Geographical Information System and Geo-Spatial Operational Planning, Management and Execution for Pakistan Army Armor Regiment

By

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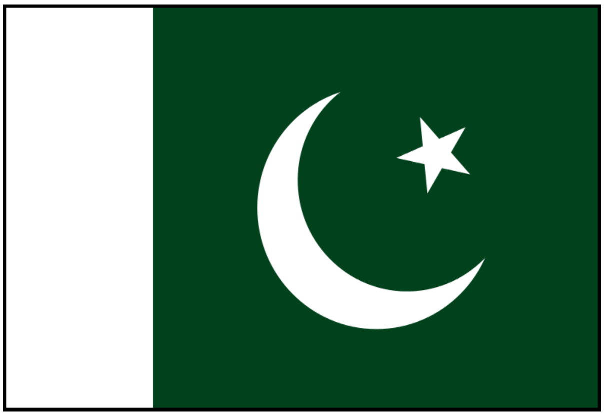
In the Name of Allah, the Most Gracious, the Most Merciful



DEDICATION

Dedicated to the brave men and women of the Pakistani Armed Forces

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Ali Haroon, Fahad Jahangir, Saman Mushtaq, Sarah Ovais & Zeeshan Hassan Khan

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
3D	Third Dimension
AOI	Area of Interest
API	Application Programming Interface
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
BHVS	Battle Hawk Vehicle System
BTY ARTY	Artillery Battery
C#	C-Sharp
C4I	Command, Control, Communications, Computers and Intelligence
CCIS	Command, Control, Intelligence System
CCM	Cross Country Mobility
CE	Command End
CO	Commanding officer
COP	Common Operational Picture
DEM	Digital Elevation Model
DMA	Defence Mapping Agency
DTD	Digital Topographic Data
e.g.	For Example
ESRI	Environmental Systems Research Institute
ETL	Engineer Topographic Laboratories
FE	Field End
GIS	Geographical Information Systems
GPS	Global Positioning System
HCI	Human Computer Interaction
HQ	Headquarter
i.e.	That is
IBMS	Integrated Battlefield Management System
IDW	Inverse Distance Weighting
IMU	Inertia Measurement Unit
INF COY	Infantry Company
MGIS	Military Geographical Information Systems
MOLE	Military Overlay Editor
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NMEA	National Marine Electronics Association
OPFOR	Opposition Forces
RDBMS	Relational Database Management System
RF	Radio Frequency

RS	Remote Sensing
SA	Situational Awareness
SDK	Software Development Kit
SIDC	Symbol Identification Coding
SQN	Squadron
UE	Usability Engineering
UHF	Ultra High Frequency
US	United States
VHF	Very High Frequency
WPF	Windows Presentation Foundation
WWII	World War 2

ABSTRACT

The project is a prototype design for an effective geospatial and terrain analysis based system for an Armor Regiment of the Pakistan Army. This system helps improve land operations by providing the commander better management and execution control over his under command assets. The system consists of a Command End (C.E) and a Field End (F.E). It is a Geographical Information System (GIS) based operational planning system which helps the commander make decisions based on Geospatial analysis. C.E is a workstation at the commander's end while the F.E is designed to be installed in the tanks. Three core functionalities that the system provides includes ability to visualize terrain and scenarios both the planning and execution phases, ability to view information about under command assets, and ability to effectively use this information in location based visualization of assets. The project is a complete hardware and software solution to help improve operational planning and execution for an Armor Regiment.

INTRODUCTION

The Pakistan Army faces a very dynamic and highly challenging military environment in which decision making is a difficult if not near impossible human challenge. In these environments, military decision making is affected by a number of factors and scenarios which may change as quickly as they are understood. In addition to, commanders have the added challenge of carefully balancing many aspects of war while planning and carrying out difficult operations and missions. Coupled together both these reasons cause a dystopia of Command and Control which in turn creates confusion.

The goal of the project was to help lift the fog of war off the complications which exist in the operational planning, managing and execution structure of the Pakistan Army Armor Regiment, and to assist the subordinate commanders in homing in their abilities as leaders in the battlefield. The project targets to create a system which has a very quantifiable approach towards military decision making in the context of an Armor Regiment and its operational working and functions.

The project's aims to provide a solution to this dilemma by incorporating the already existing different tools and technologies to design an effective geospatial and terrain analysis based Geographical Information System (GIS) for the Armor Regiment of the Pakistan Army.

1.1 BACKGROUND INFORMATION

The use of longstanding and deep-rooted principles in the Command and Control system of the Pakistan Army has been its pride and glory since its inception. A tradition handed down rank after rank and long course after long course has its roots in the army's vibrant history as part of the greater British Army prior to Independence in 1947. Since that time the army has perfected this form of Command and Control and has created a very efficient system for its management, running and functioning. Unfortunately though the very asset that this type of Command and Control system took pride in i.e. it's time tested ways; is now fast becoming the reason for its downfall. Time fades everything and it waits for no one, not even one of the largest and most powerful armies of the world.

Opposition Forces (OPFOR) routinely disrupt the cohesion and effectiveness of regular Army battalions in the modern battlefield. There is a lacking in the facilities and assets present in the battlefield to support the freedom of operation, delegation of authority and leadership from any critical point on the battlefield.

In order to improve this predicament many modern armies of the world have resorted to new and improved specialized system to help the commander better plan and manage his operations and assets respectively. These modern or futuristic systems are often computer based and more so GIS based. This is because GIS as a science handles the art of war by its very nature. It is logically a science dealing with management and planning and is thus born to be suited to the needs of a military commander.

Carrying out successful operations and missions requires that a commander be fully aware of the area his forces are operating and will be present in, for which situational awareness can prove to be a very effective that can increase the chances of survival and successful implementation of plans in the battlefield.

A similar condition exists in the management and planning of an Armor Regiment. Armor operations are by their nature very mobile, fast and dispersed. It is their prerogative to establish dynamic movement in the battlefield to achieve success and surprise. Maintaining control over such a mobile and fast force is not only challenging but can be difficult without creating two adverse conditions. The first condition of not having the optimal level of control i.e. allowing the mobile force to function without proper command. The second condition, not allowing the force to exhibit complete mobility or speed and keeping the forces in check in order to ensure proper direction and command. Both these conditions can be fatal for a good armor operation because both of them can sacrifice the very advantage that armor has over other arms.

A tank has very limited sight, since it is a metal cocoon its occupants have only a few slits to look out to maneuver in the limited terrain that it can travel on. Low light or night conditions further hamper this visibility of the crew to effectively move this massive mobile fortress. These features combined, make a tank an impressive yet difficult piece of war machinery to handle. This demands the need for a commander to effectively guide his troops on the battle field for carrying out successful operations.

1.2 RATIONALE

The rationale for the project is solely the lack of such a system in Pakistan Army. Most modern armies of the world have already begun indoctrination of such systems into their working. This system can be of utmost importance for the army if it wishes to remain at par with other leading militaries of the world including the rival army of India.

Such systems do already exist in the world and can be acquired through substantial expenses on the part of the client military. This project is aimed at creating an indigenously designed system devoid of any interference.

1.3 REQUIREMENT OF THE ARMY

The requirements of an Armor Regiment are very diverse and complex. It can be rightly concluded that these requirements themselves require a complex study process to determine and plan for. The project team has tried to understand these requirements as best as it could be, given the limited time and resources. A number of army officers have been instrumental in helping us understand these requirements as follows:

i. **Real Time Location of Assets:** The commander needs to be able to know where his under command assets are at all the time. This assists him for future plans, better command, and to effectively coordinate the efforts of the assets to ensure the success in battle. This knowledge has to be real time and up to date.

ii. **Terrain and Visual Representations of the Battlefield:** A commander needs to know how the battlefield looks like where he is sending his assets into. He needs to have complete remote knowledge of every aspect of the battlefield in order to be able to gauge what his under command assets are seeing and experiencing.

iii. **Location of Friendly and Enemy Forces:** The commander also needs to be aware of where other friendly and enemy forces are. This can be the crucial point in a battle i.e. knowing where and what is with respect to your location. If the commander is aware of the location of the enemy, he can act better in planning his moves.

iv. **Planning and Decision Making Tools:** These can be a number of separately designed tools which take the data that the system has and create a meaningful output. These tools will help the commander better plan his operations and with successful planning he is sure to experience a success in battle.

v. **Ammunition, Fuel, Morale, Health etc.:** A commander must know the condition of his assets. How are they managing as far as ammunition and fuel is concerned? Are they stuck/bogged down while moving? Has the tank broken down? Etc. All these events ultimately affect the success of the mission and the commander needs to be aware of them.

1.4 CURRENT MANUAL SYSTEM USED BY THE ARMY

The current system that is used in the Armor Regiment is purely mechanical and manual. The unit's Headquarter (HQ) staff maintains paper maps for all possible theaters of conflict. When war does erupt, these maps are used manually to plan, manage and execute armor operations. In order to get location of assets, the HQ staff use the wireless set and then manually adds pins and marks to the physical maps present in the Command Headquarter. The commander then uses this updated map to give out further orders and commands. There is no use of advanced Geospatial tools and technologies in the field currently to help in planning and management. The physical maps offer limited visualization and map control. The location of other friendly and enemy forces is also handled manually by displaying it on the physical map at the Command HQ. This information is gathered through wireless communication and is rarely ever used in future plans at the speed that it can be used. Also this information is never transferred to the field commanders unless explicitly required. The status of the field assets is also gathered manually and is done so in a time consuming fashion. The fuel and ammunition count is sent manually over the wireless. Refill points and areas of safety and camouflage are pre-battle decided and cannot be changed as it is difficult to pass the changes to field commanders. Field commanders also have to rely on physical maps to navigate the battlefield. These maps are often outdated and at a very high scale to allow for good navigation.

1.5 PROPOSED SYSTEM

The system proposed in the project is a dynamic Geographical Information System (GIS) which employs the tools and methods of Geospatial sciences to ensure better planning, managements and execution of the operations of an Armor Regiment. Through this system the commander will be able to view his under command assets at real time location on dynamic maps which will be updated automatically as the assets move. The system will allow for better terrain and visual representation of the battlefield. The system will focus on giving the commander tools and protocols to plan for his assigned mission. These plans will then be displayed dynamically to all his under command units in order to allow for better cohesion and synergy between the commander and the commanded. The system will allow for changing parameters on the fly in order to display the battlefield as it changes. The system will show the status of each asset to the commander in order to allow him to update and mange his plans accordingly. The system will focus on automation in order to make it easy for the commander and the under command to understand and carry out missions successfully.

1.6 OBJECTIVE

The objective of the project is to **"create a geo-spatial data based framework for operational planning, management and execution of an Armor Regiment using geographical information systems."**

In order to achieve this objective, the work was divided into phases as described below:

i. Gather information about already existing similar solutions, identify their strengths and weaknesses, and use these in the proposed system in order to make it more efficient.
ii. Develop a prototype hardware system to facilitate in hosting the software and in the development of the data.
iii. Develop a prototype software system focusing on the most immediate need in the domain. In this domain the focus is further upon:
    a. Ability to visualize terrain.
    b. Ability to get information about under command assets.
    c. Ability to use/incorporate this information for future planning.

1.7 STUDY AREA

The Study Area or Area of Interest (AOI) is part of Kasur District in the province of Punjab, Pakistan. The latitude and longitude of Kasur district are 31.00 and 74.16 respectively. The district is bounded by the Ravi River in the North-West and River Sutlej in the South-East. The total area of the AOI is 255 Square Kilometers. Topographically the study area consists of barren lands, farm lands and sporadic villages and small towns. It has an elevation of 160 – 216 meters above sea level. The area is sloping from North-West to South-West. The AOI contains a broad gauge railway line from Lodhran to Kasur and multiple metaled major roads connecting the towns and villages. The most prominent feature in the area is River Sutlej which divides the area into two equal parts. The river also is roughly the border between Pakistan and India, making the study area half lie in Pakistan and half in India. The study area is shown in *Figure 1 IKONOS Imagery of the Area of Interest*.

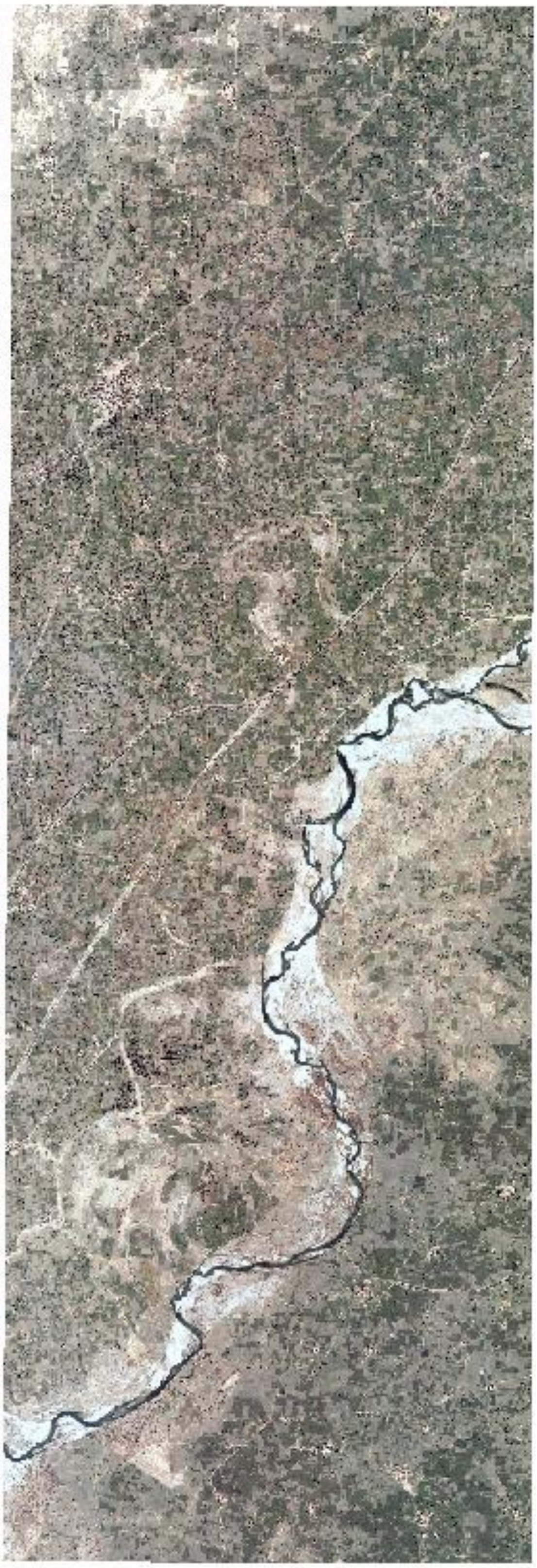

Figure 1 IKONOS Imagery of the Area of Interest

1.8 SCOPE OF THE STUDY

The effort involved in this project was by no means an easy task and not only was its implementation tedious but also time consuming. Keeping this in mind, it was wise to define the development objectives as short and precise as possible. The primary focus of the project is to help solve some of the problems related to an Armor Regiment's planning and management using GIS. Other aspects of the system such as Communications, Encoding etc. are secondary objectives.

