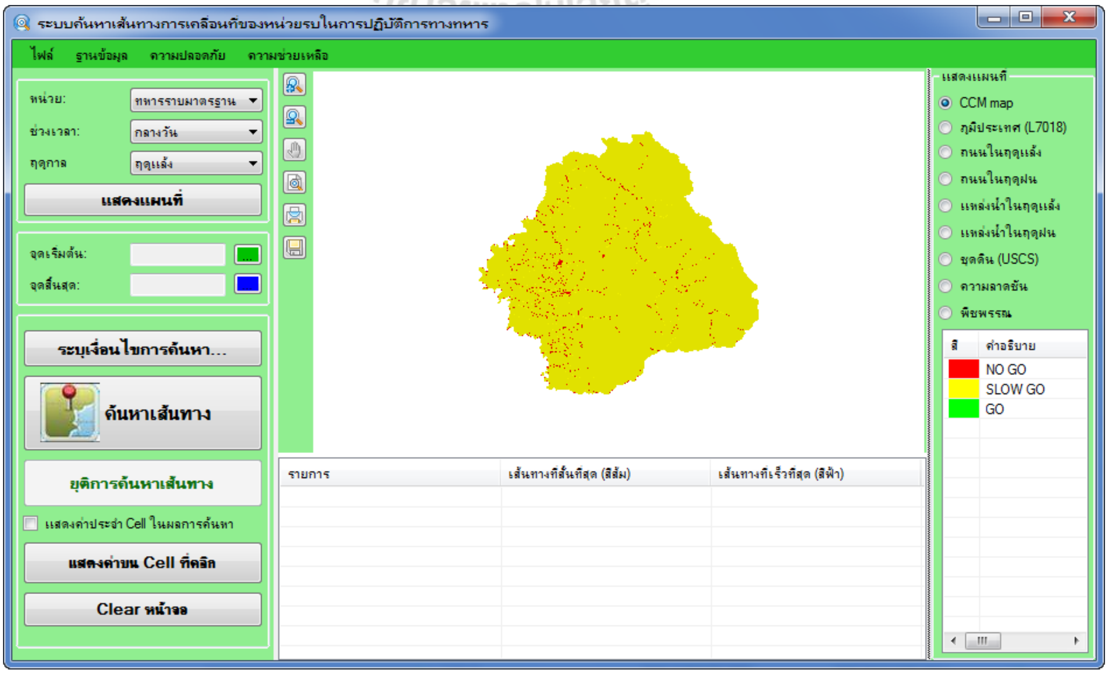
1. คลิกปุ่ม Start บน Windows แล้วเข้าไปที่ CCM4CM จะพบโปรแกรม CCM4CM ดังภาพ ให้ทำการคลิกที่โปรแกรม CCM4CM




2. เข้าสู่ระบบ โดยการใส่ชื่อผู้ใช้งาน และรหัสผ่านให้ถูกต้อง แล้วคลิกปุ่ม 

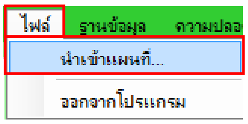

3. รอสักครู่ประมาณ 20-30 วินาที หน้าจอโปรแกรมหลักจะปรากฏดังภาพด้านล่าง



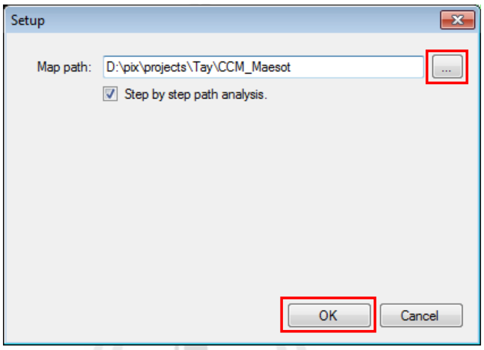
## C.3 การกำหนดค่าตั้งต้นก่อนการใช้งาน

ก่อนการใช้งานต้องทำการกำหนดค่าเริ่มต้นในการทำงานครั้งแรกดังต่อไปนี้

1. ในโปรแกรม CMM4CM คลิกที่เมนู ไฟล์ → นำเข้าแผนที่…




2. ทำการระบุตำแหน่งที่เก็บไฟล์แผนที่ทั้งหมดที่จำเป็นต้องใช้โดยการพิมพ์ตำแหน่งที่เก็บไฟล์ลงไปหรือคลิกปุ่ม [...] แล้วเลือกแฟ้มที่ต้องการ



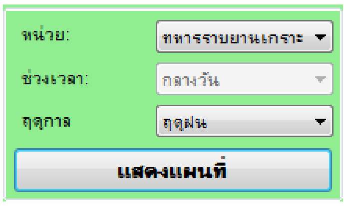

3. หากต้องการให้โปรแกรมทำการหน่วงเวลาและแสดงผลการค้นหา node ต่างๆ แบบทีละขั้นตอน ให้ใช้เมาส์คลิกให้มีเครื่องหมายถูกที่ช่อง Step by step path analysis