Although being in the domains of multiple highly complex engineering fields, the project focused on aspects of Geoinformatics Engineering and its associated technologies and theories. Other engineering domains such as hardware engineering, software engineering, network engineering etc. were not the primary goal of the project and were considered as optional or future development steps.

The scope of the study is to create a prototype Geographical Information System for the Area of Interest in order to improve and add on to the existing decision making system in the Armor Regiment by providing improved tools and technologies.

As the battlefield of the future expands and the battle becomes more chaotic and complex, the line that divides the indirect leader (commander) from the direct leader (field commander) will continue to shift lower down the levels of command. The circumstances of future wars will demand a more reliable and fast decision making system by providing visual representation of the battlefield, location of friendly and enemy assets, planning and decision making.

1.9 LIMITATIONS

All projects, whatever their scope or domain is have certain limitations. This project similarly has certain limitations but it should be clear that unlike most projects the limitations in this case are many in number and a lot more complex. These limitations are:

i. **Human resource Limitations:** The project team is a group of students developing this system and this means that they have certain inherent limitations in terms of resources.
ii. **Knowledge Limitations:** The project's domain lies in multiple fields of equally challenging engineering disciplines. It is important to know here that the project team will focus on the domain of their expertise, i.e. the Geoinformatics. All other components of the project which are in other domains are subject to time and knowledge. Also most of the papers and documents on military topics are kept highly secret and it is not possible to gain the knowledge on these topics easily as may be the case in other projects.
iii. **Time Limitations:** Time is another crucial factor in this project, usually such projects are developed over multiple years but this project's duration is limited to two semesters (8 months).
iv. **Financial Limitations:** Since the project is hardware and software based solution, it requires a lot of funds to buy the different components and parts. These parts are not cheap, but the approved budget was limited to funding from the university.
v. **Data Limitations:** Most of the data being used are related to the military, which are kept secretive and is not shared openly by military organizations.

1.10 LITERATURE REVIEW

This section of the document will provide details of similar projects or works being carried out in other armies of the world. It should be noted here that most of the data and papers on military applications of GIS and geospatial tools and technologies are kept secret by the armies, this results in a shortage of available literature on how to develop such a system.

The research work done in the military domains is not published due to reasons which makes it difficult to know about technologies being used by different military organizations and what future areas are being explored. As far as the project and use of geospatial technologies is concerned, publicly available literature is usually in a very basic form.

The establishment of such a basic form of GIS and use of geospatial technology is merely an advancement of the GIS used for civilian purposes. Armies in different parts of world are using much more complex GI Systems for operational planning and their efficient execution.

Different software companies especially those working in the geospatial domain though usually extend their research from the civil to military domain to attract more clients e.g. ArcGIS military analyst. Such companies usually publish their research in different journals to attract military clients and this research is extensively covered in the literature review.

For the purpose of this literature review, the papers which have contributed usually come from the domain of research of Geospatial software companies rather than the military itself.

1.10.1 Situational Awareness

Situation awareness (SA) according to the military perspective is the knowledge and understanding of the battlefield scenario which would help in timely decision making by assessing different aspects of friendly and enemy forces. For conducting successful operations, a commander must be able to determine quickly the context and relevance of events that are unfolding.

1.10.2 Auftragstaktik

The first doctrine emphasizing situational awareness was the German Wehrmacht doctrine of "Auftragstaktik"; which was employed in World War II (WWII). This doctrine enabled junior level commanders to initiate alterations to the planned operations in the face of changing scenarios and conditions in the battlefield.

The "Auftragstaktik" doctrine is labelled by many leading military tacticians and authorities as the sole reason for the successes that the German Army had in land operations during WWII. It is observed, that armies wish to emulate the Germans of World War II because their victories were won against considerable numerical odds, under extreme logistical constraints, and without the expected disintegration and loss of cohesion normally associated with men and units confronted with a clearly hopeless situation. In light of these successful field tests of such a military theory, many armies have now effectively adapted this type of Command and Control structure.

It is important for a commander to be aware of the area his forces are present or operating. Having complete knowledge of different attributes related to friendly and enemy forces can greatly increase the effectiveness of military operations.

1.10.3 Joint Battle Command Platform

The U.S. Army and Marine Corps are developing next-generation observational software for an array of platforms, including handheld devices under the program titled "Joint Battle Command-Platform".

"In an effort to improve situational awareness down to the squad leader level, the U.S. Marines Corps and Army intend to provide the next-generation situational awareness software on ruggedized handheld platforms similar to smart phones or personal digital assistants." (Guyan, 2010)

It is extremely important that a commander both in the field and at headquarters be aware of how the situation is developing around them. This awareness of ones surrounding can be critical to the success on the battlefield and can make or break an operation. The information has to be timely and precise.

"It's not until recently that technology has gotten to the point where you can realistically enable a soldier with the same information that was previously only available at a command post. Today, because of low-power processors, because of high-capacity rechargeable batteries and new communications technologies, you can now put in the hand of a soldier the kind of connectivity that at one point, you had to erect an antenna mast to achieve" (Guyan, 2010)

According to this article the technology and software have now gotten to the development level where they can be employed in military applications because they possess the processing power, battery life and communication protocols to function successfully in the battlefield.

"It's only right that we push that technology and capability to where the soldiers need it and to where the fight is. As a nation at war in areas where a lot of the fighting is being done on foot, it's really imperative that we extend the network and the situational awareness out to where the soldier is." (Guyan, 2010)

As stated above, it has now become feasible to attach the necessary hardware and software tools with the assets in order to incorporate it into a network of fighting nodes which can then be commanded and controlled.

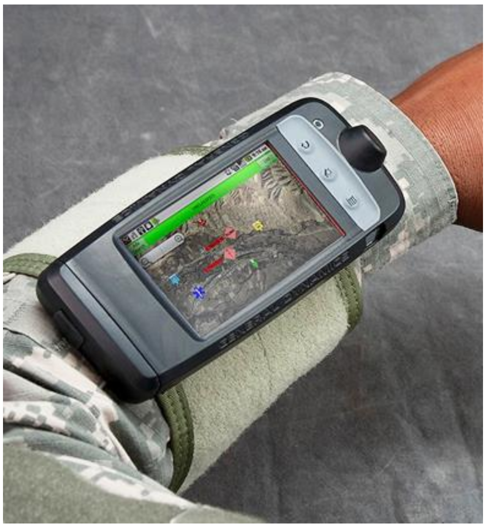

Figure 2 Joint battle Command Platform for Dismounted Troops

Figure 3 Joint battle Command Platform for Vehicle Mounted Troops

1.10.4 Military Requirements

1.10.4.1 Terrain

Terrain refers to the lay of land and, is usually expressed in terms of slope, elevation and orientation of features. It affects the flow of water and over a large area climate and weather patterns. The study of terrain in military is very important as it determines areas with can be penetrated easily or through which the movements of materials is easy, it is used in both defensive and offensive operations.

Terrain factors are used to determine the traffic ability of vehicles over an area. Predetermined calculations of traffic ability of military vehicles such as tanks etc. are very important in operational planning.

"An army should be aware of the areas that have a smooth terrain enough for the enemy to penetrate easily and such which have highly rugged terrain which requires less monitoring because an enemy is less likely to waste effort by making its forces climb on e.g. mountains." (Satyanarayana & Yogendran, 2013)

It is important for modern armies to have the information of terrain both within their boundaries as well as outside their boundaries. The collection of such important information is very crucial to military applications. Remote sensing and photogrammetric techniques are applied to collect data of terrain in the form of satellite images, vector data, DEMs etc. Once this data is acquired, it is important to store it efficiently in forms of databases. Many spatial RDBMS have been developed for the storage and manipulation of such data.

"Vehicle mobility model is concerned only with the effects on the vehicle caused by the interaction of the vehicle with the environment. Both the terrain and atmosphere contribute to the interaction of the vehicle with the environment. The term "terrain traffic ability" is commonly used to denote the terrain component of the environment which affects ground vehicle mobility." (Birkel, 2003)

Terrain Factors:

The major traffic ability factors which influence vehicle mobility are as follows:

i. Slope: Includes aspect with respect to direction of travel.
ii. Obstacle descriptions: Cross-sectional geometry; generic models acceptable.

iii. Surface materials: rocky, asphalt etc.

iv. Soil Type: The type of soil.

v. Soil strength: Characterized by several inter-related factors such as RCI: Remoulding Cone Index, Cohesion: "C", Density, Moisture content, Freeze/thaw depths.

vi. Surface roughness.

vii. Surface slipperiness/wetness/ice/Snow.

viii. Non-woody vegetation: Vegetation with stem diameter less than 1.0 inch, includes bushes and crops.

ix. Woody vegetation.

x. Hydrology.

xi. Water Table.

1.10.4.2 Digital Elevation Models (DEMs)

Digital Elevation Models are a raster where each pixel contains information about a continuous phenomenon that can be displayed in 3D. DEMs can be used to extract a lot of information such as slope, aspect, depressions hills etc.

"There exists software tools which can extract topographic structures from a DEM. We can calculate slope, aspect, shaded relief and point of inflection from a DEM and through these analyses we can find the watersheds and overland flow paths and the direction of flow and can tell whether an area is flat or is having some elevated feature and using certain tools we can generate vector data of these features." (Jenson, 1988)

1.10.4.3 Digital Topographic Data

Digital topographic data are the data about the earth's topography contained in a digital format. As military mission planning and execution is shifting towards computer based systems, the need for digital data has increased. Topographic data includes:

i. Roads.
ii. Rail.
iii. Canals.
iv. Urban Areas.
v. Borders line.
vi. Points of Interests (Wells, Hospitals etc.).

"There is a growing requirement throughout the Army for digital topographic data, and the need for Digital Topographic Data (DTD) will certainly increase as greater use of digital processing is introduced into Army systems. This increased need will be both in terms of the number of systems using the data and the degree of data content, accuracy, and resolution required." (Herrraann, 1985)

It is however necessary that the dataset follows some requirements in terms of data consistency, interoperability, and accuracy etc.

The Engineer Topographic Laboratories (ETL) conducted a study in Vicksburg, Mississippi, USA and assessed the Digital Topographic Data (DTD) needs of the United States Army. The objective was to define Army DTD requirements for the Defence Mapping Agency (DMA). The evaluations were performed on testing the dataset to support terrain analysis, the analysis community, and existing and emerging systems/programs covering tactical, combat modelling, simulation, training, testing, and developmental applications. In the same study DTD requirements were defined and evaluated in terms of format, data content, resolution, accuracy and a data base specification for DTD, encompassing the requirements for terrain analysis, and other programmes.

1.10.4.4 Weather

Weather is an important aspect of battlefield. It is important for a commander to have knowledge of weather of an area beforehand. This knowledge is very important for successful military operations. For example extreme rain can hamper the movement of forces. The weather database is normally developed by the collection of weather information from imagery interpretations units, engineer units, ARTY MET units etc. Finally, the impact of weather on terrain and operations helps in planning purposes.

Weather Analysis Matrix:

These matrices greatly help in order to study the impacts of weather on the terrain roughness as well as on the capabilities of friendly and enemy forces. For example, their manoeuvrability, visibility clearance to target enemy as well their communication with the commander.

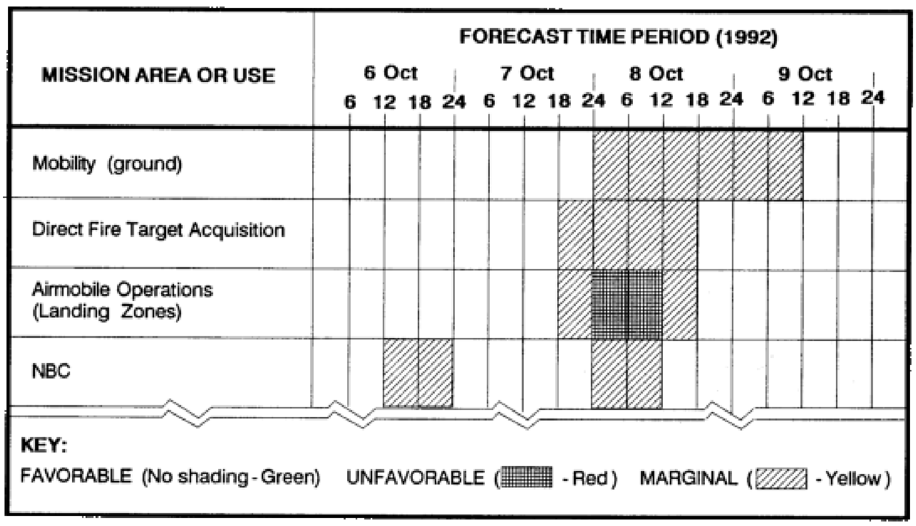

Figure 4 Weather Analysis Matrix *(US-Army, 1992)*

The matrix takes into account the area it affects, the severity of the effects, and the time period. It produces a result of favourable, unfavourable and marginal time periods for impacts on the overall operation with respect to these factors.

1.10.4.5 Military Geographical Systems

One of the technologies that are used to manage the all sorts of information is Geographic Information Systems (GIS). This technology links the various types of the information in a computing environment provide analysing tools for decision makers and save their time as compared to not using a GIS. If spatial and non-spatial information are linked together with a geographic model, the use of such information and the analysis becomes easier, and the information can be used in many useful ways. A typical GIS will provide functionalities to store, query and analyse geographic information.

"One of the major GIS application areas is armed forces applications. GIS has a wide range of applications in Military. It not just mapping functionality that GIS contributes to Military domain. GIS has become an integral module of CCIS. Most of the geospatial analysis capabilities and functional utilities of the GIS were developed and adopted to Functional Area Services of CCIS." (Ucuzal & Kopar, 2003)

Liao in 2001 proposed a system architecture that basically considered the military geographical intelligence system as a problem solving procedure for supporting the military operations as well as the situational analysis and also generating a planning process at the tactical level.

The data collected from surveillance and reconnaissance missions can be usefully manipulated through GIS and integration and incorporation of its tools. Attribute database, spatial database, rule base as well as knowledge repository can greatly help for the development of a knowledge based decision support system specially to manage the Battlefield environments. For example, it can help identify the position of targets and possible threats, the combination of such information along with terrain and other useful knowledge can help plan missions and operations and provide greater analysis capabilities.

Uses of GIS in Military:

There are many different uses of GIS in military, some of them are:

i. **Command, Control, Communication, Information Operations and Intelligence Systems:** The map data that military usually maintains is used for various purposes and functional applications at military CCIS systems. All of these systems rely on locational information and maps, thus they make use of GIS.

ii. **Unit/Troop Tracking Systems (GPS):** The units, organizations and even troops are tracked via GPS embedded equipment on the different levels of maps.

iii. **Intelligence and Operations systems:** For intelligence systems, it is required that the information should be collected form maps that are current and have detailed topographic and cultural information. Currency of information is of prime importance, together with the ability to associate the information within an appropriate position referencing system. Where possible, maps are supported by photographic or other imagery. In other words, the most up-to-date geographic information is essential, together with the ability to relate it back to the standard products used by the operators. The requirement for military operations is that detailed map and chart information be available, in sufficient quantities, for all forces concerned. These maps and charts must be current, contain standard navigation and position information (in the form of a grid or graticule) plus detailed topographic and hydro graphic information. Interoperability and standardization of information is of prime importance.

iv. **Logistic Information Systems:** Such information systems require such capabilities like route definitions, distribution models, shortest path analysis, query and display of the facilities and logistic infrastructure and other related issues that assist in planning for logistics. These fundamental capabilities are provided by GIS Logistic Information Systems.

v. **Electronic Warfare Systems:** All electronic warfare systems require terrain data either for analysis or for display.

vi. **Radar Coverage and Frequency Analyses Systems:** For the site selection of the radars and radio antennas, coverage area analysis, propagation analysis, weapon and or missile corridors, flight corridors and etc. are analysed and displayed via GIS tools.

vii. **Common Operational Picture (COP), Land/Maritime/Air Recognized Picture:** This is totally a new concept in GIS.

viii. **3D Terrain Modelling, Drape and Fly through Systems:** It is important to model the terrain and evaluate it before the operation. Draping of various accuracy maps and imagery on the terrain also is very helpful for intelligence. This technology is also used for flight simulation.

ix. **Military Map Browsing Systems:** Together with the central use of GIS data, increase in the performance of GIS data usage with multi-user environment, it has been very popular to browse the maps on the web. As mentioned above the maps are very intensively used for various purposes and the high performance access to the maps is very important now with easy to use browsing capabilities.

1.10.4.6 Imagery

The birth of remote sensing took place when the balloonist G. Tournachon (alias Nadir) made photographs of Paris from his balloon in 1858. Messenger pigeons have also been used for spying over the enemy territory. During the cold war era aircraft were used for collecting images of enemy land. But this form of intelligence could not be practical as explained by an example by CDRE Pat Tyrell OBE Royal Navy (Rtd.) "US airman Gary Powers was shot down in a U2 aircraft over the Soviet Union. The recovery of these photographs in the early days was slightly hair-raising, with aircraft catching the film as it dropped through the atmosphere!" This evolution process matured in the form of satellite based remote sensing.

With the advancement in satellite remote sensing systems, as number of satellites in the sky increases with better sensors of high resolution and more uses of satellite images are being discovered. It is being used in in many military systems such as imagery intelligence, reconnaissance missions etc. Modern weapon systems have become so advanced that they require a complete picture of target area. During World War II, the Korean War, the Vietnam War, the Gulf War, Haiti, Somalia, Bosnia and other military operations, commanders relied on imagery for targeting, terrain analysis, intelligence, mapping, command and control, mission planning, battle damage assessment, feature extraction and threat analysis. Without the "eye-in-the-sky," these commanders would not have had the relevant common picture of the battlefield and the area of operation.

Uses of Imagery in Military:

Imagery intelligence is a discipline which collects information via satellite and aerial photography. Image based products can be used to derive DEMs. DEMs are very useful tools for terrain analysis. They can help in vehicular movement, identifying obstacles such as tank ditches etc.

The role of imagery in military is very important. The different bands provide intelligence information such as change detection that gives information about the expansion activities of enemies. Since images are very useful for developing vector based maps, their resolutions affect the development of digital database.

Figure 5 Satellite Image of Pakistan - MODIS

1.10.5 Vehicle Performance

Vehicle Performance in this context is defined as the speed, power, durability and capabilities of land vehicles with regards to terrain, slope, vegetation, etc.

1.10.5.1 ModSAF/SIMNET Vehicle Performance

"ModSAF was initially developed by the Defence Advanced Research Projects Agency (DARPA)" (Birkel, 2003)

With ModSAF the operator is able to perform various tasks that are influenced by the terrain of an area. Different standard values that are calculated to put in the models to generate the vehicular movement output.

ModSAF uses a simple parametric formulation which characterizes vehicle performance according to vehicle type and 16 soil types. These six parameters are:

- Maximum speed forward (km/h)
- Maximum speed reverse (km/h)
- Maximum acceleration (m/s2)
- Maximum deceleration (m/s2)
- Maximum turning rate (Arc Degrees/second)
- Maximum climb angle (Arc Degrees)

In addition, a fuel usage rate is specified for engine idle and maximum power.

"The ModSAF ground vehicle mobility model generally treats stemmed vegetation and localized terrain obstacles (e.g., anti-tank ditches) as discrete objects which are handled by either maneuvering (avoidance) or as a series of localized slopes. Snow does not currently affect ground vehicle movement in ModSAF." (Birkel, 2003)

Movement of vehicles on ground is effected by the terrain of a region. It is important to know how fast military vehicles move over an area such as tanks etc. for different operations. Predetermined information about traffic ability on a region can be very useful. The incorporation of vehicle performance model with this information helps determine how vehicles will perform and are important for planning.

1.10.6 Military and Defence Symbology

A military symbol is a graphic representation of units, equipment, installations, control measures, and other elements relevant to military operations. As a part of doctrine, these symbols provide a common visual language for all users.

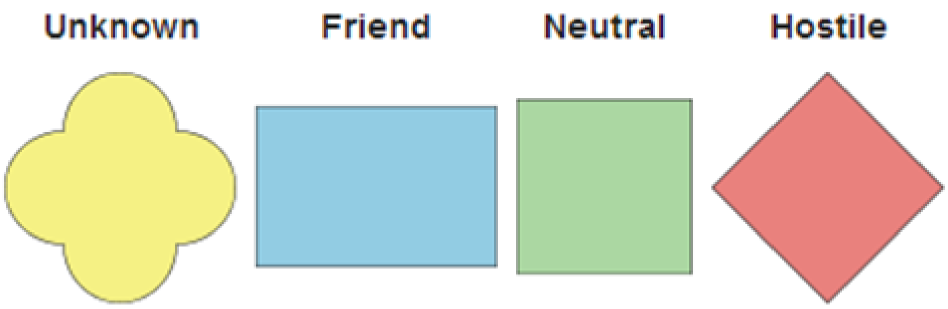

Figure 6 2525C Symbology (employed by Pakistan Army)

1.10.6.1 Allied Procedural Publication 6A (APP-6A)

This is a North Atlantic Treaty Organization (NATO) defined military symbology. APP-6A recognises five broad sets of symbols, each set using its own SIDC (Symbol identification coding) scheme:

i. Units, Equipment, and Installations.
ii. Military Operations (Tactical graphics).
iii. METOC (Meteorological and Oceanographic).
iv. Signals Intelligence.
v. MOOTW (Military Operations Other Than War).

1.10.6.2 Common Warfighting Symbology (MIL-STD-2525C)

This is the American Armed Forces defined symbology. The contents are essentially identical, but MIL-STD-2525 has been evolving faster than NATO's APP-6. This is also the military symbology employed by the Pakistan Army.

1.10.6.3 Military Overlay Editor (MOLE)

Through MOLE, ArcGIS Military Analyst provides support for war fighting symbology (point, line, and polygon) in accordance with MIL-STD 2525B; automatic laddering, stacking, and de-cluttering of symbols; and user customizable symbols. Order of battle databases can be imported/located and displayed in accordance with MIL-STD 2525B and corresponding symbols and attributes created and edited in MOLE. Linking to unattended ground sensors and real-time track information with the ArcGIS Tracking Analyst extension makes true intelligence fusion and situational awareness a reality. MOLE enables other applications, such as ArcMap and ArcGIS Server, to take advantage of military symbology in creating custom applications.

1.10.7 Data Transfer Protocols

These pre-designed XML protocols to transfer data from one computer to another.

1.10.7.1 National Marine Electronics Association (NMEA) Sentences

NMEA Sentences are a combined electrical and data specification for communication between marine electronics such as echo sounder, sonars, anemometer, gyrocompass, autopilot, GPS receivers and many other types of instruments. It has been defined by, and is controlled by, the National Marine Electronics Association.

```
$GPVTG,,T,,M,0.004,N,0.008,K,A*2F
$GPGGA,180035.00,3737.54176,N,12206.62934,W,1,09,1.86,-11.0,M,-25.2,M,,*7E
$GPRMC,180036.00,A,3737.54169,N,12206.62979,W,0.026,255.90,070907,,,A*7D
$GPVTG,255.90,T,,M,0.026,N,0.048,K,A*3E
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$GPGGA,180042.00,3737.54019,N,12206.63165,W,1,09,0.99,-8.2,M,-25.2,M,,*4E
```

Figure 7 Raw NMEA Sentences

1.10.8 Military Software Applications

1.10.8.1 ArcGIS Military Analyst

It is a specialized set of tools designed by ESRI for Military users. ArcGIS military analyst is a key component to the following application areas:

i. Command and Control.
ii. Battlefield Management.
iii. Intelligence Gathering.
iv. Mission Planning and Response.
v. Search and Rescue.
vi. Defence and Intelligence geospatial Analysis.

1.10.8.2 Battle Hawk Vehicle System (BHVS)

The Battle Hawk platform system is a ruggedized computer system designed specifically to meet the harsh environment associated with armoured combat fighting platforms. The system provides situational awareness, navigation, command and control, through an easy-to-use interface specifically designed to reduce the crew's work load.

Figure 8 Battle Hawk Vehicle System

1.10.8.3 Blue Force Tracking

Blue forces according to NATO military symbology represents friendly forces, since this software provides a picture of the location of friendly forces to commanders therefore it is referred to as the "Blue Force" tracker. This system uses GPS to provide locational information, other than the friendly forces this system also provides information of hostile forces. This system consists of:

i. Computer, used to display location information.
ii. Satellite terminal and satellite antenna, used to transmit location and other military data.
iii. Global Positioning System receiver (to determine its own position).
iv. Command-and-control software (to send and receive orders, and many other battlefield support functions).
v. Mapping software, usually in the form of a Geographic Information System (GIS) that plots the BFT device on a map.

The location of the host vehicle is displayed on the computer's terrain-map display, along with the locations of other platforms (friendly in blue, and enemy in red) in their respective locations by this system. BFT can also be used to send and receive text and imagery messages, and Blue Force Tracking is also capable of reporting the locations of enemy forces and other battlefield conditions (for example, the location of mine fields, battlefield obstacles, bridges that are damaged, etc.).

Figure 9 Blue Force Tracking

1.10.8.4 ERDAS Imagine and Military Applications

With the passage of time as data acquisition became better, more efficient software and techniques were developed for the analysis storage and representation of this data. Many software companies have developed dedicated systems for military uses realizing their importance in this field. Some of the frequently used imagery-based products and products derived from imagery for military applications include:

i. Basic Target Graphics (BTGs).

ii. Cross Country Mobility Maps (CCMs).

iii. Battle damage assessment (BDA) graphics.

iv. Non-combatant evacuation operations (NEO) graphics.

v. Obstacle overlays, combined obstacle overlays.

vi. Gridded Installation Photomaps.

vii. Gridded Airfield Photomaps.

viii. Drop Zone Overlays.

ix. Helicopter Landing Zone Overlays.

x. Elevations and Contours.

1.10.8.4 Rehbar Integrated Battlefield Management System (IBMS)

This system is developed for Pakistan Army, installed in tanks and used to track friendly and enemy positions similar to that of US Army's Blue Force Tracking. The Al-Sakb, Al-Khalid and Al-Zarrar tanks are being equipped with this system. It allows the vehicles to work together and plan attack and other battlefield movements, the vehicles exchange information for this purpose. IBMS uses VHF and UHF communications and each vehicle can act as a relay.

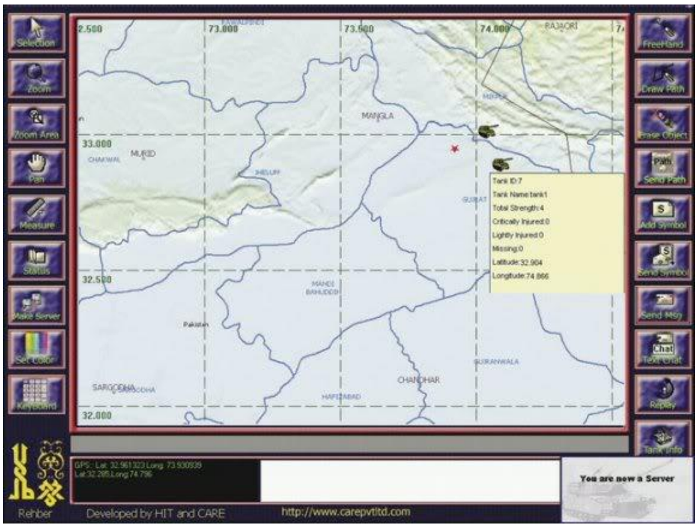

Figure 10 Rehbar IBMS

MATERIALS AND METHODS

2.1 DATA

2.1.1 Raster Data

2.1.1.1 IKONOS Satellite Imagery

Four IKONOS Multispectral images of AOI having five bands (Pan, Red, Green, Blue and Near Infrared)

Table 1 IKONOS Imagery Details

Mode	Spatial Resolution	Spectral Band Range	Date of Acquisition
Panchromatic	1 Meter	0.49 – 0.90 µm	6th December 2000
Multispectral	4 Meters	0.45 – 0.69 µm	6th December 2000
Near Infrared	4 Meters	0.76 – 0.90 µm	6th December 2000

The four images were mosaicked in order to make one combined image. The Panchromatic band of the image had a much higher spatial resolution as compared to the four multispectral bands. In order to increase the spatial resolution of the multispectral bands, the image was processed and enhanced using the Gram-Schmidt Pan Sharpening method.

Gram-Schmidt Algorithm

Gram-Schmidt Algorithms mainly works on the orthogonalization of the multi-dimensional vectors by rotation of different vectors that are not orthogonal to make them orthogonal. In case of images each band (Red, Green, Blue and NIR) corresponds to one high dimensional vector. Moreover the number of dimensions equals to the number of pixels. The weights assigned for the IKONOS Multispectral imagery were: 0.85 for Red, 0.65 for Green, 0.35 for

Blue and 0.9 for Near Infrared. These weights produce the closest image spectrally to the original image. The weights and method is prescribed by Environmental Systems Research Institute (ESRI) itself for Pan Sharpening IKONOS images.