4. คลิกปุ่ม [OK] เมื่อการกำหนดค่าแล้วเสร็จ

## C.4 การใช้งานแผนที่

### C.4.1 การแสดงแผนที่

1. ทำการเลือกข้อมูลในหน้าจอเงื่อนไขแผนที่ดังนี้



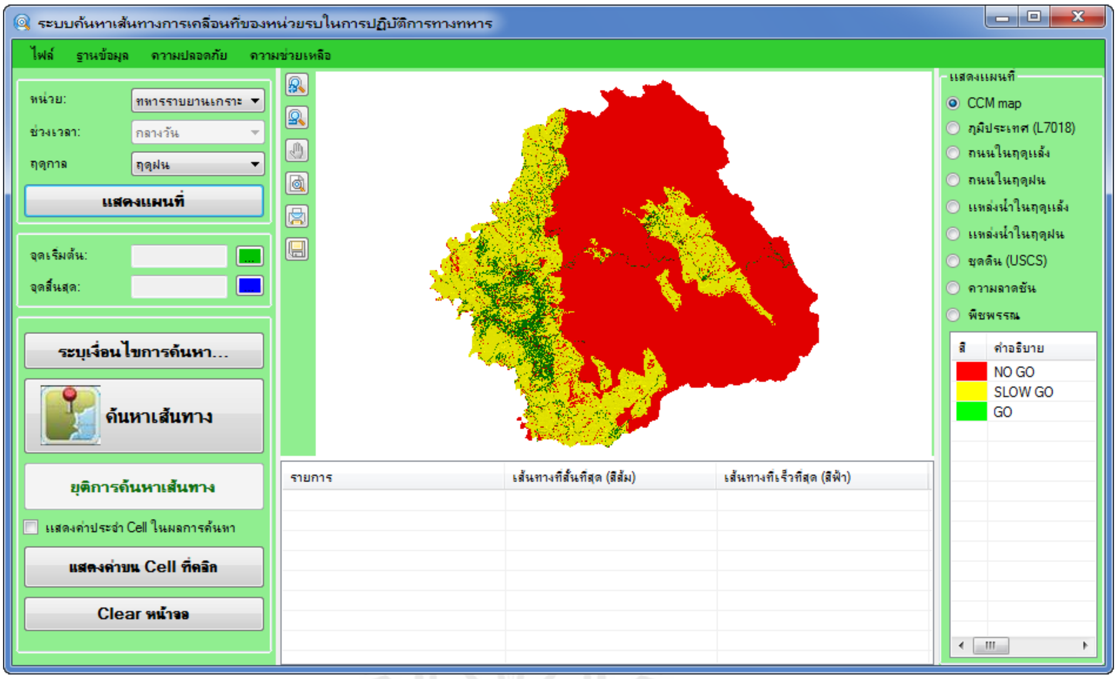

a. หน่วย - ทำการเลือกหน่วยรบที่ต้องการ

b. ช่วงเวลา - ทำการเลือกช่วงเวลาที่ต้องการ (ใช้ได้เฉพาะกับหน่วยรบทหารราบมาตรฐาน)

c. ฤดูกาล - ทำการเลือกฤดูกาลที่ต้องการ

2. คลิกปุ่ม [แสดงแผนที่] แล้วรอจนกว่าแผนที่จะปรากฏ (เวลาที่ใช้ขึ้นอยู่กับประสิทธิภาพของเครื่องคอมพิวเตอร์)

3. โปรแกรมจะแสดงแผนที่ตามเงื่อนไขที่ระบุ ดังภาพด้านล่าง โดยบริเวณที่มีสีเขียวแสดงว่าสามารถเคลื่อนที่ผ่านได้โดยสะดวก (Go) บริเวณที่มีสีเหลืองแสดงว่าสามารถเคลื่อนที่ผ่านได้ช้า (Slow Go) และบริเวณที่มีสีแดงแสดงว่าไม่สามารถเคลื่อนที่ผ่านไปได้ (No Go)




สามารถใช้เครื่องมือควบคุมการแสดงแผนที่ได้ดังนี้

a.  ใช้ในการขยายแผนที่ (Zoom in) ณ จุดหรือบริเวณที่ใช้เมาส์คลิก

b.  ใช้ในการย่อแผนที่ (Zoom out) ณ จุดหรือบริเวณที่ใช้เมาส์คลิก

c.  ใช้ในการเลื่อนแผนที่โดยการคลิกเมาส์ค้างไว้แล้วลากเมาส์

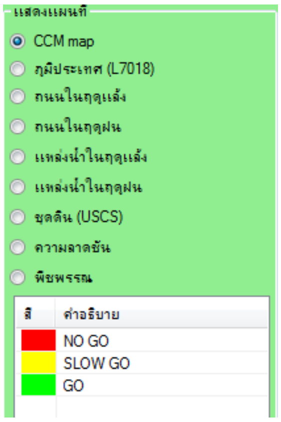
d.  ใช้ในการดูรายงานผลลัพธ์การค้นหา

e.  ใช้ในการพิมพ์รายงานออกทางเครื่องพิมพ์

f.  ใช้ในการบันทึกผลการค้นหาลงในไฟล์

### C.4.2 การแสดงชั้นข้อมูลของแผนที่ (Layer)

1. ในหน้าต่างแสดงแผนที่ ให้ใช้เมาส์คลิกให้มีเครื่องหมายถูกหน้า ชั้นข้อมูลของแผนที่ที่ต้องการให้แสดง โดยโปรแกรมจะแสดง ชั้นข้อมูลของแผนที่ ใหม่ทับชั้นข้อมูลของแผนที่เดิมที่อยู่ในชั้นต่ำกว่า โดยชั้นข้อมูลของแผนที่ที่อยู่บนสุดจะถือเป็นชั้นข้อมูลของแผนที่ที่อยู่ล่างสุด และชั้นข้อมูลของแผนที่ที่อยู่ล่างสุดจะถือเป็นชั้นข้อมูลของแผนที่ที่อยู่บนสุด

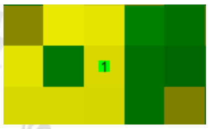



2. ในตารางด้านล่างของหน้าต่างแสดงแผนที่ จะแสดงรายละเอียดของแผนที่ในแต่ละชั้นข้อมูล