(1)


(2)

Figure 11 IKONOS multispectral image before (1) and after (2) Pan Sharpening

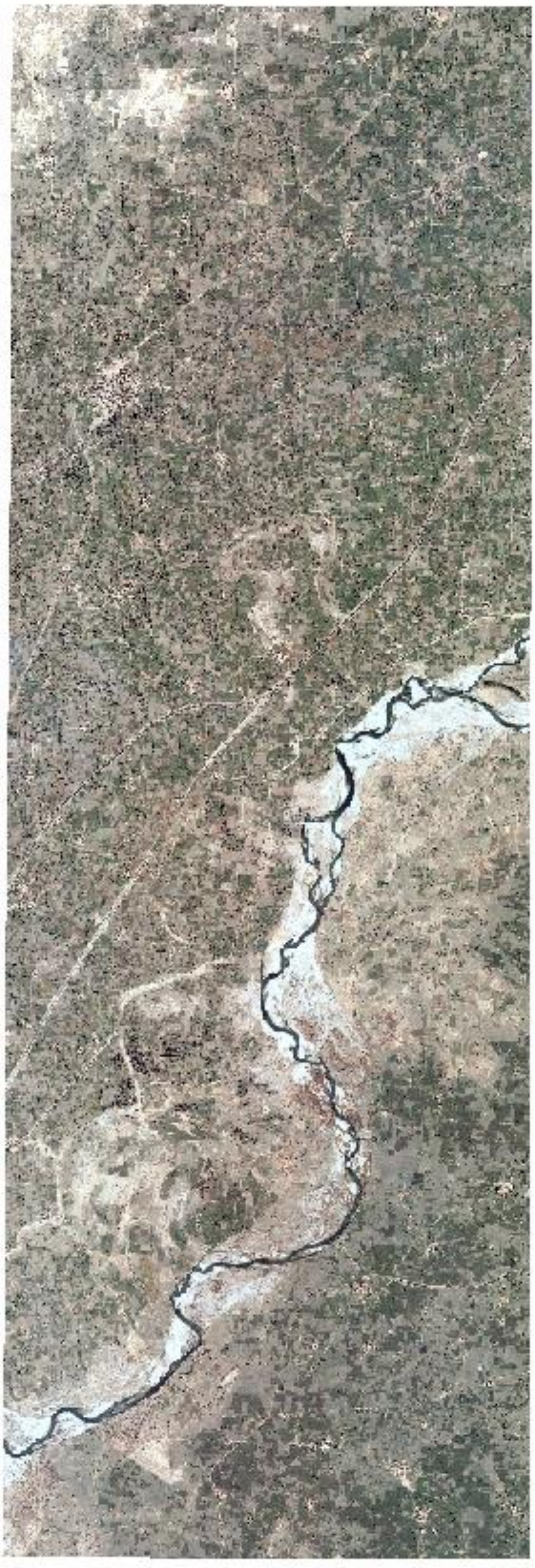

Figure 12 IKONOS Imagery

2.1.1.2 ASTER Digital Elevation Model

In order to depict the terrain of the AOI, the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) from National Aeronautics and Space Administration's (NASA) Terra Satellite was used.

Table 2 ASTER DEM Properties

Data	Spatial Resolution	Vertical Resolution
ASTER	30 Meters	20 Meters

The downloaded Aster DEM was of thirty meters resolution while the IKONOS satellite image was of one meter resolution so in order to bring the resolution of the DEM at par with the satellite image it was enhanced using Inverse Distance Weighting (IDW).

Inverse Distance Weighting (IDW)

The Inverse Distance Weighting method was used to enhance the ASTER DEM. First the DEM was converted from Raster to point, next these points were interpolated using IDW to generate a new raster of resolution one meter.

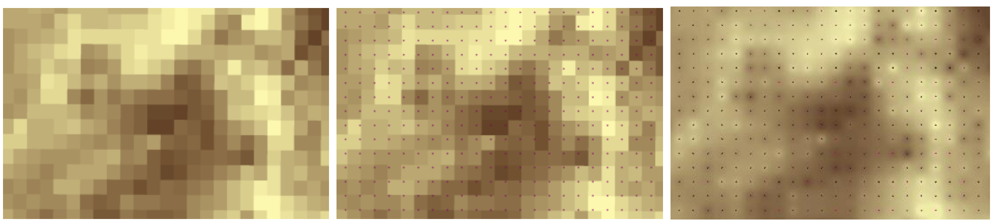

Figure 13 Enhancement of ASTER DEM

IDW basically implements the basic assumption of "the things closer together are more alike" explicitly. Hence in order to predict the unknown value it calculates the new value by assigning high weights to that points that are closer and gradually low weights to those points which basically at increasing distance from the point of interest. The choice of using IDW over other interpolation methods was because of the above reason that it takes local points into more account as compared to far away points.

By using the IDW method the output DEM was enhanced to very high horizontal accuracy, by keeping the vertical accuracy unchanged.

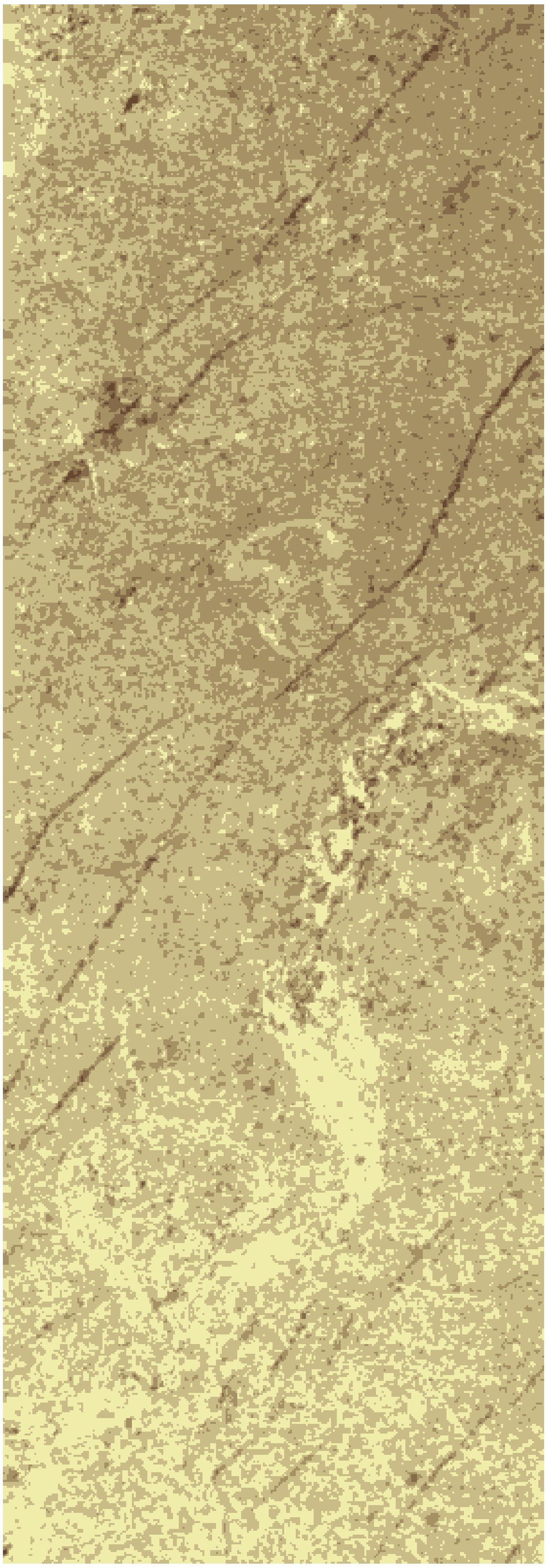

Figure 14 ASTER Enhanced Digital Elevation Model

2.1.1.3 Soil Map

Soil maps provide diverse information of soil types of the area of interest. Digital map was prepared from soil surveys inventory.

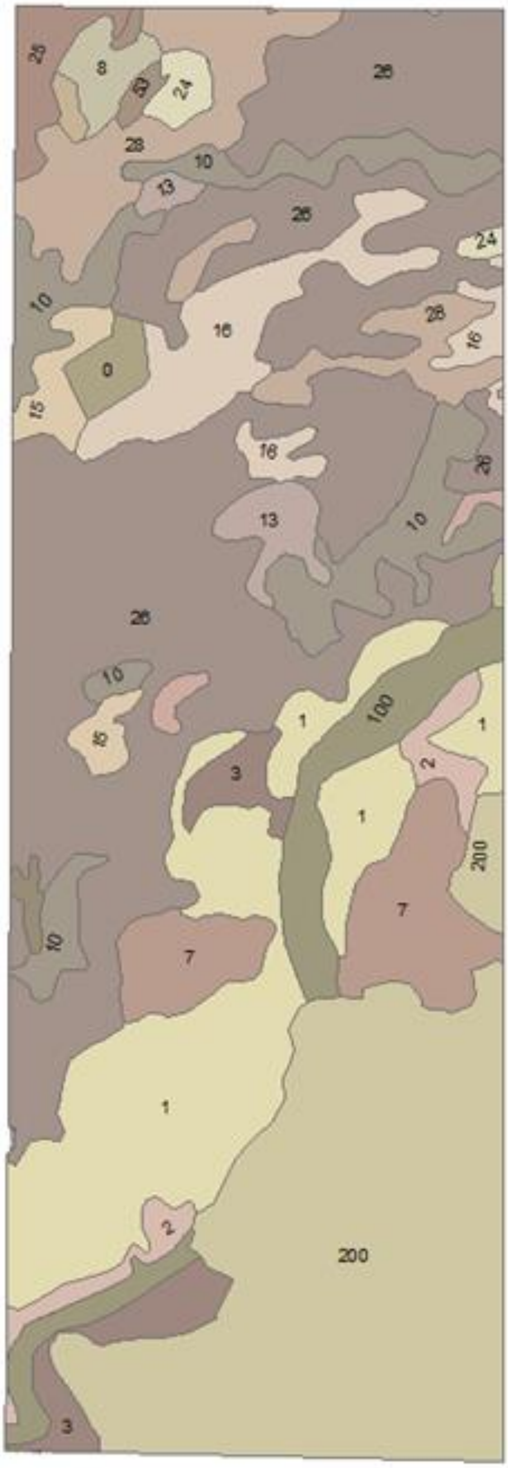

Figure 15 Soil Map

2.1.2 Vector Data

Vector data was acquired as part of geodatabase containing information about roads, hydrological features (Canals, wells, etc.), rail, settlements, vegetation (Trees, crops, etc.), points of interest (Hospitals, schools, etc.). The geodatabase comprised of two vector topographic maps of Kasur. The symbology in the geodatabase for the shapefiles was already present and as prescribed by the military it was maintained throughout the project's use of this data.

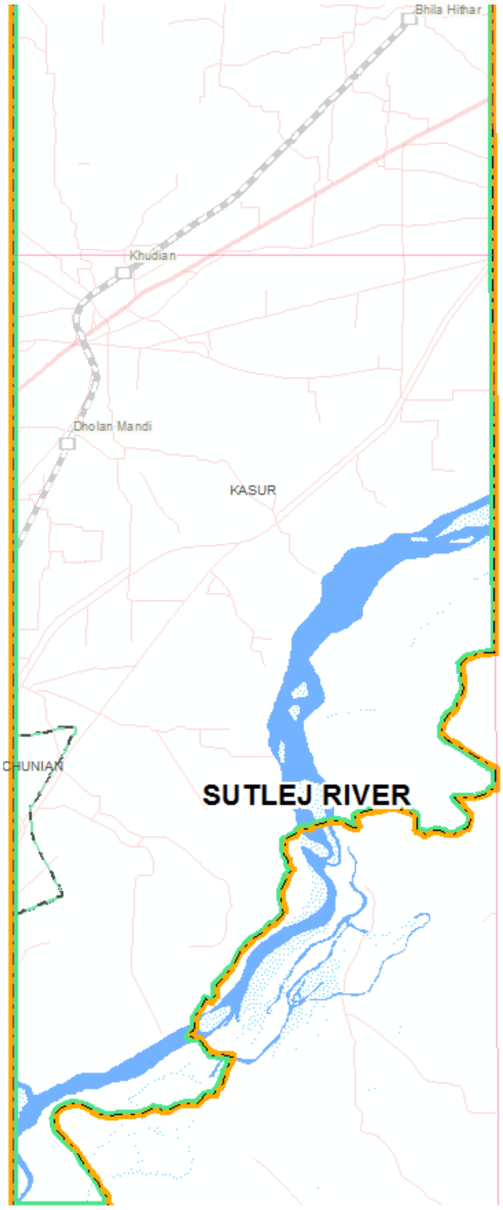

Figure 16 Vector data of AOI

2.2 DATA SOURCE

The data was acquired from multiple sources depending upon the data types. The sources of data were:

i. The satellite images were acquired by IGIS from Army Survey Group and C4I.
ii. The Aster DEM was acquired from the United States Geological Survey website.
iii. Soil Maps were acquired by IGIS from Soil Survey of Pakistan.
iv. Vector Data was acquired by IGIS from C4I.
v. Attribute data about vehicles, symbols etc. was acquired from C4I.

2.3 MAKING DATA USEFUL

The acquired data were transformed and enhanced by the previously mentioned approaches. Afterwards that data were used for generation of the more useful products for the sake of efficient decision making purposes for carrying out the operational analysis in the battlefield environments. The model used to make the data useful is shown in *Figure 17 Model for Data Creation.*

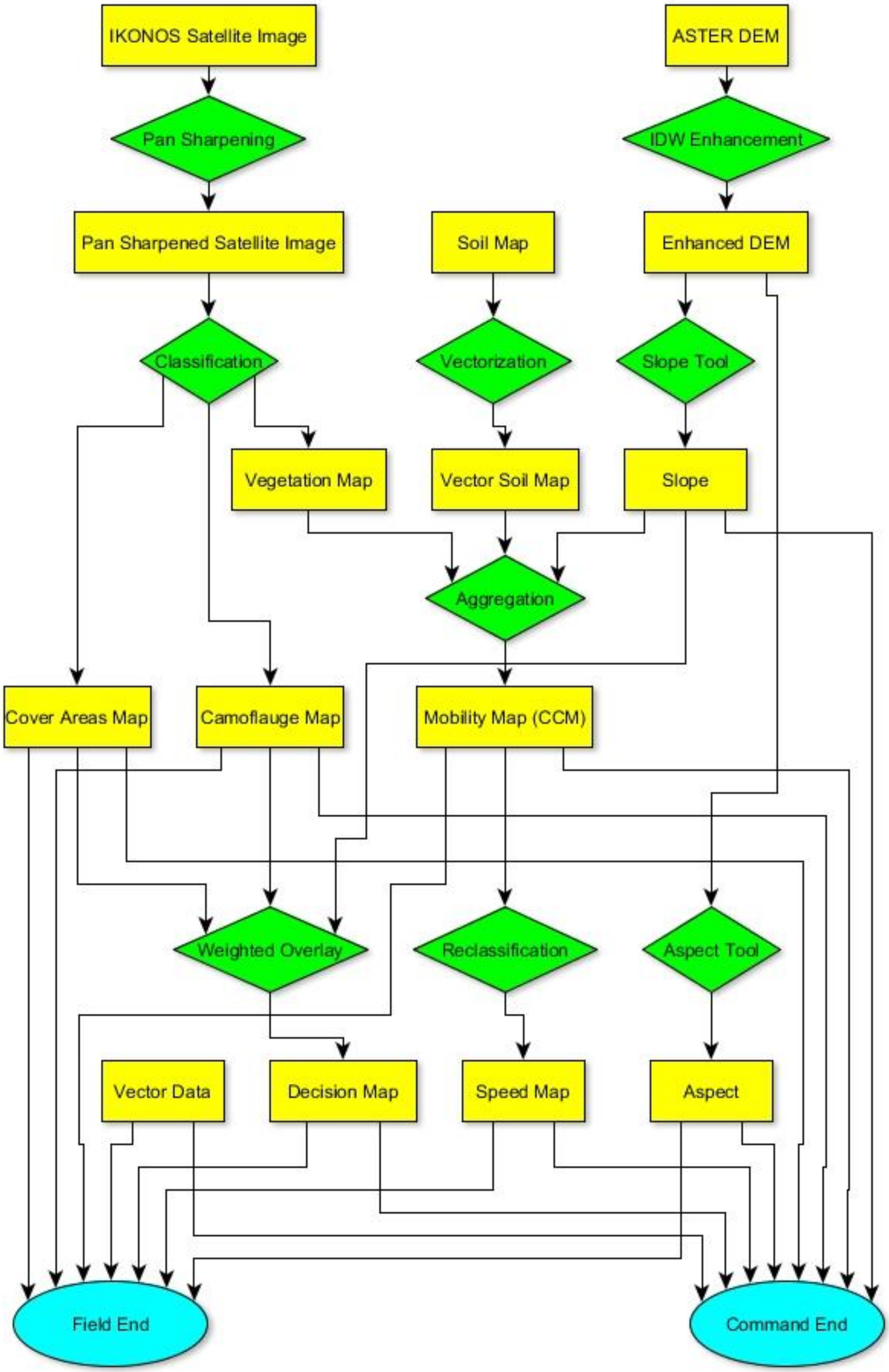

Figure 17 Model for Data Creation

In order to classify the Pan Sharpened IKONOS image, a series of spectral classes were made using signature files in ArcGIS. The spectral signatures included the following classes and were then used in the generation of decision maps as per requirement of the map itself:

i. Barren land
ii. Urban area
iii. Light vegetation
iv. Medium vegetation
v. Dense vegetation
vi. Water
vii. Marshes
viii. River alluvium /sand
ix. Crops
x. Empty fields

The generated maps for efficient decision making were the following:

2.3.1 Camouflage Map

The camouflage map shows areas where a tank can hide from the enemy i.e. camouflage itself from sight. The map has four classes which are:

i. Water
ii. No Camouflage
iii. Ground Camouflage
iv. Air Camouflage

Water and No Camouflage are self-explanatory while Ground Camouflage means that the tank is invisible to ground based reconnaissance while Air Camouflage means that the tank is invisible to aerial reconnaissance. In the model each class is assumed to be a subset in terms of attributes of its immediately inferior class i.e. all areas in Air Camouflage are automatically also part of Ground Camouflage. These information classes includes following spectral classes:

i. Water:
   a. Water
   b. Marshes
ii. No Camouflage
   a. Barren Land
   b. Light Vegetation
   c. River Alluvium/Sands
   d. Empty Fields
iii. Ground Camouflage
   a. Medium Vegetation
   b. Crops
iv. Air Camouflage
   a. Dense Vegetation
   b. Urban Area

The classification result is shown in *Figure 18 Camouflage Map.*

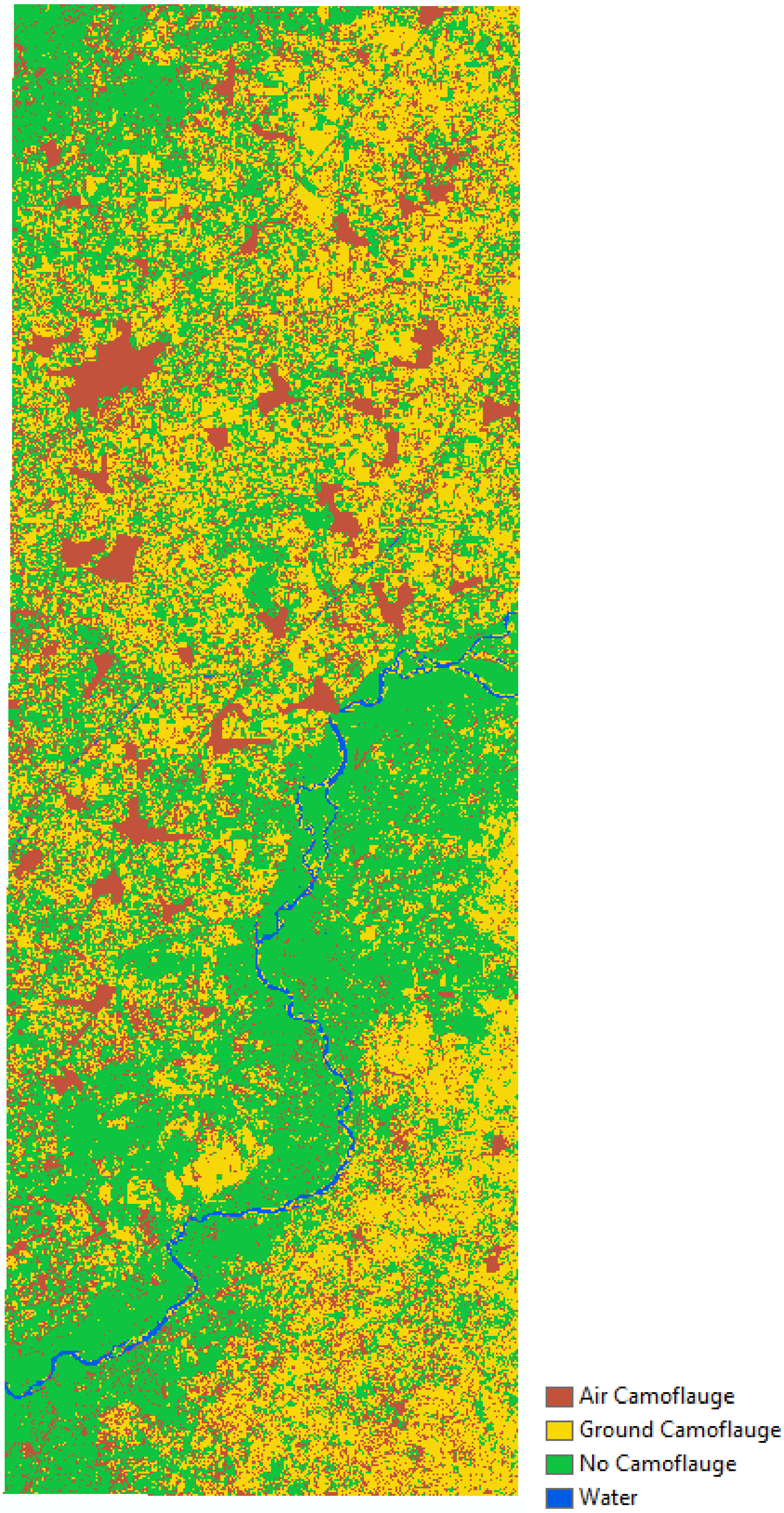

Figure 18 Camouflage Map

2.3.2 Cover from fire Map

The cover from fire map shows areas where a tank can take cover from enemy fire i.e. protect itself from bullets, anti-tank, artillery, etc. fire. The map has four classes which are:

i. Water
ii. No Cover
iii. Light Cover
iv. Heavy Cover

Water and No Cover are self-explanatory while Light Cover means that the tank is protected from small arms fire while heavy cover means that the tank is protected from anti-tank and artillery fire. In the model each class is assumed to be a subset in terms of attributes of its immediately inferior class i.e. all areas in Heavy Cover are automatically also part of Light Cover. The spectral signatures included in each class were as follows:

i. Water:
   a. Water
   b. Marshes
ii. No Cover
   a. Barren Land
   b. Light Vegetation
   c. River Alluvium/Sands
   d. Empty Fields
   e. Crops
iii. Light Cover
   a. Medium Vegetation

iv. Heavy Cover

a. Dense Vegetation

b. Urban Area

The classification result is shown in *Figure 19 Cover from Fire Map*.

Figure 19 Cover from Fire Map

2.3.3 Slope Map

The slope map shows the slope extracted from the enhanced ASTER DEM. The slope is classified according to its effect on a tank's mobility. Documents on tank specifications state that a tank can handle slopes of up to 45°. Keeping this is mind, the generated map was given the following classes:

i. No Slope (0° – 5°)
ii. Very Mild Slope (5° – 10°)
iii. Mild Slope (10° – 20°)
iv. Small Slope (20° – 45°)

The result of the slope tool after the above classification is shown in Figure *20* Slope Map.

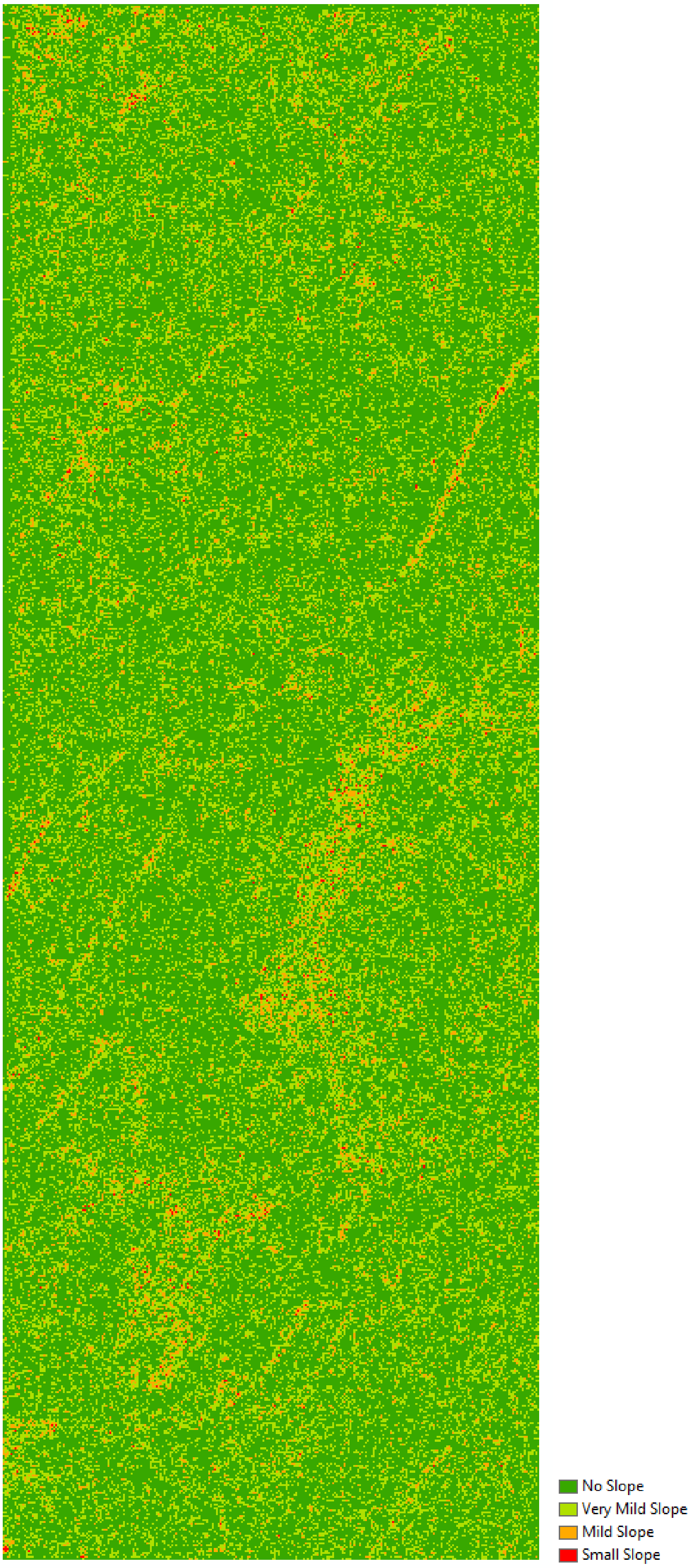

Figure 20 Slope Map

2.3.4 Aspect Map

The aspect map provides information about the way the slope faces. Its classes are related to all the eight directions like North, South, North-East, etc. The aspect map is shown in Figure *21* Aspect Map (Degrees).

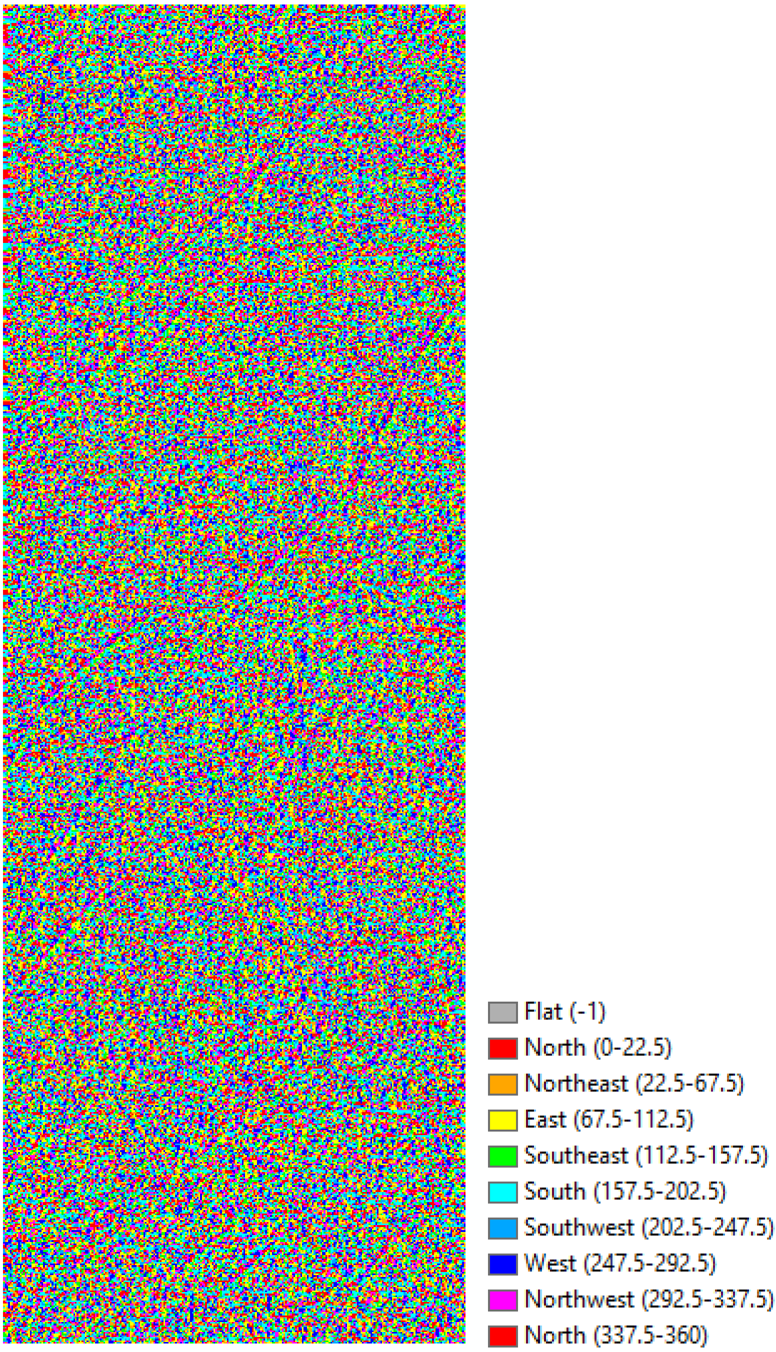

Figure 21 Aspect Map (Degrees)

2.3.5 Cross Country Mobility Map (CCM)

The Cross Country Mobility (CCM) Map depicts the cost of manoeuvrability of the vehicles (Tanks) on open terrain. Cross country mobility maps are generated by assigning costs to different maps like soil, slope and vegetation. These maps are then aggregated to produce a total CCM Map which can be classified according to vehicle type using set of standards.