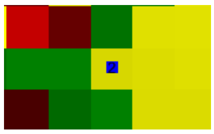
## C.5 การค้นหาเส้นทาง

### C.5.1 การค้นหาแบบปกติ

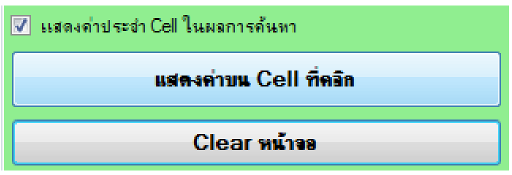
1. ทำการขยายแผนที่ไปยังจุดที่ต้องการเคลื่อนที่โดยใช้ปุ่ม
2. ตรงจุดเริ่มต้นให้คลิกที่ปุ่ม แล้วใช้เมาส์คลิก 1 ครั้งบนแผนที่เพื่อกำหนดจุดเริ่มต้นที่ต้องการ

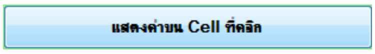
3. ตรงจุดสิ้นสุดให้คลิกที่ปุ่ม แล้วใช้เมาส์คลิก 1 ครั้งบนแผนที่เพื่อกำหนดจุดสิ้นสุดของการค้นหาที่ต้องการ

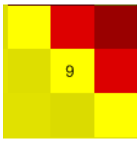
4. ทำการระบุรูปแบบการแสดงผลการค้นหา ดังนี้

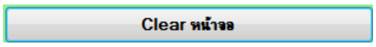


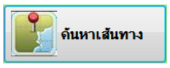

a. ในกรณีที่ต้องการให้แสดงค่าความเร็วในแต่ละพิกเซล ให้ใช้เมาส์คลิกให้มีเครื่องหมายถูกหน้า แสดงค่าประจำ Cell ในผลการค้นหา

b. ในกรณีที่ต้องการให้แสดงค่าความเร็วในพิกเซลที่ต้องการ ให้คลิกปุ่ม 

จากนั้นให้ใช้เมาส์ไปคลิกในพิกเซลที่ต้องการทราบค่าความเร็วประจำพิกเซล ก็จะแสดงผลลัพธ์ ดังภาพ

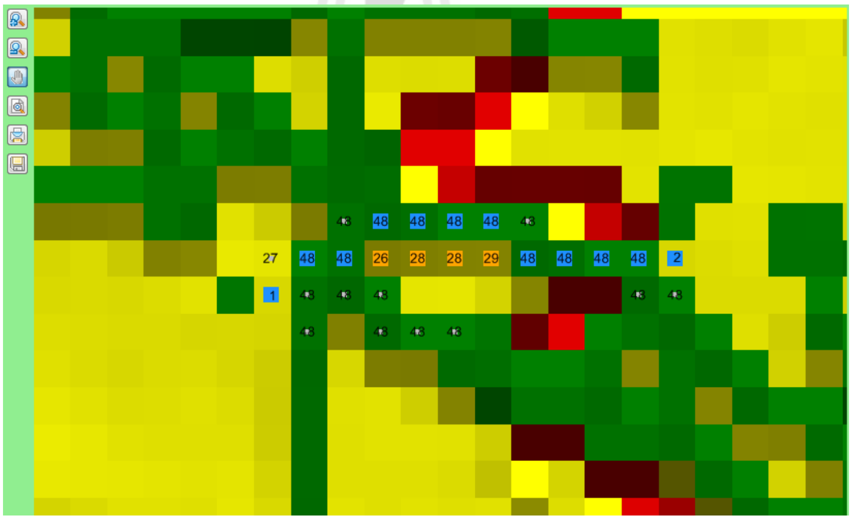



c. ในกรณีที่ต้องการลบข้อมูลที่ได้กำหนดไว้ก่อนหน้านี้ทั้งหมด ในหน้าจอการแสดงผล ให้คลิกปุ่ม 


5. คลิกปุ่ม 

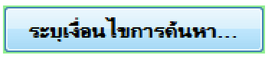
เพื่อเริ่มการค้นหาเส้นทาง

6. หากการค้นหาเสร็จสิ้น จะแสดงเส้นทางที่ค้นหาพบ โดยเส้นทางที่สั้นที่สุดจะแสดงด้วยสีส้ม ส่วนเส้นทางที่เร็วที่สุดจะแสดงด้วยสีน้ำเงิน ดังภาพ โดยจะแสดงความเร็วในแต่ละพิกเซลด้วย

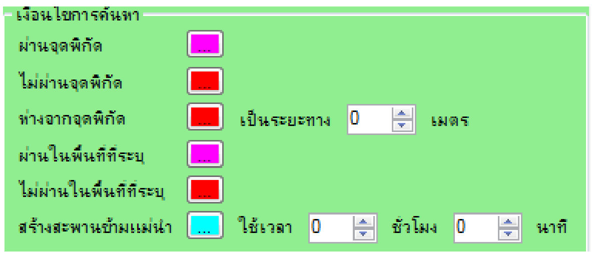


7. หากการค้นหาใช้เวลานานแล้วต้องการยกเลิกการค้นหาให้คลิกที่ปุ่ม 


### C.5.2 การค้นหาแบบมีเงื่อนไข

1. คลิกที่ปุ่ม 

หน้าจอเงื่อนไขการค้นหา ดังภาพ



2. ทำการระบุเงื่อนไขการค้นหา ดังนี้

a. ผ่านจุดพิกัด - ทำการคลิกปุ่ม [...] แล้วคลิกบนแผนที่เพื่อระบุจุดที่บังคับให้ผ่าน

b. ไม่ผ่านจุดพิกัด - ทำการคลิกปุ่ม [...] แล้วคลิกบนแผนที่เพื่อระบุจุดที่ห้ามผ่าน

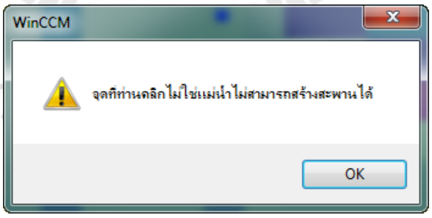
c. ห่างจากจุดพิกัด - ทำการคลิกปุ่ม [...] แล้วคลิกบนแผนที่เพื่อระบุจุดที่ห้ามผ่านและต้องเว้นระยะห่างไว้ตามช่อง [เป็นระยะทาง 0 เมตร]

d. ผ่านในพื้นที่ที่ระบุ - ทำการคลิกปุ่ม [...] แล้วลากเมาส์บนแผนที่เพื่อระบุพื้นที่ที่บังคับให้ผ่าน

e. ให้ผ่านในพื้นที่ที่ระบุ - ทำการคลิกปุ่ม [...] แล้วลากเมาส์บนแผนที่เพื่อระบุพื้นที่ที่บังคับห้ามผ่าน