The Cost values assigned to the Soil Map are:

Table 3 Mobility Cost of Soil

Soil Class	Mobility Cost
Alluvial Deposits	200
Silty Riverine Deposits	180
Clayey Deposits	180
Silty Loam High Water Table	140
Silty Loam Low Water Table	60
Silty Loam Medium Water Table	100
Silty Loam	80
Silty Clayey Loam	60

The Cost values assigned to Vegetation Map are:

Table 4 Mobility Cost of Vegetation

Vegetation Class	Mobility Cost
Grass Lands	10
Desert Shrubs	20
Wood Land (Less Dense Forest)	100
Dense Forest	2500
Water Body	5000

The Cost values assigned to Slope Map are:

Table 5 Mobility Cost of Slope

Slope (Degrees)	Mobility Cost
0 – 3	10
4 – 6	11
7 – 10	12
11 – 15	13
16 – 20	14
21 – 25	16
26 – 30	22
31, 32, 33, 34, 35 and 36	23, 24, 25, 26, 27 and 29
37, 38, 39, 40, 41 and 42	30, 32, 35, 37, 40 and 43
43 and 44	47 and 52

The above maps were aggregated according to the CCM cost and a CCM map was produced which had a lot of salt noise (white pixels) in it. These were removed using the raster calculator with a mean filter. Once the noise was removed using the mean filter the raster was classified into the following classes according to standard criteria defined by US Army Field Manual 5-33:

Table 6 CCM Classification

CCM Class	CCM Cost
Go	< 150
Go Slow	150 – 250
No Go	> 250

The resulting CCM Map is shown in Figure *22* Cross Country Mobility Map.

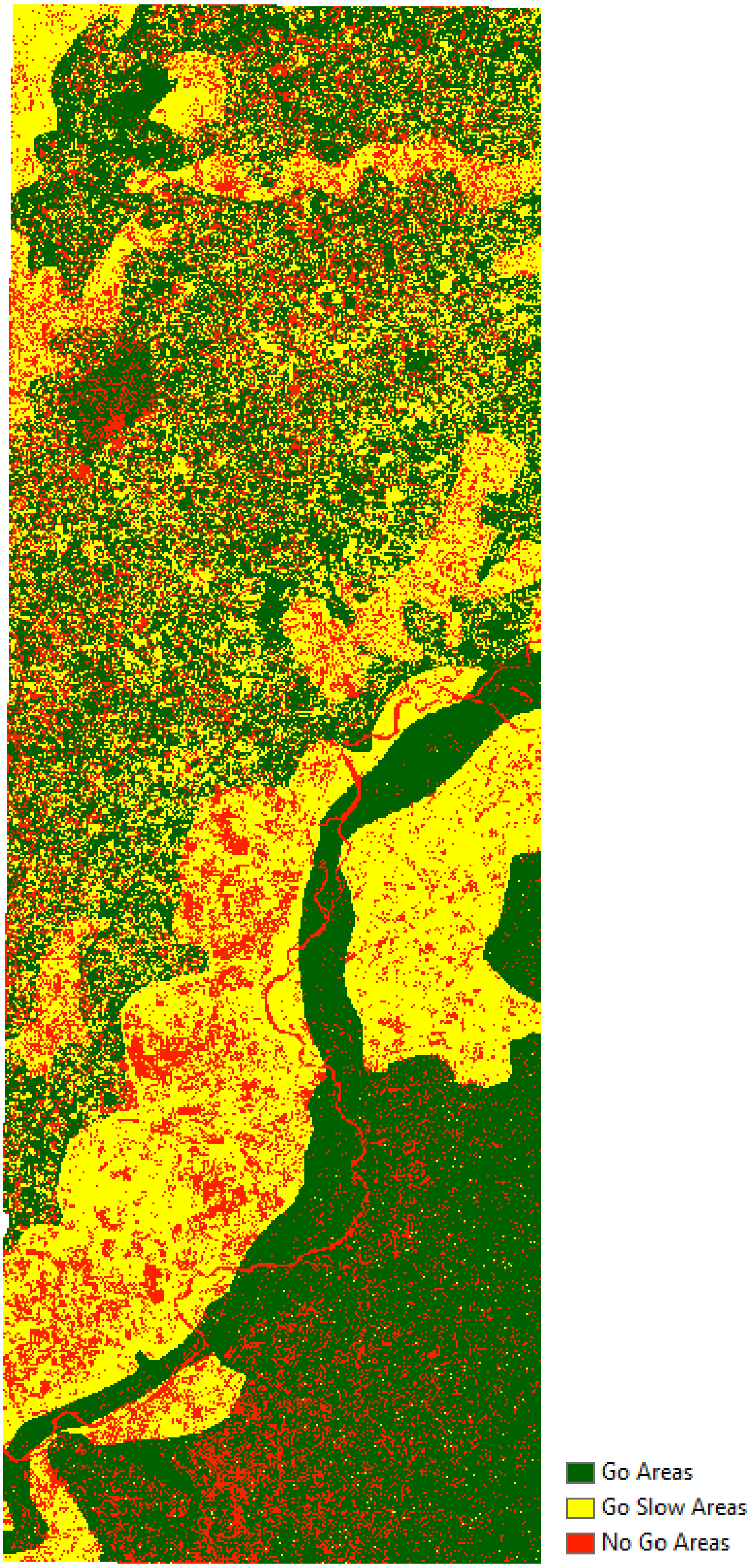

Figure 22 Cross Country Mobility Map

2.3.6 Speed Map

The Mobility Map is designed using the CCM Map i.e. the Mobility Cost values are used to compute the possible maximum speed a vehicle can achieve over the terrain. The speed map in the project shows the optimal maximum speed that the tank Al-Khalid can achieve over a certain type of terrain. Al-Khalid has a maximum on ground speed of 65 Kilometres per Hour. This maximum speed is hampered by mobility cost factors and this aspect can be categorized according to the CCM Cost.

Table 7 CCM to Speed Relationship

Mobility Cost	**Optimum Speed**
Below 50	60 km/h
Between 50 and 150	50 km/h
Between 150-250	30 km/h
Above 250	0 km/h

The Mobility Map is reclassified according to the above optimum speed values and the map produced is shown in Figure *23* Speed Map.

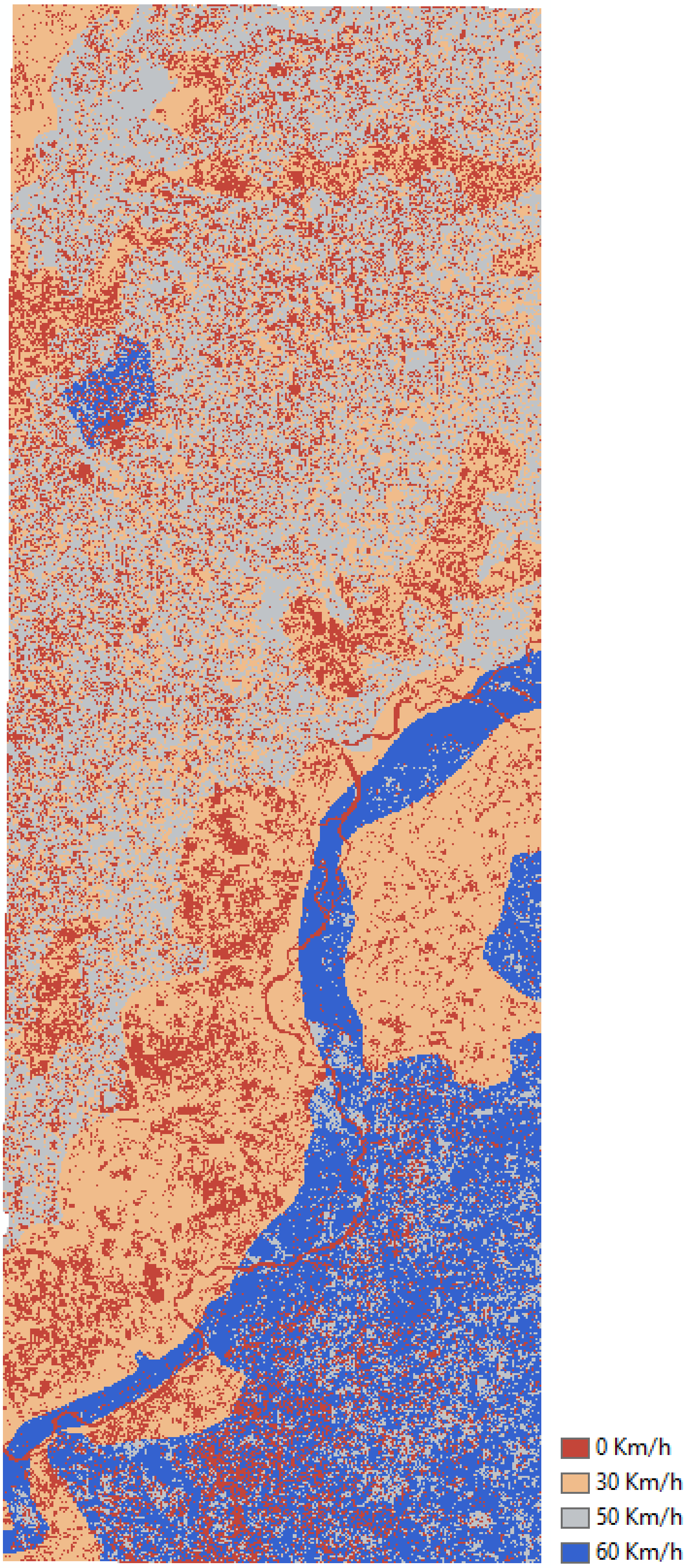

Figure 23 Speed Map

2.4 MAP CACHING

Map caching effectively makes the maps of ArcGIS Server to run faster. A map cache draws the entire map at various scales and stores the copies of map images.

2.4.1 Map Tile Caching

Map tile caching is a form of Map caching for Raster data. Map tile caching generates tile from the map document and package them to create a compressed document of Tiled Package (.tpk) file format.

2.4.2 Map Packages

Map Packages supports tile/map caching for vector data resulting into generation of a single compressed file of Map Package (.mpk) format.

Map Caching was used in the application in order to improve the speed of map displaying, panning and zooming in the application.

2.5 DATA LIMITATIONS

Following were some limitations in the data:

i. Traffic-ability maps for the Area of Interest could not be acquired being classified in nature.
ii. Certain classes in classification would mix and had to be manually differentiated.
iii. Military symbology was used and hence limited to what could be changed to better show in the application.

2.6 LOGICAL DISTRIBUTION

The logical distribution of the project components is shown in Figure *24* Project Components Logical Distribution.

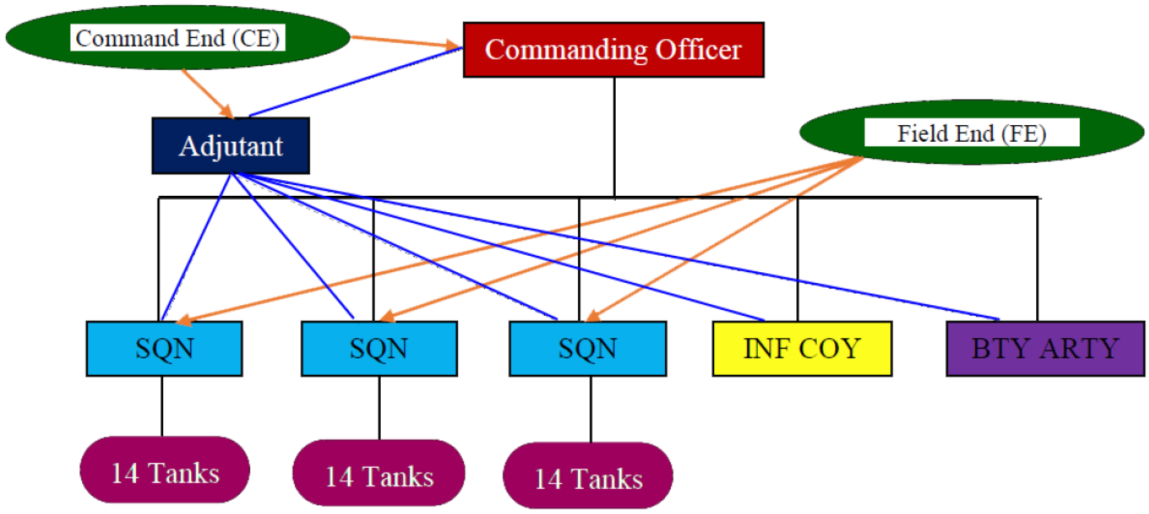

Figure 24 Project Components Logical Distribution

2.7 PHYSICAL DISTRIBUTION

The physical distribution of the project is shown in the figure below:

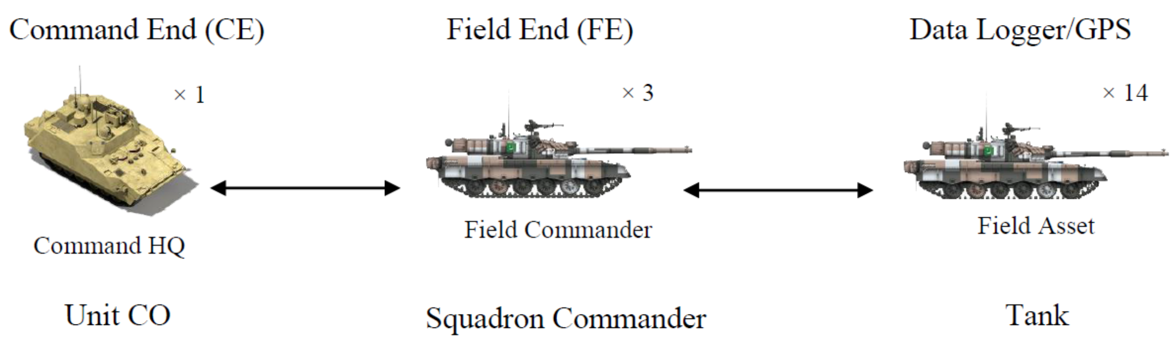

Figure 25 Project Components Physical Distribution

2.8 ANALYTICAL FRAMEWORK

2.8.1 Software Used in Development

The Software's technical details can be summarized as the application of geo-technologies either as prebuilt software Application Programming Interfaces (API's) or development environments along with their application in software design and coding programs i.e. Compilers. The software used in the making of the application includes:

i. ArcGIS
ii. ArcGIS Server
iii. Visual Studio
iv. Windows Presentation Foundation (WPF)
v. ArcGIS Runtime for WPF
vi. .NET 4.5 Framework
vii. C#
viii. Arduino Integrated Development Environment

2.8.2 Hardware

The hardware for the application is designed and prototyped in order to facilitate the development of data and hosting of the application. The hardware is chosen to provide the best possible solutions which exist to the requirements of the application and data creation.

2.8.2.1 Arduino

Arduino is a single-board microcontroller. It is a complete hardware and software package which is used as a prototyping platform. In Arduino, a variety of sensor can be used to get different input values from the environment.

Arduino can be used to develop interactive objects, taking inputs from a variety of switches or sensors, and controlling a variety of lights, motors, and other physical outputs. Arduino projects can be stand-alone, or they can communicate with software running on a computer (e.g. Flash, Processing, MaxMSP.)

Arduino Hardware:

i. Arduino Nano (Micro-Controller)
ii. RF 24 Radio (Communicate Between F.E and C.E)
iii. Global Positioning System Receiver (Positioning)
iv. Compass (Orientation)
v. Inertia Measurement Unit (IMU) (Acceleration)

Figure 26 Arduino Components

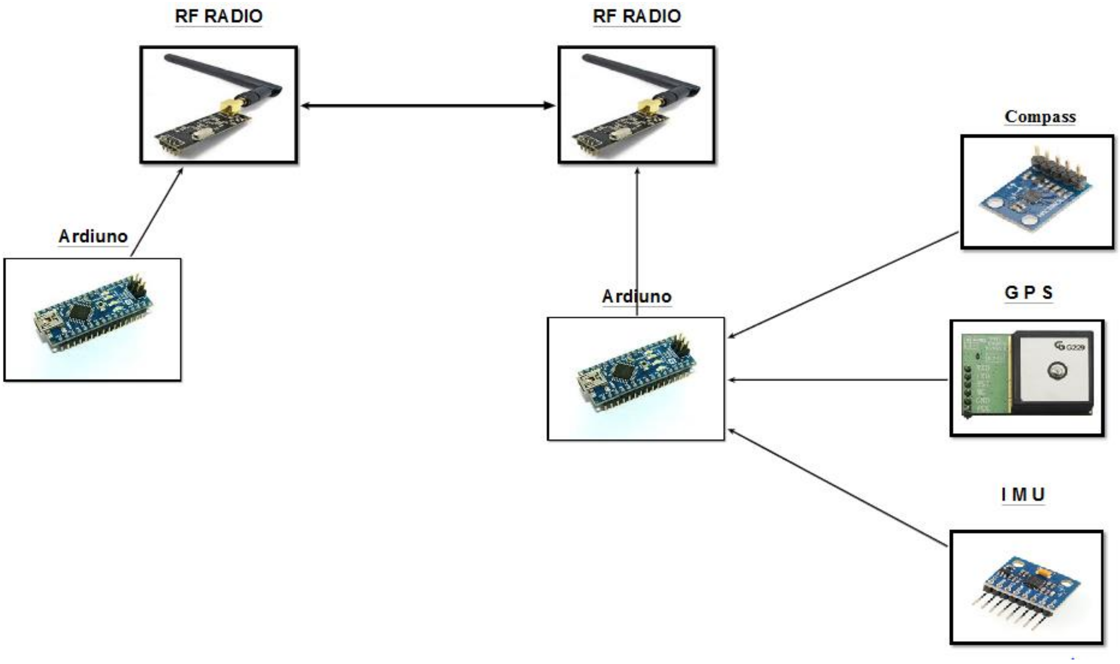

Figure 27 Flow Chart of Arduino use in Project

2.8.2.2 Field End

The hardware for the Field End (F.E) although was not acquired in the project but it was emulated on another computer. The proposed hardware though is any windows based tablet which has sufficient computation and graphical power to handle the Field End software.

2.8.2.3 Command End

The hardware for the Command End (C.E) was acquired and prototyped to provide the best computational and graphical power for the development of data and the running of a graphic intensive application, especially when it came to power three monitors. The hardware is listed below:

i. EVGA GeForce GTX 780 Ti Dual Classified Graphics Card

ii. Intel Core i7-4770K Processor

iii. Sabertooth TUF Z87 Motherboard

iv. 1200W Power Supply

v. 16GB (2x8GB) RAM

vi. 1 TB Hard Drive

vii. 120 GB Solid State Drive

2.8.3 Developed Software

The software developed for all three modules of the application was not only built to be efficient in what it was currently being used for but was also built in such a way as to allow for future improvement and expansion. The Languages, Application Programming Interfaces (API's) and Software Development Kits used in the making of the applications at each module or level are chosen in the project because they are proprietary and would not lose the developmental backing of their parent or hosting organization. The applications are designed to be expanded, changed and altered without losing their working ability.

2.8.3.1 Arduino

The Arduino software was developed in order to show the capabilities of the micro-controller in the GIS field. The software uses the sensors to provide information about the latitude, longitude, date, time, speed, heading and acceleration.

```
Serial.begin(9600);
Serial.println("Sats HDOP Latitude  Longitude  Fix  Date       Time     Date Alt    Course Speed Card  Acceleration  Heading  Chars Sentences Checksum");
Serial.println("          (deg)     (deg)      Age                      Age  (m)    --- from GPS ----  (g)           (o)      RX    RX        Fail");
Serial.println("-------------------------------------------------------------------------------------------------------------------------------------");
```

Figure 28 Information from the Arduino

2.8.3.2 Field End (F.E)

The software in the field end is designed to be used inside a tank with a touch enabled device. The software is simple in implementation, easy to use and contains basic functionalities. The purpose of this software is to provide the Field Commander the ability to communicate with the Commander, receive his orders and use the maps etc. to maneuver in the battlefield.

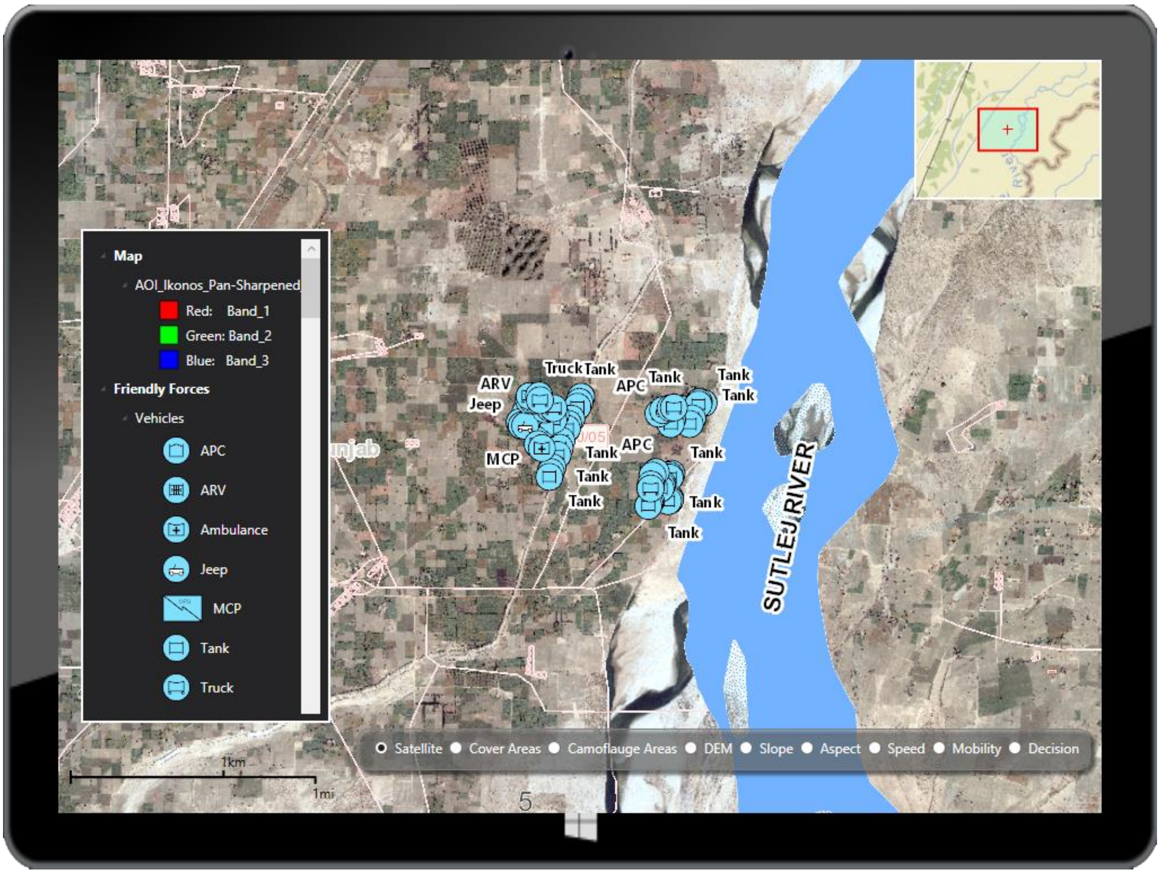

Figure 29 Field End (F.E)

2.8.3.3 Command End (F.E) (JÄGER)

The Command End (C.E) is designed to be a workstation, its purpose is to serve as a central point in the complete command distribution. The software for the Command End is called "JÄGER" meaning hunter in German and it features advanced GIS and Geospatial functionalities in order to facilitate the commander in making informed decisions. It allows the commander to review his under command assets, plan for battles, send orders and view information related to the battlefield, friendly and enemy forces. The software has multiple views and has been built keeping in mind further extension of its features and uses. Also the software is designed with concepts of Human Computer Interaction (HCI) and Usability Engineering (UE).

Figure 30 JÄGER Logo

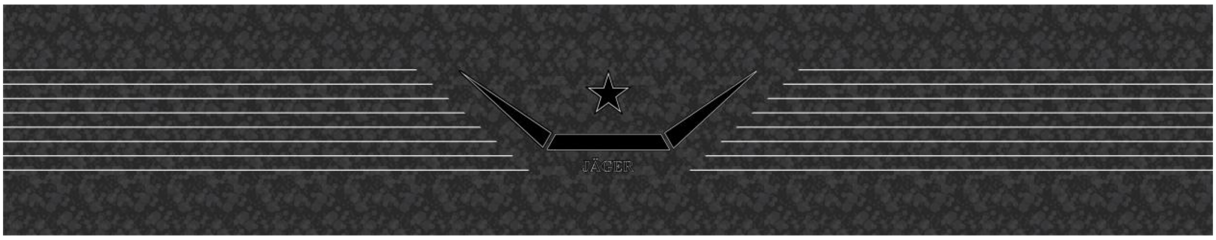

Figure 31 JÄGER Splash Screen

Figure 32 Main View of JÄGER

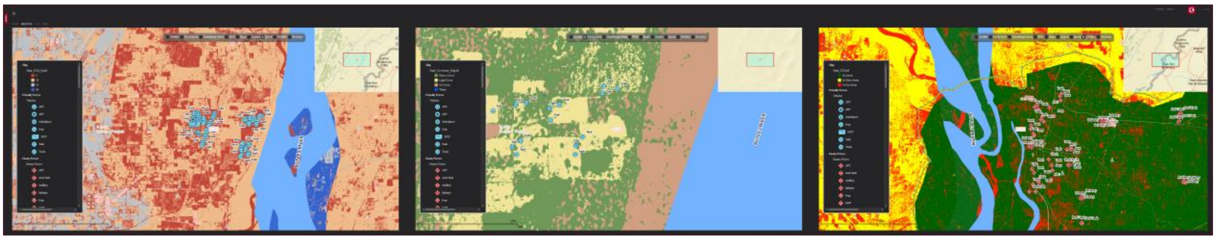

Figure 33 Multiple View of JÄGER

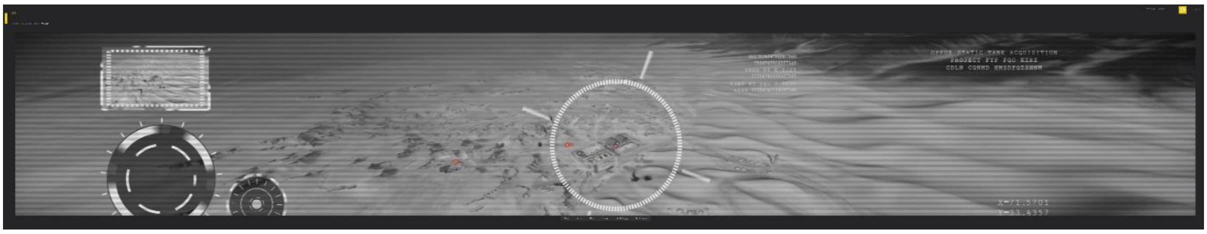

Figure 34 Video View of JÄGER

Figure 35 Themes and Settings View of JÄGER

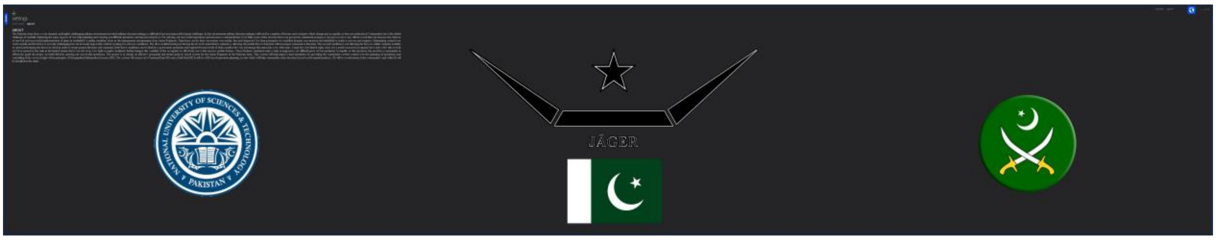

Figure 36 About Page View of JÄGER

Larger images of the software are provided in the appendices. JÄGER features include multiple types of controls including:

i. Pan, Zoom, Orientation Tool
ii. Dynamic Legend
iii. Map Switcher
iv. Dynamic Scale Line
v. Bookmarks
vi. Mini Map
vii. Draw Tool
viii. Attribute Table
ix. Map Point Coordinates

x. Map Tips

xi. Spot Tool

RESULTS AND DISCUSSION

3.1 DATA

Armies usually have an increased quality of data as compared to civilian sources and this proved to be an immense benefit for the project. The data produced as part of the project were also of great quality because it was well maintained by the army under standards and specifications.

3.2 HARDWARE

The hardware proved to be one of the greatest assets of the project both in the development of data and hosting of the application. Since the hardware was extremely powerful it reduced the computation time for a lot of data development processes e.g. a map caching process would take four to ten hours on a normal computer while it took only forty minutes on the Command End. Since the Command End has three displays which provide optimal coverage and increased visual estate, the hardware was very important in ensuring smooth graphics and display.

The Arduino hardware also exceeded expectations with very accurate results from the GPS, IMU and Compass. This provided us with accurate location, speed, acceleration and heading readings. The RF 24 Radio modules were also quite capable in handling data transfer but were limited by range and obstacles.

3.3 SOFTWARE

The two softwares developed in the Command End and Field End are very powerful. They are desktop based software running on the machine itself rather than on a browser. The software features the capability to incorporate all future developments and since they have been made using proprietary languages and API’s, they have the capacity for continuous future development potential. The software are open to all future development in multiple programming languages and can be developed and matured over time not only by future graduating batches but also by military organizations like C4I.

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSION

The project addresses a very important and real problem that exists in the Pakistan Army today, i.e. the Operational Management, planning and execution of a large, mobile, dispersed and modern armor fighting force. This problem though not unique to the Pakistan Army; as it is being faced by all modern armies of the world, has become unique given the nature of the task in the scenarios that the army faces in current times.

It is important that such a system not only be built indigenously but also should focus on the core requirements of the Pakistani Army and build its functionalities accordingly. The Military Geographic Information System (MGIS) must cater to long term objectives more than inconsequential short term objectives if its utilization is to be optimized based on the Modern Warfare and Future War doctrines. The system must gradually become more and more complex in its abilities in order to support the multiple possibilities that a commander and his subordinates may face in the future battlefields. These technologically more sophisticated and dynamic decentralized systems require a coherent integration of the principles of Geographical Information Sciences and Geospatial technologies. The Pakistan Army must be reconciled with both the requirements of administrative and logistical functions and the state of technology. The Army must adapt to the changing environments of the times and as per the need of the current time the Army must step into the digital battlefield of the future.