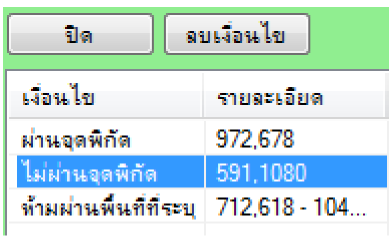
f. สร้างสะพานข้ามแม่น้ำ - ทำการคลิกปุ่ม [...] แล้วคลิกบนแผนที่เพื่อระบุตำแหน่งที่ต้องการจะสร้างสะพานข้ามแม่น้ำ จากนั้นให้ทำการกรอกเวลาที่ต้องใช้ในการสร้างสะพานในช่อง [ใช้เวลา 0 ชั่วโมง 0 นาที] ตามลำดับ

g. โปรแกรมจะทำการตรวจสอบตำแหน่งว่าพิกเซลที่เลือกสร้างสะพานใช่แม่น้ำหรือไม่ หากไม่ใช่พิกเซลที่เป็นแม่น้ำ จะแสดงข้อความเตือนดังภาพ




h. คลิกปุ่ม [ปิด] เพื่อปิดหน้าจอเงื่อนไขการค้นหา

i. กรณีที่ต้องการยกเลิกเงื่อนไขใด ให้คลิกเลือกที่เงื่อนไขที่ต้องการยกเลิกแล้วคลิกปุ่ม [ลบเงื่อนไข]



### C.5.3 การอ่านผลการค้นหา

เมื่อการค้นหาเส้นทางแล้วเสร็จโปรแกรมจะแสดงผลการค้นหาดังภาพ

| รายการ | เส้นทางที่สั้นที่สุด (สีส้ม) | เส้นทางที่เร็วที่สุด (สีฟ้า) |
|---|---|---|
| ผลการค้นหาเส้นทาง | พบจุดหมาย | พบจุดหมาย |
| จุดพิกัดเริ่มต้น | 515,995 | 515,995 |
| จุดพิกัดสิ้นสุด | 518,999 | 518,999 |
| เงื่อนไข | | |
| ระยะทางรวมทั้งหมด | 0.15 กม. | 0.15 กม. |
| เวลาที่ใช้ในการเดินทาง | 0 ชม. 2 นาที 15 วินาที | 0 ชม. 2 นาที 15 วินาที |

a. จุดพิกัดเริ่มต้น - แสดงตำแหน่ง X,Y ของ Cell ที่เริ่มค้นหา

b. จุดพิกัดสิ้นสุด - แสดงตำแหน่ง X,Y ของ Cell เป้าหมาย

c. เงื่อนไขการค้นหา – หากมีการกำหนดเงื่อนไขไว้ จะแสดงทุกเงื่อนไขที่ใช้ในการค้นหาในรายการนี้

d. ระยะทาง - แสดงระยะทางจากจุดเริ่มมาจุดสิ้นสุด

e. เวลาในการเดินทาง - แสดงเวลาที่ใช้ในการเดินทางจากจุดเริ่มมาจุดที่สิ้นสุด

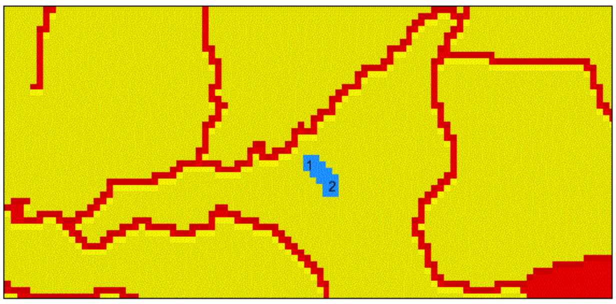
### C.5.4 การดูรายงานผลลัพธ์การค้นหา

1. ทำการค้นหาตามปกติ

2. เมื่อทำการค้นหาเสร็จสิ้นให้ทำการคลิกปุ่ม ที่หน้าจอแผนที่ โปรแกรมจะทำการแสดงรายงานผลการค้นหาในหน้าจอใหม่ดังภาพ

**รายงานผลการค้นหาเส้นทาง**

**ภาพแผนที่การค้นหา**



**สรุปผลการค้นหาเส้นทางที่ของหน่วย ()**

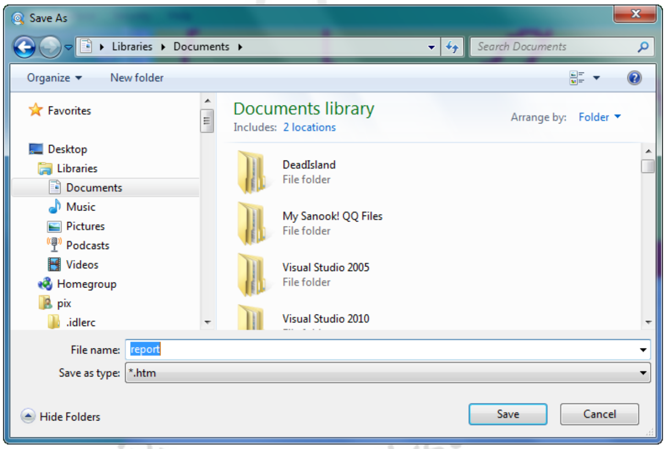
| รายการ | เส้นทางที่สั้นที่สุด (สีส้ม) | เส้นทางที่เร็วที่สุด (สีฟ้า) |
|---|---|---|
| ผลการค้นหาเส้นทาง | พบจุดหมาย | พบจุดหมาย |
| จุดพิกัดเริ่มต้น | 515,995 | 515,995 |
| จุดพิกัดสิ้นสุด | 518,999 | 518,999 |
| เงื่อนไข | | |
| ระยะทางรวมทั้งหมด | 0.15 กม. | 0.15 กม. |
| เวลาที่ใช้ในการเดินทาง | 0 ชม. 2 นาที 15 วินาที | 0 ชม. 2 นาที 15 วินาที |

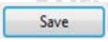
### C.5.5 การพิมพ์รายงานออกทางเครื่องพิมพ์

1. ทำการตั้งค่าและเชื่อมต่อเครื่องพิมพ์ให้เรียบร้อย
2. ทำการค้นหาตามปกติ
3. เมื่อทำการค้นหาเสร็จสิ้นให้ทำการคลิกปุ่ม  ที่หน้าจอแผนที่
4. โปรแกรมจะเริ่มส่งข้อมูลไปยังเครื่องพิมพ์และทำการพิมพ์ออกมาตามต้องการ

### C.5.6 การบันทึกผลการค้นหาลงในไฟล์

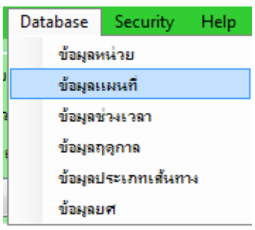
1. ทำการค้นหาตามปกติ
2. เมื่อทำการค้นหาเสร็จสิ้นให้ทำการคลิกปุ่ม  ที่หน้าจอแผนที่
3. ทำการเลือกแฟ้มปลายทางที่ต้องการบันทึก และพิมพ์ชื่อไฟล์ที่ต้องการบันทึกตามต้องการ



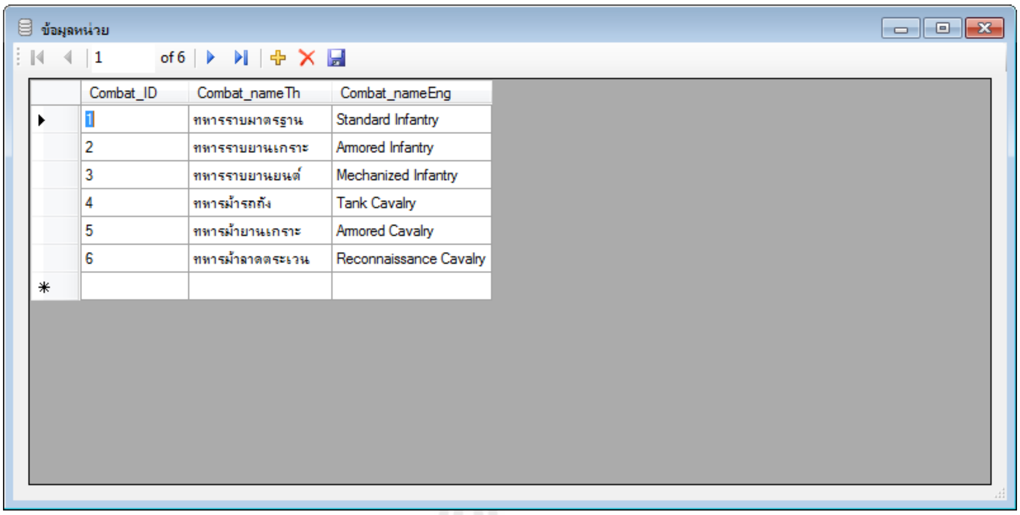

4. คลิกปุ่ม  เพื่อทำการบันทึก
5. โปรแกรมจะทำการบันทึกไฟล์ 2 ไฟล์โดยไฟล์แรกจะมีชื่อตามที่ระบุไว้และมีนามสกุลเป็น .htm และอีกไฟล์จะเป็นไฟล์รูปภาพแผนที่มีชื่อไฟล์เดียวกันกับไฟล์รายงานแต่มีนามสกุลเป็น .gif

## C.6 การแก้ไขฐานข้อมูล

1. ที่โปรแกรม CCM4CM ทำการเลือกเมนู Database แล้วเลือกชื่อตารางข้อมูลที่ต้องการแก้ไข



2. โปรแกรมจะแสดงหน้าจอการแก้ไขฐานข้อมูลดังภาพ




### C.6.1 การเพิ่มรายการข้อมูลใหม่

1. ในหน้าต่างแก้ไขฐานข้อมูลคลิกที่ปุ่ม โปรแกรมจะแสดงแถวข้อมูลว่างๆ ดังภาพ

2. ทำการกรอกข้อมูลใหม่ตามต้องการ หรือกดปุ่ม Esc บนแป้นพิมพ์เพื่อยกเลิก
3. คลิกปุ่ม เพื่อบันทึกผลลงในฐานข้อมูล

### C.6.2 การแก้ไขรายการข้อมูล

1. ทำการพิมพ์ข้อมูลทับลงในแถวข้อมูลที่ต้องการแก้ไข


2. กดปุ่ม Esc บนแป้นพิมพ์เพื่อยกเลิก
3. คลิกปุ่ม เพื่อบันทึกผลลงในฐานข้อมูล

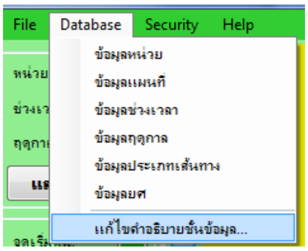
### C.6.3 การลบรายการข้อมูล

1. ทำการคลิกเลือกแถวข้อมูลที่ต้องการลบ

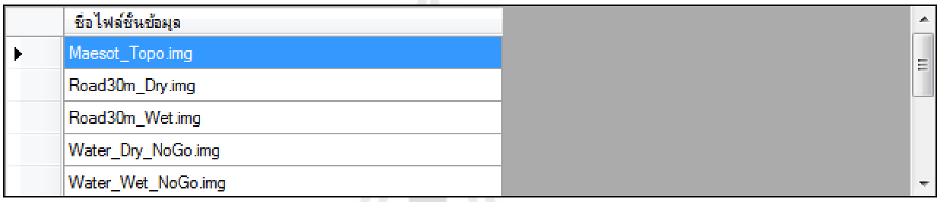

2. ทำการคลิกปุ่ม เพื่อทำการลบ
3. คลิกปุ่ม เพื่อบันทึกผลลงในฐานข้อมูล

## C.7 การแก้ไขข้อมูลคำอธิบาย Layer ต่างๆ

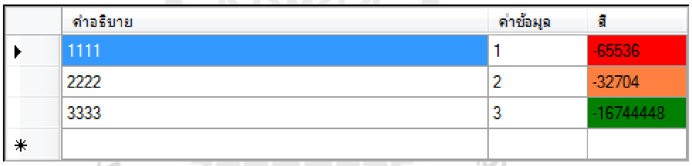
1. ทำการเลือกเมนู Database → แก้ไขคำอธิบายชั้นข้อมูล




2. ทำการเลือกไฟล์ Layer ที่ต้องการแก้ไขข้อมูลคำอธิบายด้วยการคลิกที่ชื่อไฟล์ที่ต้องการแก้ไข

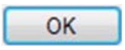


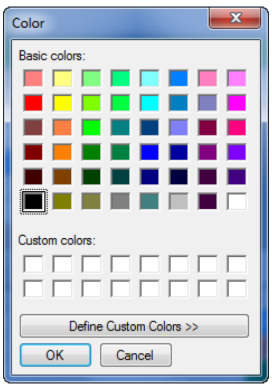

3. ทำการพิมพ์ข้อมูลลงไปในช่องด้านล่าง โดยเรียงลำดับจากข้อมูลที่มีค่าข้อมูลน้อยที่สุดไว้บนสุดไล่ไปเรื่อยๆ




a. คำอธิบาย - ให้กรอกคำอธิบายที่ต้องการให้ปรากฏสำหรับสี และค่าข้อมูลที่ระบุไว้

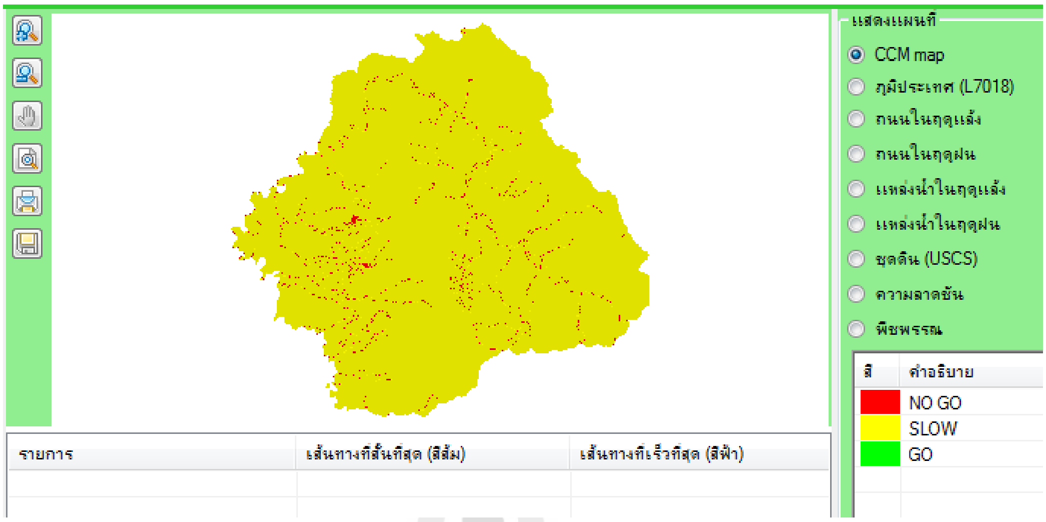
b. ค่าข้อมูล - ระบุค่าของข้อมูลสูงสุดที่ต้องการให้มีสีตามต้องการ เช่นข้อมูลมีค่าอยู่ในช่วง 0 - 30 ต้องการให้มีแสดง ให้ทำการระบุตัวเลข 30 ลงในช่องค่าข้อมูลนี้

c. สี - ทำการคลิกแล้วเลือกสีที่ต้องการจากหน้าต่างงานสี หรือหากสีที่เลือกไม่เป็นที่ต้องการให้คลิกปุ่ม Define Custom Colors เพื่อเลือกสีเองโดยการไล่ระดับสี เมื่อเลือกเสร็จแล้วให้คลิกที่ปุ่ม 

4. ปิดหน้าจอแล้วเลือก Yes เพื่อทำการบันทึกข้อมูลคำอธิบายที่ได้กำหนดไว้

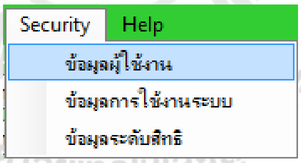
5. ทำการปิดโปรแกรมแล้วเปิดใหม่อีกครั้งข้อมูลที่ได้ระบุไว้จะปรากฏเมื่อเลือก Layer ที่ต้องการ



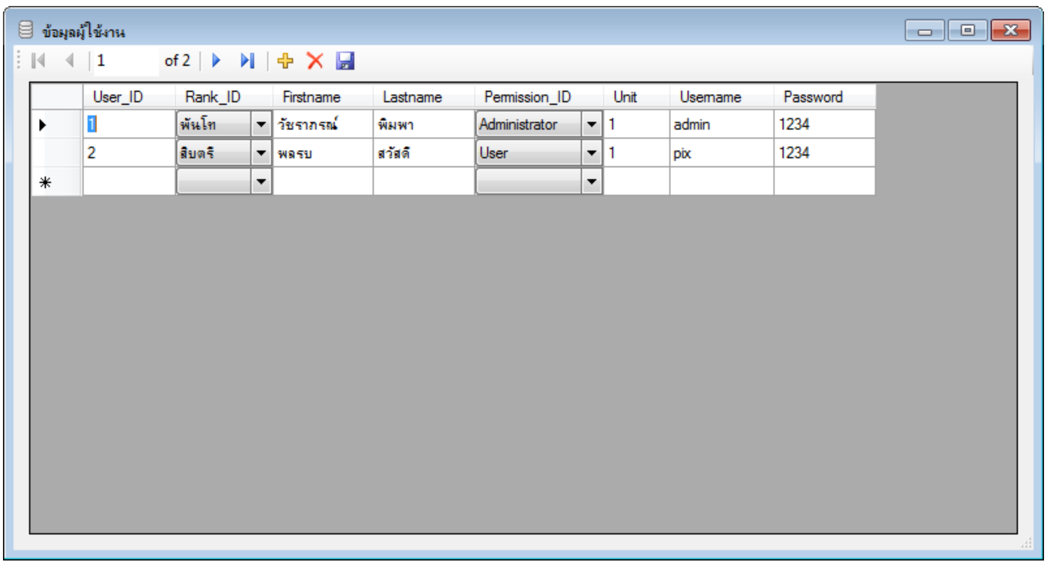

## C.8 การเพิ่ม/แก้ไข/ลบ ผู้ใช้งานระบบ

### C.8.1 การเพิ่มผู้ใช้งานระบบ

1. ที่โปรแกรม CCM4CM ทำการเลือกเมนู Security → ข้อมูลผู้ใช้งาน



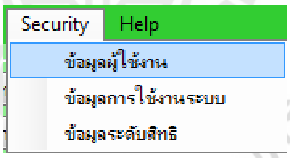

2. หน้าจอรายการผู้ใช้งานจะแสดงดังภาพ



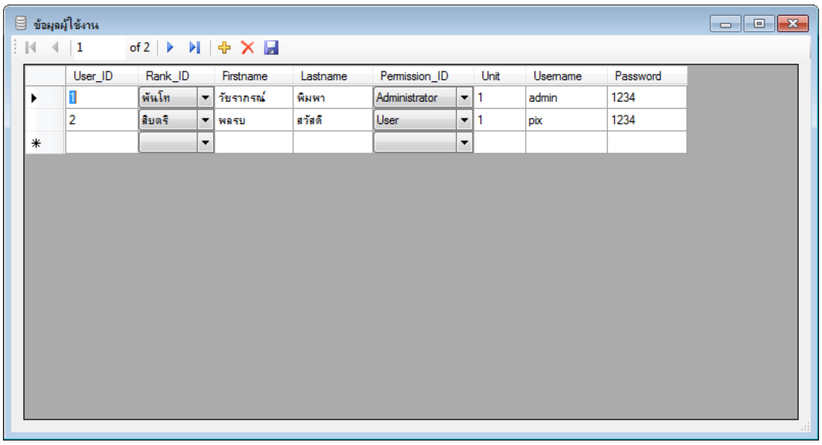
3. คลิกปุ่ม เพื่อเพิ่มชื่อผู้ใช้งานใหม่
4. ทำการกรอกข้อมูลดังนี้
    a. User_ID - ไม่ต้องกรอกระบบจะกำหนดให้อัตโนมัติ
    b. Rank_ID - ให้เลือกยศของผู้ใช้งาน
    c. Firstname - ระบุชื่อของผู้ใช้งาน
    d. Lastname - ระบุนามสกุลของผู้ใช้งาน
    e. Permission_ID - ระบุสิทธิ์ของผู้ใช้งาน ได้แก่
        i. Administrator - สามารถใช้งานได้ทุกเมนู
        ii. User - สามารถใช้งานได้ทุกเมนูยกเว้นเมนู Secuirty
    f. Unit - กำหนดรหัสหน่วย
    g. Username - กำหนดชื่อผู้ใช้งานสำหรับการเข้าสู่ระบบ
    h. Password - กำหนดรหัสผ่านสำหรับการเข้าสู่ระบบ
5. คลิกปุ่ม เพื่อบันทึกลงฐานข้อมูล

### C.8.2 การแก้ไขผู้ใช้งานระบบ

1. โปรแกรม CCM4CM ทำการเลือกเมนู Security → ข้อมูลผู้ใช้งาน



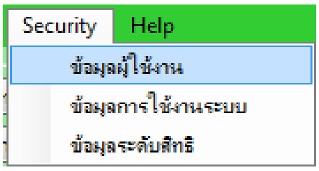

2. หน้าจอรายการผู้ใช้งานจะแสดงดังภาพ



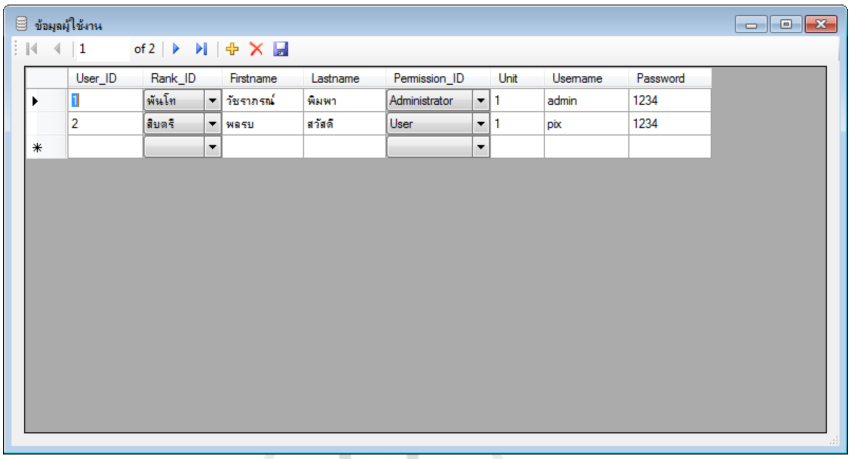

3. คลิกเลือกชื่อที่ต้องการแก้ไข แล้วพิมพ์ข้อมูลใหม่ทับข้อมูลเดิม สำหรับความหมายของข้อมูลคอลัมน์ต่างๆให้อ่านได้จากหัวข้อ 7.1 การเพิ่มผู้ใช้งานระบบ
4. คลิกปุ่ม เพื่อบันทึกลงฐานข้อมูล

### C.8.3 การลบผู้ใช้งานระบบ

1. โปรแกรม CCM4CM ทำการเลือกเมนู Security → ข้อมูลผู้ใช้งาน




2. หน้าจอรายการผู้ใช้งานจะแสดงดังภาพ




3. คลิกเลือกชื่อที่ต้องการลบ แล้วคลิกปุ่ม
4. คลิกปุ่ม เพื่อบันทึกลงฐานข้อมูล

# APPENDIX D

# QUESTIONNAIRE

แบบสอบถาม

ระบบค้นหาเส้นทางการเคลื่อนที่ของหน่วยรบในการปฏิบัติการทางทหาร

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คำชี้แจง

1. แบบสอบถามมีวัตถุประสงค์ เพื่อต้องการทราบผลการใช้งานระบบค้นหาเส้นทางการเคลื่อนที่ของหน่วยรบในการปฏิบัติการทางทหาร เพื่อเป็นข้อมูลพื้นฐานในการปรับปรุงและพัฒนาระบบให้มีประสิทธิภาพในโอกาสต่อไป

2. ความคิดเห็นที่ท่านตอบนี้จะมีคุณค่าเป็นอย่างยิ่ง และคำตอบนี้จะไม่ส่งผลกระทบต่อ ผู้สอบถามใดๆ ทั้งสิ้น

แบบสอบถามมีทั้งหมด **3** ตอน คือ

ตอนที่ 1: ข้อมูลของผู้ตอบแบบสอบถาม

ตอนที่ 2: ประสิทธิภาพของการใช้งานโปรแกรม

ตอนที่ 3: ข้อเสนอแนะและแนวทางในการปรับปรุงและพัฒนาระบบ

ตอนที่ 1: ข้อมูลของผู้ตอบแบบสอบถาม

โปรดทำเครื่องหมาย ✓ ลงใน ☐ หน้าข้อความซึ่งตรงกับความเป็นจริง

1. ท่านอยู่ในกลุ่มอายุ

☐ ต่ำกว่า 29 ปี ☐ 30 - 39 ปี

☐ 40 - 49 ปี ☐ 50 - 60 ปี

2. เพศ

☐ ชาย ☐ หญิง

3. ตำแหน่งหน้าที่ของท่านที่เกี่ยวข้องกับระบบค้นหาเส้นทางการเคลื่อนที่ของหน่วยรบในการปฏิบัติการทางทหาร

☐ ผู้บังคับบัญชา

☐ ผู้บริหารระบบ

☐ เจ้าหน้าที่วิเคราะห์ข้อมูล

ตอนที่ 2: ประสิทธิภาพของการใช้งานโปรแกรม

โปรดพิจารณาคำถามแล้วทำเครื่องหมาย ✓ ในช่องที่ท่านเห็นว่าเป็นจริงที่สุด

| ข้อที่ | ลักษณะการใช้งานโปรแกรมในด้านต่างๆ | ระดับความคิดเห็น | | | | |
|---|---|---|---|---|---|---|
| | | มากที่สุด | มาก | ปานกลาง | น้อย | น้อยที่สุด |
| 1 | ข้อมูลตอบสนองความต้องการของผู้ใช้งาน | | | | | |
| 2 | ระบบงานมีความสอดคล้องกับลักษณะงานที่ปฏิบัติ | | | | | |
| 3 | ข้อมูลเป็นประโยชน์ต่อการทำงาน | | | | | |
| 4 | ระบบมีการออกแบบให้ง่ายต่อการใช้งาน | | | | | |
| 5 | เมนูและเครื่องมือมีความชัดเจน เข้าใจง่าย และ สื่อความหมายได้ดี | | | | | |
| 6 | ความถูกต้องของการจัดการข้อมูล | | | | | |
| 7 | ระดับประโยชน์ของระบบงานที่มีต่อการค้นหาเส้นทางการเคลื่อนที่ของหน่วยรบในการปฏิบัติการทางทหาร | | | | | |
| 8 | ระดับความน่าจะเป็นที่สามารถนำระบบงานนี้ ไปประยุกต์ใช้งานเป็นต้นแบบในพื้นที่อื่นๆ | | | | | |

ตอนที่ 3: ข้อเสนอแนะและแนวทางในการปรับปรุงและพัฒนาโปรแกรม

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ขอขอบคุณที่ให้ความร่วมมือในการตอบแบบสอบถาม

# CURRICULUM VITAE

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1998 - 2002 Bachelor of Science (Computer Science), Rajabhat Institute Pibulsongkram, Phitsanulok, Thailand

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