Specialization of equipment and talent plays a more important role because the nature of war and technology has changed. Without change in the context of the age and a long term view of the dynamics of Command and Control, it is unlikely that we will remain a force to be reckoned with in the world.

If for no other reason than the good of the Army and the security of the Nation, the Pakistan Army needs this form of a System.

4.2 RECOMMENDATIONS

A project of this magnitude requires be developing and maturing over time. The development team recommends that this project be continued with future graduating batches so that it can be expanded in scope and implementation. The Desktop application is developed using the proprietary languages of Microsoft (.NET, C#) which have the capacity to incorporate infinite set of potential capabilities utilizing the SDK's for ArcGIS, windows and .NET. The framework created as a result of this application development has the capability to incorporate any future developments. As the application is designed to be expanded upon future batches, it can incorporate new GIS tools, methods and implementations into the project. Some areas of research and future development in the project can be:

i. Implementation of more Geoprocessing tools and methods into the existing project for better information gain for the users.
ii. Implementation of 3D visualization.
iii. Implementation of Artificial intelligence and Intelligent systems in the project.
iv. Implementation of project in other domains within the armed forces and externally such as law enforcement, health, education, disaster management, business, etc.
v. Incorporation of other modules, sensors and hardware into the project.

The project has an immense capability to incorporate future development and it would be a real waste of its potential not to develop it further. The project can also be improved further by the involvement of individuals from other development domains i.e. domains other than GIS. This will bring together the diverse knowledge group that is required for the development of such projects.

4.3 APPLICATIONS

The project has the capability to be implemented quite easily in domains other than the military. These domains can include but are not limited to:

i. Law Enforcement
ii. Fire Fighting
iii. Disaster Management
iv. Telecommunication Companies
v. Mineral Resource Companies
vi. Mining
vii. Health
viii. Education
ix. Election Information and Management
x. Agriculture
xi. Businesses
xii. Transportation
xiii. Fleet Management
xiv. Electricity

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APPENDICES

ARDUINO:

Arduino has several types, depending upon the use. We used Arduino Nano in our project. It has the following specifications:

Specifications:

Microcontroller: Atmel ATmega168 or ATmega328

Operating Voltage: (logic level) 5 V

Input Voltage : (recommended) 7-12 V

Input Voltage : 6-20 V

Digital I/O Pins : 14 (of which 6 provide PWM output)

Analog Input Pins : 8

DC Current per I/O Pin : 40 mA

Flash Memory : 16 KB (ATmega168) or 32 KB (ATmega328) of which 2 KB used by bootloader

SRAM : 1 KB (ATmega168) or 2 KB (ATmega328)

EEPROM : 512 bytes (ATmega168) or 1 KB (ATmega328)

Clock Speed : 16 MHz

Dimensions : 0.73" x 1.70"

RF 24 Radio:

RF radio was used for wireless communication to transmit the reading from field end to command end. It has a pair of transmitter and a receiver. The nRF24L01 is a highly integrated, ultra-low power (ULP) 2Mbps RF transceiver IC for the 2.4GHz ISM (Industrial, Scientific and Medical) band. With peak RX/TX currents lower than 14mA, a sub μA power down mode, advanced power management, and a 1.9 to 3.6V supply range, the nRF24L01 provides a true ULP solution enabling months to years of battery lifetime when running on coin cells or AA/AAA batteries.

The nRF24L01 integrates a complete 2.4GHz RF transceiver, RF synthesizer, and baseband logic including the Enhanced ShockBurst™ hardware protocol accelerator supporting a high-speed SPI interface for the application controller. No external loop filter, resonators, or VCO varactor diodes are required, only a low cost ±60ppm crystal, matching circuitry, and antenna.

Specifications:

Low cost single-chip 2.4GHz GFSK RF transceiver IC

Worldwide license-free 2.4GHz ISM band operation

1Mbps and 2Mbps on-air data-rate

Enhanced ShockBurst™ hardware protocol accelerator

Ultra low power consumption – months to years of battery lifetime

On-air compatible with all Nordic nRF24L Series in 1 and 2Mbps mode

On-air compatible with Nordic nRF24E and nRF240 Series in 1Mbps mode

GPS:

The SKM53 GPS module Starter Kit (SKGPS-53) is a special designed starter kit which offer convenient yet safer GPS module for user. Power for SKGPS-53 should be from 5V of UART pin. UART communication is provided for user to interface this starter kit to PC/laptop or microcontroller. The SKM53 Series with embedded GPS antenna enables high performance navigation in the most stringent applications and solid fix even in harsh GPS visibility environments. It is based on the high performance features of the MediaTek 3329 single-chip architecture. It is -165dBm tracking sensitivity extends positioning coverage into place like urban canyons and dense foliage environment where the GPS was not possible before.

The 4-pin and 6-pin UART connector design is the easiest and convenient solution to be embedded in a portable device and receiver like PND, GPS mouse, car holder, personal locator, speed camera detector and vehicle locator.

Specifications:

Ready pin for UART interface, TTL 5V.

Ultra high sensitivity: -165dBm

22 tracking/66 acquisition-channel receiver

WAAS/EGNOS/MSAS/GAGAN support

NMEA protocols (default speed: 9600bps)

Internal back-up battery

One serial port

Embedded patch antenna 18.2 x 18.2 x 4.0 mm

Operating temperature range: -40 to 85℃

Compass:

GY-273 HMC5883L Module Triple Axis Compass Magnetometer Sensor is based on the Honeywell HMC5883L IC for low-field magnetic sensing with a digital interface for applications such as low cost compassing and magnetometry. The HMC5883L includes state-of the art, high-resolution HMC118X series magneto-resistive sensors plus an ASIC containing amplification, automatic degaussing strap drivers, offset cancellation, and a 12-bit ADC that enables 1° to 2° compass heading accuracy. The I2C serial bus allows for easy interface.

The HMC5883L utilizes Honeywell's Anisotropic Magnetoresistive (AMR) technology that provides advantages over other magnetic sensor technologies. These anisotropic, directional sensors feature precision in-axis sensitivity and linearity. These sensors' solid-state construction with very low cross-axis sensitivity is designed to measure both the direction and the magnitude of Earth's magnetic fields, from milli-gauss to 8 gauss. Honeywell's Magnetic Sensors are among the most sensitive and reliable low-field sensors in the industry.

Specifications:

HMC5883L module (three-axis magnetic field module)

Model: GY-273

IC: HMC5883L

Module Power supply : 3-5v

Communication: IIC communication protocol

Measuring range: ± 1.3-8 gauss

Size: 13.9 * 18.5

Inertia Measurement Unit:

The MPU-6050 is a little piece of motion processing technology. By combining a MEMS 3-axis gyroscope and a 3-axis accelerometer on the same silicon die together with an onboard Digital Motion Processor™ (DMP™) capable of processing complex 9-axis MotionFusion algorithms, the MPU-6050 does away with the cross-axis alignment problems that can creep up on discrete parts.

Specifications:

I2C Digital-output of 6 or 9-axis MotionFusion data in rotation matrix, quaternion, Euler Angle, or raw data format

Input Voltage: 2.3 - 5V

Selectable Solder Jumpers on CLK, FSYNC and AD0

Tri-Axis angular rate sensor (gyro) with a sensitivity up to 131 LSBs/dps and a full-scale range of ±250, ±500, ±1000, and ±2000dps

Tri-Axis accelerometer with a programmable full scale range of ±2g, ±4g, ±8g and ±16g

Digital Motion Processing™ (DMP™) engine offloads complex MotionFusion, sensor timing synchronization and gesture detection

Embedded algorithms for run-time bias and compass calibration.

COMMAND END PHYSICAL COMPONENTS:

i. EVGA GeForce GTX 780 Ti Dual Classified w/ EVGA ACX Cooler:

This is the graphics card of the Command End. It has the following features:

- 1020 Mhz Base Clock
- 1085 Mhz Boost Clock
- 244.8 GT/s Texture Fill Rate
- 3 Gb DDR5 Memory
- 7000 Mhz Memory Clock
- 336 Gb/s Memory Bandwidth

ii. Intel® Core™ i7-4770K Processor (8M Cache, up to 3.90 GHz) (64-Bit):

This is the Core Processing Unit (CPU) of the Command End. It has the following features:

- 4 Ghz Processing Power
- 4-Core (8-Logical Cores Hyper threading)
- LGA 1150 Socket

iii. Sabertooth TUF Intel® Z87 motherboard:

This is the motherboard of the Command End (CE). It has the following features:

- Z87 Motherboard
- 2 PCIe Slots in (16x or 8x8)
- 4 Memory DIMMS with up to 32 Gb Support.
- Supportive Thermal Armor front and back Plate to cater for high stress, heat and dust environments

iv. Cooler Master Silent Pro Gold 1200W 80 PLUS Gold Power Supply:

This is the power supply of the Command End (CE). It has the following features:

- 80+ Gold Power Supply
- Modular Cables
- 1200 Watts Maximum Power Delivery

v. Corsair Vengeance 16GB (2x8GB) RAM:

This is the Random Access Memory (RAM) of the Command End (CE). It has the following features:

- 1866 Mhz
- 16 Gb Size
- DDR3

vi. Western Digital WD1002FAEX Caviar Black:

This is the Mechanical Hard drive of the Command End (CE). It has the following features:

- 1 Tb Size
- SATA III
- 7200 RPM
- 64 MB Cache

vii. Samsung 840 EVO Solid State Drive:

This is the Solid State Drive (SSD) of the Command End. It has the following features:

- 120 Gb Size
- 6 Gb/s Transfer

viii. NZXT Technologies KRAKEN X40 Premium:

This is one of the two liquid cooling radiators of the Command End (CE). It has the following features:

- 140MM Size
- Ultra Performance Liquid Cooler

ix. NZXT Technologies KRAKEN X60 Premium:

This is one of the two liquid cooling radiators of the Command End (CE). It has the following features:

- 280MM Size
- Ultra Performance Liquid Cooler

x. NZXT Technologies Computer Case H630:

This is the case for the Command End (CE). It has the following features:

- Ultra Tower.
- All Steel Construction.
- Silent.
- Dust Proof.
- Strong.

SOFTWARE:

ArcGIS:

Esri's ArcGIS is a geographic information system (GIS) for working with maps and geographic information. It is used for creating and using maps; compiling geographic data; analyzing mapped information, sharing and discovering geographic information; using maps and geographic information in a range of applications; and managing geographic information in a database.

ArcGIS Server:

ArcGIS Server provides the fine-grain control needed to provide secure, reliable GIS services to every web, mobile, and desktop application.

Visual Studio:

Microsoft Visual Studio is an integrated development environment (IDE) from Microsoft. It is used to develop computer programs for Microsoft Windows superfamily of operating systems, as well as web sites, web applications and web services.

Windows Presentation Foundation (WPF):

Windows Presentation Foundation (or WPF) is a graphical subsystem for rendering user interfaces in Windows-based applications by Microsoft.

ArcGIS Runtime for WPF:

The ArcGIS API for WPF enables you to create rich desktop applications that utilize the powerful mapping, geocoding, and geo-processing capabilities provided by ArcGIS Server and Bing™ services.

.NET 4.5 Framework:

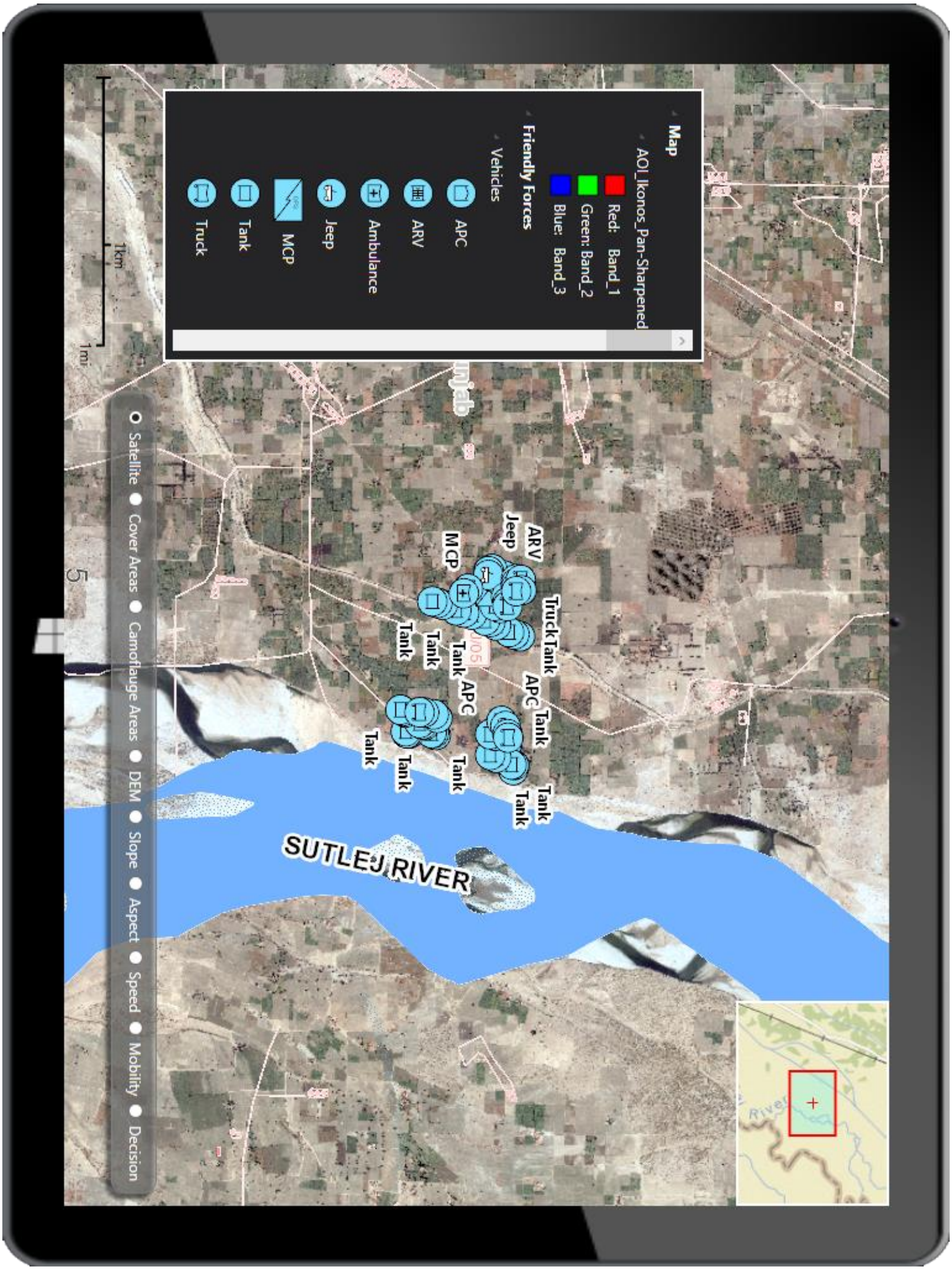
The .NET Framework is a development platform for building apps for Windows, Windows Phone, Windows Server, and Microsoft Azure. It consists of the common language runtime (CLR) and the .NET Framework class library, which includes classes, interfaces, and value types that support an extensive range of technologies.

C#:

C# is one of many .NET programming languages. It is object-oriented and allows you to build reusable components for a wide variety of application types

SOFTWARE SCREEN SHOTS:

Field End:



Command End: