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Using smartphone and GIS to measure IRI in Gaza road network

إستخدام الهاتف الذكي ونظم المعلومات الجغرافية في قياس
معامل الإحتكاك في شبكة الطرق في قطاع غزة

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إقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:


إستخدام الهاتف الذكي ونظم المعلومات الجغرافية في قياس معامل الإحتكاك في شبكة الطرق في قطاع غزة

Using smartphone and GIS to measure IRI in Gaza road network

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using smartphone and GIS to measure IRI in Gaza road network

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نائب الرئيس لشئون البحث العلمي والدراسات العليا

أ.د. عبدالرؤوف علي المناعمة

Abstract

Road network inventory has gain significant importance in last few years especially after wars and natural disasters which makes the urgent need for quick and economical ways to do an inventory of roads. The current methods used to create road networks inventories involves high costs and requires many instruments and detailed planning. The availability of low cost sensors in Smartphones and the rapid increase in the rate of Smartphone users make the necessary to develop systems which are able to road inventories using Smartphone. Several smartphone application have been proposed towards addressing this problem such as Roadroid, Road Recorder and other.

This study presents a new method for road network inventories based on the use of the latest generation of smart-phones that provide a low cost, efficient and adaptable option for the inventory of different types of roads, using GIS software to enhance the road network inventory and using AHP (Analytical Hierarchy Process) method to compare between several methods used in the road network inventory and determine the most efficient and less expensive for use in the Gaza Strip.

The results indicate that the ease of data inventory using smartphone with less time period compared with other method used in road network inventory. Its low cost, gives a good date quality with available resources because most of people have a smartphone today.

Keywords: Road Network; Inventory; Roadroid; Smartphone; GIS; AHP.

الملخص

عملية حصر شبكة الطرق اكتسبت أهمية كبيرة في السنوات القليلة الماضية وخاصة بعد الحروب والكوارث الطبيعية. مما يجعل الحاجة ملحة لطرق سريعة واقتصادية للقيام بعملية حصر شبكة الطرق. الطرق الحالية المستخدمة في عملية حصر شبكات الطرق مكلفة وتتطلب العديد من المعدات والتخطيط التفصيلي. لذلك تم الاستفادة من توافر أجهزة الإستشعار منخفضة التكلفة في الهواتف الذكية والزيادة السريعة في معدل مستخدمي الهاتف الذكي لتطوير نظم قادرة على حصر شبكة الطريق باستخدام الهاتف الذكي. و قد تم اقتراح عدة تطبيقات للهاتف الذكي لمعالجة هذه المشكلة مثل برنامج " Road Recorder " و " Roadroid "

يقدم هذا البحث طريقة جديدة لحصر شبكة الطرق باستخدام أحدث جيل من الهواتف الذكية التي توفر تكلفة منخفضة وكفاءة عالية لعملية جرد شبكة الطرق. واستخدام برمجيات نظم المعلومات الجغرافية (GIS) لتعزيز عملية حصر الطرق. وكذلك تم استخدام عملية التحليل الهرمي (AHP) للمقارنة بين عدة طرق مستخدمة في عملية حصر شبكة الطرق وتحديد الأكثر كفاءة منها وأقل تكلفة للإستخدام في قطاع غزة.

نتائج البحث توضح سهولة الحصول على البيانات باستخدام الهاتف الحديث بأقل فترة زمنية ممكنة بالمقارنة بالطرق الأخرى المستخدمة في عملية حصر شبكة الطرق. حيث أن حصر شبكة الطرق باستخدام تطبيقات الهواتف الذكية منخفض التكلفة ويوفر دقة في جمع البيانات مع توفر المواد المتاحة لذلك.

الكلمات المفتاحية: شبكة طرق، جرد، هواتف ذكية، نظم معلومات جغرافية، عملية التحليل الهرمي.

Dedication

*I would like to dedicate this work to
my beloved family
for their endless and generous support*

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First of all, all thanks and appreciations go to Allah for his unlimited blessings and for giving me the strength to complete this study.

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List of Abbreviations

AHP	Analytic Hierarchy Process
ANN	Artificial Neural Network
CSV	Comma-Separate Value
CMWU	Coastal Municipalities Water Utility
DCP	Dynamic Cone Penetrometer
FHWA	Pavement Condition Criteria
FTP	File Transfer Protocol
GIS	Geographic Information System
GIS-T	GIS in transportation engineering
GPS	Global Positioning System
GSM	Global System for Mobile communication
IRI	International Roughness Index
LRP	Location Reference Points
MPWH	Ministry of Public Works and Housing.
OS	Operation System
PMMS	Pavement Maintenance Management System
PSD	Power Spectral Density
POI	Points of Interest
RQ	Road Quality
RST	Laser Road Surface Tester
SAAS	Software as a Service

Chapter 1

Introduction

Chapter (1): introduction

1.1 Background

The road network management process requires the collection of many detailed data from the road network in order to assist in decision-making and achieve a better return on investment process. So it is necessary to create a road network inventory that includes both road characteristics and road maintenance conditions. The current methods used to create road networks inventories involves high costs, requires many instruments and detailed planning. These requirements prevent a quick implementation of this method. This is important to consider in critical cases like making inventories after natural disasters or after wars. Since the vehicles used in this procedure are specialized for taking measurements on paved roads designed for standard car widths, it is very difficult to use them for other types of roads. The goal of this research project is to use software for smart-phones that provide a low-cost, efficient and adaptable option for the inventory of different types of roads and use GIS software to enhance the approach of road network inventory. This research presents both the applications and their implementation in part of the road network in Deir Al-Balah city.

GIS offers some special features that can enhance the approach of road network inventory and maintenance. Standard GIS functions include thematic mapping, statistics, charting, matrix manipulation, decision support systems, modeling algorithms, and simultaneous access to several databases.

In many engineering applications the final decision is based on the evaluation of a number of alternatives in terms of a number of criteria and we may be comfortable with decisions that are made based on only intuition. On the other hand, when risks are high, it is important to properly structure the problem and explicitly evaluate multiple criteria. This problem may become a very difficult one when the criteria are expressed in different units or the pertinent data are difficult to be quantified. The Analytic Hierarchy Process (AHP) is an effective approach in dealing with this kind of decision problems. Cost or price is usually one of the main criteria. Some measure of quality is typically another criterion that is in conflict with the cost (Weistroffer, 2005).

This research use AHP method to compare between using smart-phones applications and other methods used in road network inventories based on several criteria.

1.2 Research Problem

Road network inventories are needed in the planning of road networks and they allow for efficient management and a better return on the investment. The current method used to create road networks inventories involves high costs, requires a broad range of instruments and detailed preplanning. These requirements prevent a quick implementation of road inventories.

Current techniques for road inventories are characterized by:

- Carrying out road inventories are expensive and requires long planning processes and data processing.
- Some types of road networks are not accessible to cars, so it's difficult to do inventories of all types of road.
- Can't manage the routine maintenance of small road networks.
- The high cost required for the inventory process and needs for many equipment and crews.
- Time and effort required for road network inventories.

On the other hand:

Gaza strip is facing a great challenge in dealing with an aging infrastructure. For pavements in particular, it is sought that many streets were built 20 or 30 years ago and they are near the end of their economic life.

Indeed, Gaza strip road network have the following current threats:

- Poor maintenance of roads in Gaza Strip.
- Increase rate of deterioration.
- Overloading of vehicles.
- Rapid traffic growth.
- Israeli occupation (direct and indirect effects)
- Limited resources (funds, equipment, materials ...etc)
- Insufficient information for decision-making.
- No previous study in Gaza Strip used smartphone application in road network inventory.

1.3 Aim and Objectives

1.3.1 Research Aim:

This study aims to present a new method to create road network inventories based on the use of the latest generation of smart-phones that provide a low cost, efficient and adaptable option for the inventory of different types of roads and using Geographic Information System (GIS) software to enhance the road network inventory.

1.3.2 Research Objectives:

To achieve the aim of this research there are many objectives, these objectives can be summarized as bellow:

- Use smartphone for the first time to calculate International Roughness Index (IRI) in Gaza Strip as a part of road network inventory.
- Use software for smart-phones that provide a low-cost, efficient and adaptable option for the inventory of different types of roads.
- Apply of new and easy method for road network inventory instead of the traditional methods used.
- Compare between using smart-phones applications and other methods that used in road network inventories using AHP method.

1.4 Methodology

In achieving the proposed system, the following steps are performed:

- Literature review of important aspects related to methods that used in road network inventories.
- Using smart-phones application “Roadroid” (This is an Android application) in road network inventory. And apply it on case study in two main roads in Deir Al-Balah city.
- Using spatial analysis and Geostatistical analysis by GIS software to create a map illustrate the road network inventory in part of the road network in Deir Al-Balah city.
- Using Analytical Hierarchy Process (AHP) to compare between using smart-phones applications in road inventories and other methods used in road network inventories based on several criteria.

1.5 Dissertation Contents

The chapters in this dissertation are arranged carefully in the order or sequence of steps to make it clear and understandable.

Chapter (1): Introduction

This chapter provides general introduction about the nature of this study. It discusses the research problem of presents a new method for create road network inventories based on the use of the latest generation of smart-phones that provide a low cost, efficient and adaptable option for the inventory of different types of roads and using GIS software to enhance the road network inventory.

Chapter (2): Literature review

This chapter is oriented as a literature review about the main topic of this study. It focuses on the part "Road network inventory". It also illustrated many previous studies used multiple methods and techniques in road network inventory field such as Aerial/Satellite, road surface laser tester (RST) , visual inspection, smartphone applications and other methods that used in road network inventory. It also illustrates the Smartphone application that can be used in road network inventory and discusses GIS application for smartphone and explains the Analytical Hierarchy Process (AHP) and characteristics of AHP method and how to apply it.

Chapter (3): Methodology

This chapter is considered the methodology in this dissertation. It discusses the development steps of the proposed Road network inventory using Smartphone for Deir Al-Balah city which is the aim of this study. It also illustrates the use of GIS application to display and analysis the results. This chapter also outlines AHP method steps that are performed to compare between different Road Network inventory methods.

Chapter (4): Results and discussion

This chapter presents the results achieved in using Roadroid application as a case study in road network inventory and GIS output of road network inventory. This chapter also explain result of AHP method to compare between using smartphone applications and other methods used in road network inventory.

Chapter (5): Conclusion and Recommendations

Finally, chapter Five summarizes the conclusions of this research as well as the suggested recommendations.

Chapter 2

Literature Rearview

Chapter (2): literature Review

2.1 Introduction:

Road network inventory is important for improving the quality of the network in an efficient way. It should contain all the roads elements including historical data, traffic, road geometry, cross sectional element, vertical and horizontal alignment and road pavement condition such as International Roughness Index (IRI) and other related data. Road network inventory should also be updated regularly to inspect any changes in road condition and the make a quick solutions to avoid more problems which can affect the traffic and the economic situation. Road network inventory can be done through traditional methods such as visual inspection survey or through advanced methods such as Aerial/ Satellite photography and laser road surface tester (RST) but in some conditions, these methods may not be suitable because these methods may need a longer period of time or higher cost (Cheng et al., 2007).

Rapid update of the inventory of urban road features, on a regular basis, is of great importance for transportation infrastructure management departments, as well as for intelligent transportation-related applications, including driver assistance and safety warning systems (Cheng et al., 2007).

Road inventory is very important for effective transportation management. This process is usually done by a technician in the field, manually from obtained aerial/satellite images or semi-automatically by a software application. The first two options are very time consuming, hence expensive. Many companies therefore try to process at least part of this task automatically. The road inventory process comprises an identification of objects that can be found either on the road or in the road proximity. Examples include road signs, road markings, guardrails and many more. It can register much information about these objects, such as their position, condition or type. (Landa J. and Prochazka D., 2014).

This chapter explain many previous studies that used multiple methods and techniques in road network inventory field such as Aerial/Satellite, road surface laser tester, visual inspection, smartphone applications and other methods that used in road network inventory. These methods range between accuracy, cost, time required, available resources and environmental impact.

2.2 Road network inventory:

Road network inventory is considered as the main component in the planning of road networks. They allow for efficient management and a better return on the investment. It serves to collect data describing the road network in terms of the actual cross-sectional elements and the vertical and horizontal alignment. These data are essential for network asset management and are extensively used for managing road rehabilitation programs and maintenance (Higuera, 2014).

Accurate and real-time information regarding current road conditions, traffic flow, and the surrounding environment forms significant inputs to the Intelligent Transportation Systems. The absence, or lack of visibility of necessary traffic signals, is often the cause of terrible traffic accidents. Thus, effective advance detecting and monitoring of potential disasters on the road can reduce casualties and improve traffic safety. According to manuals in different countries, documentation of urban road feature inventory includes road geometries (e.g., longitudinal and transverse slopes, road curvatures, lane width, number, and direction of travel), road surface features (e.g., road markings, manholes, sewer wells, and cracks), and roadside infrastructure (e.g., light poles, traffic signposts, power lines, and bus stations). Not only can the vectorized data be considered by transportation agencies to maintain, repair, and reconstruct current road signals, but they also provide auxiliary information for intelligent vehicle applications to make decisions and improve driving safety. Thus, effective, automated extraction of urban road facilities, such as street light poles, traffic signposts, and bus stations, can assist in rapid update of urban road feature inventories (Yongtao et al., 2015).

Film inventories are a fundamental part of current road inventories. They can be created either by taking photographs of the road at specific distance intervals or by video-taping the routes. High-quality digital cameras are used for this purpose. In general, panoramic formats are used with a viewing angle of at least 120°. Photographs are stored in JPEG graphic formats, which allow for adding metadata to the images. Resolution types differ depending on the instrument used. In some cases, vehicles are also equipped with mechanisms that automatically correct the camera orientation while taking curves (Joint Photographic Experts Group, 2013). These Mapping Systems, which are generally used to make road inventories, are expensive and not

very suitable to inventory roads in emergency cases or for roads that are narrow, for pedestrians or of difficult accessibility. For these reasons, in recent years, international organizations have been promoting the use of low-cost equipment to make road inventories in developing countries. In this context, it is important to highlight the project carried out by Kayondo et al. The goal of this study was to do a preliminary evaluation of roads conditions in Uganda by using two video cameras mounted on both sides of a 4WD. One of the cameras takes real color pictures while the second camera takes infrared images (Kayondo et al., 2011). Likewise, (Yusuf et al., 2007) use a video camera mounted on a car dashboard to do a preliminary evaluation of side slopes with the highest risk of landslides in the roads of Missouri. The results were meant to establish baseline standards in maintenance work. Based on measurements done by means of the videos, they calculate several parameters, including their angle or their height. In both cases, the vehicles had GPS equipment and at least a personal computer, in addition to the video cameras. These methods can reduce by ten times the real cost of making road inventories.

(Hallag and Jendia., 2004) Integrated Micro PAVER with GeoMedia professional software to review, interpret and evaluate data for constructing a suitable database for the maintenance works of Gaza city pavements.

(Yongtao et al., 2015) in their research proposed automated algorithm for rapidly extracting urban road facilities, including street light poles, traffic signposts, and bus stations, for transportation-related applications. A detailed description and implementation of the proposed algorithm is provided using mobile laser scanning data.

(Landa J. and Prochazka D., 2014) in their article, they compared information that can be obtained from camera images and LiDAR measurements. This comparison was presented on three example objects: traffic signs, road markings and general pole-shaped objects (e.g. city lights or trees). Further, they described a process based on their algorithm that detects traffic signs in LiDAR measurement and transformed the results to a common format used in geographic information systems. They test their method on an approximately two-kilometer long road in an urban area. They compared information that can be obtained from RGB images (from the visible part of the

spectrum) and LiDAR measurements (so called point clouds) on three selected examples: road signs, road markings and general pole-like objects.

A. *Road Signs*

The automatic road signs inventory process comprises two steps: detection of the sign position and identification of the sign type (e.g. “Roundabout” or “Main road”). These two steps can be done separately. Moreover, even the sign position detection provides a substantial speedup of the inventory process. It provides exact sign location (possibly even its condition) and just the specific sign type must be chosen by the operator.

B. *Road Markings*

Road markings detection is widely used for autonomous car driving or as a driver assistance service. Hence, most of the approaches use data obtained from common RGB camera to detect road markings. The use of RGB cameras is substantially cheaper in comparison to LiDAR.

C. *Pole-shaped object*

There are many objects that can be classified as pole-shaped. This group comprises electricity poles, public lights that are placed along the road, in some cases even trees (particularly tree trunks). Detection of these objects is in most cases based on point clouds. The basic idea of pole-like object identification is the detection of points distributed in the horizontal direction as a cylinder.

Generally, only information that can be obtained from RGB images is the color of the object. However, to detect the object color, the object itself must be identified first. Therefore, common RGB images are usually not suitable for detection or identification of pole-shaped objects and should be used mainly in a pair with the point clouds. On the other hand, LiDAR data can be used to extract most of the information needed. The most widely used information is a position of the object. It can be either a position of the centroid or position of the base of the trunk. However even information such as height of the pole and trunk diameter can be easily extracted from the point cloud that represents the object.

(Ramos et al., 2014) in their paper prepare a methodology for the Inventory of Road Culverts Pathologies is proposed by the establishment of appropriate categories, the development of a database easy to operate; and the implementation of all this information in a Geographic Information System (GIS) for decision making support. As an example, this methodology has been applied to the Andalusian regional road network in the province of Jaen, (Spain).

2.2.1 Data collection for road network inventory:

All road network inventory require some level of data. These data typically include road accident, traffic, road geometry, cross-sectional elements and the vertical and horizontal alignment, vehicle, road user and other related data. The level of details also varies depending on the tool that is being applied. The frequency and manner in which such data are collected depend on both the nature of the required analysis and the purpose for which it is intended (Cheng et al., 2007).

The road network inventory is the foundation of any pavement management system; since it supports the other system components and provides the information those components will need to function. The basic purpose of the inventory is to provide information describing the pavements physical features. Certain basic information must be known about each roadway in the inventory. The minimum required data for each street segment includes (Washington State Department of Transportation, 1994):

- Average Daily Traffic (ADT).
- Date of construction year.
- Street name, number and segment designation.
- Beginning and ending location of the segment.
- Functional classification.
- Number of lanes.
- Pavement type.
- Pavement thickness.
- Pavement length, width and area of the segment.

These data does not change with time until major work, such as, reconstruction or realignment of the road is carried out. Therefore, these data have to be collected only once.

A good inventory may require a computer system. A computer can quickly and easily manipulate large amount of data and may be desirable in many cases. An inventory can be recalled and used easily for making sound management decisions.

Descriptive data of the road network is also extensively used in traffic analysis, more specifically in describing the relationship between geometric criteria, traffic volumes, road crashes and driver behavior. These data can be collected in a number of ways (Candappa, et al 2011):

- *Manually*: Field workers complete inventory sheets describing the cross-section, the alignment, roadside furniture, condition of road surface, markings and signs, condition of verges and clear roadside area, visibility and any other data required by the road authority. This is an extremely labor intensive method and is time consuming, prone to high degrees of error (also due to subjective interpretations). Generally, a description of the cross-sectional elements is captured every 100m or there is a distinct change in one of the elements. The horizontal and vertical alignments are generally captured per curve (radius, curve ratio; gradient etc.). Intersections are inventoried separately and each intersection approach is described (number of lanes, lane widths, configuration etc.). Often manual inventories make use of design drawings, photos and other visual aids to control observed data.
- *Automated*: Currently there are various automated road inventory systems available on the market. These vary from relatively simple handheld data capturing units on which all data parameters have been coded and are entered by an observer in a moving vehicle, to complex fully automated systems combining video, photographic, skid resistance measurements (e.g. Scrim) and other measurement technologies to capture the data. The latter systems are capable of capturing data at relatively high speeds (80km/h) and at intervals of 5m along any road section. These data can automatically be linked to GIS systems for analysis.
- *Remote sensing*: This is a relatively new technique whereby LIDAR data is used to derive estimates of the data and including elements such as cross-fall, curvature and gradient.

Due to the relatively high cost, road network inventories are only carried out sporadically and not by all road authorities. Furthermore, where these inventories are carried out, the data are not generally available or used to maximum benefit. These inventories are predominantly used by road engineers responsible for maintenance and operation. Since these data can be useful in safety analysis, road authorities are encouraged to make these data more generally available. In addition, there is the possibility of collaboration with other departments, for instance a road safety unit may want to conduct road safety inspections that are a perfect means to collect, update and validate road network inventory data (Stefan, et. al, 2010).

Some Inventory data does not change significantly with time and therefore does not have to be collected with regular intervals. It is anticipated that the collection could be a onetime activity for most inventory items with future changes derived from as-built drawings and contract construction and maintenance records at the time of completing project works (Pavement Inventory Survey Manual”, 2005).

2.2.2 Components of road network inventory:

The inventory of a road contains the following components (Pavement Inventory Survey Manual”, 2005):

2.2.2.1 Road and Link Numbering

Road occurrence is a set of sequentially connected Links. Each Road is identified by a unique alpha digit name called a Road Name. Road class, road function, road status and road name are constant from the start to the end of a Road. If any of these changes, then this is defined as another road.

A Link is the part of a road between two intersections on that road. Links are used exclusively for traffic purposes and not in connection with other types of data collection (except traffic counts) or in connection with locating maintenance works.

As all roads contain a link with the number 1, the link number therefore cannot be used as a unique identifier for a given link. A link number can only be used in combination with a road number (i.e. N1.5 where N1 is the road number and 5 is the link number).

The following are constant from the start to the end of a link:

1. The Number of Main Carriageway lanes is constant
2. The Link is either one way or two way traffic flow

3. Ramps and roundabouts are to be treated as single links unless the number of main carriageway lanes change, or the traffic flow change. In these cases the ramp or roundabout must be split and apportioned to more than one Link.
4. A link must start a Connecting LRP but might end at a Connecting LRP or an End LRP, except in the special case of a roundabout where the Link starts and ends at the same Connecting LRP. The link must be either split or extended in accordance with Rules 1 to 3.
5. If the length of a Link (between two LRPs) is less than approximately 200 meters, then the Link is not to be considered a separate Link but to be included in the shorter of the Links either before or after.

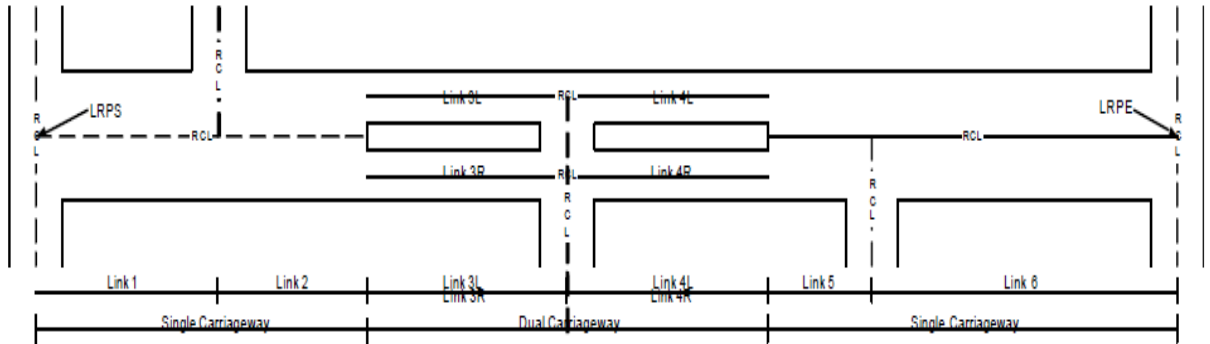


Figure (2. 1): Dual carriageways get the link extension L (left) and R (right)

2.2.2.2 Location Reference Point Survey

Location Referencing comprises the concepts and techniques used to define how the spatial and temporal position and events in the physical world are reflected within the computer system. Thus Location Referencing is the foundation on which the computerized model of the road.

The locations of Location Reference Points (LRPs) shall be established during the survey. In many instances these will be the existing km posts (Primary LRP) or, if km posts are missing, other fixed points (bridges etc. – Secondary LRP) adjacent to the carriageway.

Distance between LRP's shall be measured with 1 (one) meter accuracy and the location of each LRP measured by GPS (Longitude/Latitude). LRPs shall be clearly identified and located in a position which is easily visible, by future assessment teams.

2.2.2.3 Cross Section Inventory Survey

The first of the Network Level Surveys is the Cross-Section Survey. This survey should be a one-time survey of Cross-Section items on the network. It does not need to be repeated annually. The data to be collected during this survey are continuous section data. One of the objectives of carrying out Pavement Inventories is to measure the width of carriageway, shoulder, and non-motorized lanes etc. which form part of the crest of the road. All inventory data collection demands significant time and human resource inputs. It can only be done by manually recording the presence and location of each inventory item.

1. The width of the pavement, shoulders and verge is measured to the nearest 10cm at the beginning of the road and recorded. Type of pavement and shoulders are also recorded
2. The observation of cross section widths should be done on foot. If any element changes, the new width of each element in the cross section is measured (also these not changing) and data is recorded on the survey form together with the change in which the change takes place.
3. If there is no change of item width in the cross section, observation can be continued to the end of the road.

2.2.2.4 Drainage Inventory Survey

The drainage survey should be a one-time survey and is part of the road Cross- Section Inventory. It does not need to be repeated annually. The data to be collected during this survey are continuous section data. One of the objectives of carrying out Pavement Inventories is to measure the width of carriageway, shoulder, and non-motorized lanes etc. which form part of the crest of the road.

2.2.2.5 Construction/Maintenance Inventory Survey

The survey is intended to identify when and how the pavement was originally constructed and what maintenance has been carried out since. The main sources from which relevant data can be obtained are:

1. As-built drawings (indicating year of construction);
2. Engineers, technicians and foremen with long service record; and
3. Test pits and/or Dynamic Cone Penetrometer (DCP) testing.

2.3 Road network inventory methods.

2.3.1 Road network inventory using Smart-phones:

Smart-phones are equipped with a series of motion sensors that turn them into very low-cost mobile sensor platforms. Currently, a high-end smart-phone includes GPS, light sensors, sound, magnetic field sensors, accelerometer, gyroscope, barometer, photo camera and video camera. They can also be connected via Bluetooth, Wireless or Internet. Furthermore, they have high computational capabilities, which are much better than the functionality of computers available a few years ago. Because of all this, smart-phones can be used as powerful tools to develop all types of applications, particularly in transport sector (Higuera, 2013).

Smart-phones can be used to take photographs and digital videos. Some applications can combine track data captured by smart-phone built-in GPS with images recorded via smart-phones. Digital cameras, including smart-phone cameras, include metadata in Exif format in photographic, videos and audio files. If the device has a built-in GPS, geolocation data can be also added. There are many apps that allow users to geotag pictures. Some of these apps include additional options in addition to photo geotagging (Geotagging: is the process of adding geolocation metadata to a photograph, video or any other digital data) (Wazar, 2013). Many smartphone applications have emerged recently the integrated GPS receiver that can improve road network inventory. With the provision of fast mobile Internet access, real time communication became possible (Hasan, 2013). So with internet access smartphone can gather inventory data and upload it to the internet in the same time like what does in Roadroid application.

(Kattan, 2014) proposed a technique to aid in reporting such road problems automatically using a smartphone application. The application utilizes the phone's accelerometer to detect the "shocks" resultant from driving over such road problems. The application encodes the obtained data along with the location and sends to a data-collection cloud service. The cloud service utilizes an artificial neural network (ANN) that is trained to differentiate the "shocks" resulting from road problems and those resulting from driving maneuvers. Figure (2.2) shows the mechanism of the proposed technique.

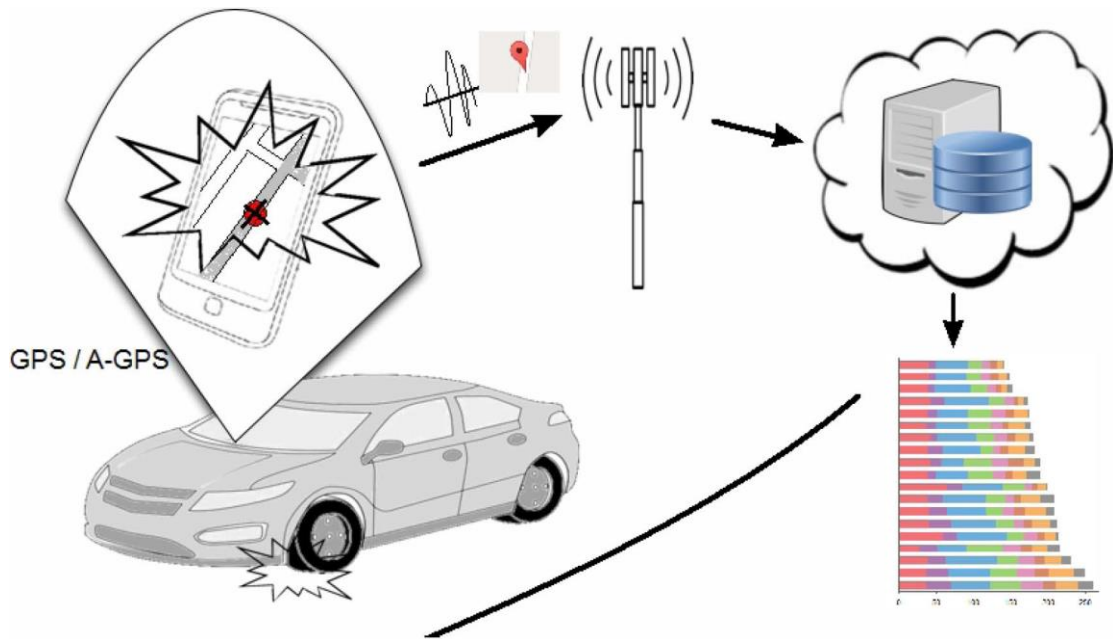


Figure (2. 2): Current location transferred by the smartphone to the cloud service (Kattan, 2014).

2.3.1.1 Client Smartphone Application

The smartphone application is written as a light background service that must be installed on the driver's smartphone. A mobile Internet connection is required to access location services, such as Google Maps, and send data. During driving, the application will detect relatively rough motion changes, i.e. shocks, and encode them into a digital pattern. Using the location hardware available (GPS), the location of the incident is recorded and a data package is prepared for sending to the cloud data-collection software. The application does not require any user intervention other than enabling data and location services on the device (Kattan, 2014).

2.3.1.2 Cloud Data-Collection Software

The cloud application was written as software as a service (SAAS) anticipating that many municipalities would be interested in using it. The software receives the data packages sent by different participating drivers and analyzes the digital patterns received. With the help of a dedicated trained artificial neural network, the software can differentiate between shock waves resultant from driving maneuvers and those resulting from road problems. The service processes and accumulates shock patterns coming from different participating clients monitoring the frequency of reporting a

certain geographic location. After a certain threshold value, this is interpreted as a possible road problem and that location is reported.

2.3.1.3 Studies used Smartphone application in road network inventory.

(Mohan et al., 2008) used mobile Smartphone to monitor road and traffic conditions. It detects potholes, braking, bumps and honks using accelerometer, microphone, GSM radio and GPS sensors present in smart phones. It uses triggered sensing where the operation a high energy consuming sensor (GPS, microphone) is activated by a low energy consuming sensor (accelerometer, cellular radio) making the system energy-efficient.

(Mednis et al., 2011) proposed a system which uses Android OS based Smart-phones having accelerometer sensor for detection of potholes in real time. This system detects events in real time and also collects the data for off-line post-processing. The data is collected using 3-axis accelerometer sensor present in Smart-phones.

(Bhoraskar et al., 2012) method used Smartphone sensors for traffic state monitoring and detection of bumps. It uses accelerometer sensor to collect the data. The Smart-phones is to be reoriented as it can have any arbitrary orientation when kept inside the vehicle. This system reorients the phone in two steps using accelerometer and magnetometer.

(Singh et al., 2013) proposed a mobile phone application that uses GPS, accelerometer and microphone to collect the data. This application detects road and traffic conditions along with driving behavior. This application is used to detect various events based upon the patterns observed. This application does not use machine learning. It is completely based upon the patterns obtained from the sensor data.

2.3.2 Road network inventory using Aerial/Satellite images.

Aerial/Satellite images technologies have been widely used for geological, military, environmental, urban planning, hydrological, and transportation planning. Remote sensing and geospatial technologies are particularly useful to accomplish the database of both geographic data and non-geographic attributes (Al-Turk, et. al, 1999). In recent years, worldwide coverage of high resolution satellite imagery has been available on affordable costs for planimetric extraction of road inventory and landuse maps for applications in infrastructure asset management and traffic management (Uddin,

2011). The use of non-intrusive 1-m and submeter resolution satellite imagery has been proved very cost-effective, less labor intensive, and less time consuming. In addition, geospatial analysis of the archived satellite imagery can provide a unique opportunity to evaluate temporal changes in landuse patterns, traffic demand trends, disaster impacts, and biodiversity and environmental sustainability (Uddin, et. al, 2013).

2.3.2.1 Studies used Smartphone application in road network inventory.

(Uddin, et. al, 2013) discuss a geospatial methodology using 0.6m high resolution satellite imagery that was successfully implemented for creating road network planimetrics for road inventory, traffic flow attributes, and traffic volume demand maps. The capacity analysis results show that the analyzed urban road sections were mostly at level of service C, D, or E. The traffic demand volume data can be used to calculate congestion costs and recommend traffic management priorities.

(Ahmed, 2009) presented a case study of an industrial site area in the port city of Karachi in Pakistan where satellite imagery was used to: create planimetric inventory of area roads, landuse map, extract traffic flow attributes of selected sections of an arterial road, calculate daily volume distribution, and evaluate level of service of road sections.

2.3.2.2 Application of Satellite Imagery for Road Network Inventory.

High resolution satellite imagery such as 1-m Ikonos or 0.6-m QuickBird2 have been used for the development of accurate and precise landuse and road inventory maps in the Karachi transportation management project (The National Academies. 2010). Traffic data extraction from satellite imagery is another important application of remote sensing technologies in transportation planning projects. The traffic data obtained from the satellite imagery can be compared with the ground-based samples to check the accuracy of the data obtained from the satellite imagery (Qureshi. 2007).

2.3.3 Road network inventory using laser road surface tester (RST).

This equipment, developed in Sweden, uses noncontact high-speed laser technology to measure pavement condition. Data outputs purportedly can be reduced to evaluate pavement discontinuities (cracking, faulting, etc.), rut depths, ride quality, and surface texture (which may correlate with skid resistance). Data collection and reduction are

fully automated and supposedly can be easily interfaced with existing pavement management systems (Thomas, 1995).

(Thomas, 1995) purposed a study to evaluate the accuracy and usefulness of data collected by a laser RST operating on Virginia's interstate highway system. In addition, a limited study of the reproducibility of the equipment's measurements was conducted. Data were collected through the use of 11 lasers spaced across a bar 2.6 m (8.5 ft) long mounted on the front of the test's van, as shown in Figure (2.3).

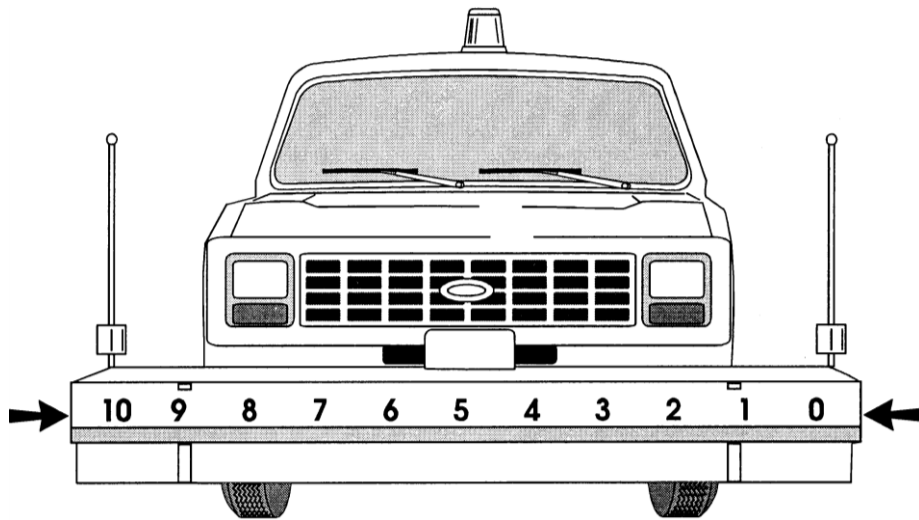


Figure (2. 3): Laser spaced across a bar 2.6m (Thomas, 1995).

The system is based on the principle that the angular relationships between the light emitted by a laser transducer and that detected by the transducer are dependent on the elevation of the transducer with respect to the pavement over time, as shown in Figure (2.4).

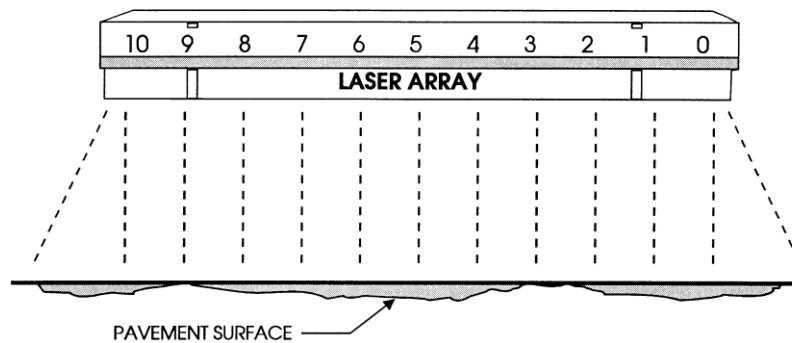


Figure (2. 4): Sample transverse laser array (Thomas, 1995).

2.3.3.1 Projects used RST in road network inventory.

(Bychkovsky et al., 2006) proposed a distributed mobile sensor computing system. This system includes a set of sensors installed in vehicles to collect and process data and send it to portal based upon the continuous queries which are processed by continuous query processor on remote nodes. It uses sensors like GPS for monitoring the movements of vehicles.

(Eriksson et al., 2008) used 3-axis accelerometer and GPS mounted on the dashboard to monitor road surface. It not only identifies potholes but also differentiate potholes from other road anomalies. It collects the signals using accelerometer. It uses machine learning algorithm to identify potholes. These signals are then passed through a series of signal processing filters, where each filter is designed in such a way that it will reject one or more non-pothole events (manholes, expansion joints, railroad crossing).

(Chen et al., 2011) system collected the sensor data using three-axis accelerometer and GPS. The sensor data has 4-tuples: current time, location, velocity and three direction accelerations. This system also does the data cleaning before processing or analyzing it to deal with technical challenges like GPS error, transmission error. This system analyses the Power Spectral Density (PSD) to detect pavement roughness using Fourier transform. The International Roughness Index (IRI) is calculated based upon PSD.

2.4 GIS-based road network inventory management model:

To integrate, analyze and represent in an efficient way all road network inventory information, a Geographic Information System (GIS) has been implemented in order to give valuable support for decision-making (Xiugang et al., 1999). GIS offers some special features that can enhance the approach of road network inventory. The key element that distinguishes GIS from other data systems is the manner in which geographic data are stored and accessed. The addition of this spatial dimension to the database system is, of course, the source of power of GIS. Linked with the spatial dimension, database features enable GIS to capture spatial and topological relationships among geo-referenced entities even when these relationships are not predefined. Standard GIS functions include thematic mapping, statistics, charting, matrix manipulation, decision support systems, modeling algorithms, and

simultaneous access to several databases. Visualization helps people approach problems in the dimensions of space and time with intuitive maps instead of dimensionally restricted data tables and graphs. GIS is becoming more popular in transportation engineering in the recent years, and has evolved into a new generation of GIS called GIS-T (GIS in transportation engineering) (Miles, 1999).

2.4.1 Geographic Information Systems for Smartphones.

Geographic Information Systems (GIS) provide inventory, analysis and visualization of geographic data to users of various levels. Users range from GIS experts who build models to analyze geographic patterns in data to general users such as travelers who need information on interesting places to visit and paths to follow. Popularity of social networks and ubiquitous use of hand held devices such as smartphones have brought the usage of GIS into the next level (Jayathilake et al, 2011). Another trend in GIS usage is to use it in smartphones. The unique feature of mobile GIS is that it enables the GIS to be held by the user anytime, anywhere (Eleiche, 2011).

Recent popularity of social networks and hand held devices has brought a new dimension into the design and use of GISs. Social networks enable individual users for connecting to and collaboratively working within friend networks, user groups and communities. Data and services are shared freely in a homogeneous platform which opens up an innovative way for individuals to contribute towards and consume a collective knowledgebase. Wide usage of smartphones has further added to this by formulating infrastructure for users to be 'always connected'. Multimedia capabilities such as photography and video recording along with the location detection functionalities clearly make up ground for users to involve with GIS in an unprecedented social way (Jayathilake et al, 2011).

Instead of depending on expert organizations to provide geodata, the users can utilize the multimedia, location detection and social networking capabilities of their smartphones to contribute to, while being consumers of, a broad and dynamic distributed geo-information system. Being truly user-driven, this kind of a system will surpass the limitations of centrally controlled geodata in addition to being economical. Use of these systems can be identified as Community GIS (Jayathilake et al, 2011).

There are some reasons that inspire the mobile GIS. First, the growth of wireless communication and the mobile networks are everywhere worldwide; second the exponential advancement in hardware, and finally the availability of geographical databases. Smartphone users can acquire their geo-locations (latitude and longitude) while moving in geographic space and have access to geographical information. They can utilize these data to make spatial decisions and to manage movements. The key purpose of the mobile GIS is to reduce the force and time of navigation and movement and make them more efficient. On the other hand, users can insert very live data into the GIS using geo-location detection and multimedia capabilities of smartphones. They can reveal new path traversals and upload photographs and videos regarding real time incidents. Mobile GIS is getting popular in fields such as health, education and entertainment (Jayathilake et al, 2011).

2.4.2 GIS applications for smartphones.

2.4.2.1 OsmAnd

OsmAnd is a GPS Navigation and map application that runs on many Android and IOS smartphones and tablets, featuring optional offline maps and turn by turn directions. OsmAnd is a collaborative, open source software project that incorporates the 100% free OpenStreetMap data to deliver a complete, user-friendly, mobile GPS solution. Rich mapping, navigation, routing, Points of Interest (POI), and historical tracking functions are all well supported. The software is well refined, reliable, globally deployed, and runs on many Android and IOS based smartphones, tablets, and a wide array of Linux-based systems.

Frequently updated map and POI data are typically downloaded beforehand and stored on the navigation device. Subsequent use does not require an Internet connection, which allows unlimited usage without incurring potentially costly data transfer charges. It also offers uninterrupted and unfettered GPS reliability despite degraded or non-existent cellular phone network signal coverage (osmand.net).

OsmAnd Features:

OsmAnd is a map and navigation application with access to free, worldwide, and high-quality OpenStreetMap data. All map data can be stored on your device's memory card for offline use. Via your device's GPS, OsmAnd offers routing, with visual and voice

guidance, for car, bike, and pedestrian. All the main functionalities work both online and offline (no internet needed when navigation).

Some of the main features of OsmAnd:

Navigation

- Works online (fast) or offline (no roaming charges when you are abroad)
- Turn-by-turn voice guidance (recorded and synthesized voices)
- Optional lane and turn lane guidance, street name display, and estimated time of arrival
- Supports intermediate points on your itinerary
- Automatic re-routing whenever you deviate from the route
- Search for places by address, by type (e.g.: restaurant, hotel, gas station, museum), by geographical coordinates, or along the route
- Mark road as impassable per session

Map viewing

- Display your position and orientation on the map
- Optionally align the map according to compass or your direction of motion
- Save your most important places as Favorites
- Display POIs (point of interests) around you
- Can display online tile maps
- Can display satellite view (from Bing)
- Can display different overlays like touring/navigation GPX tracks and additional maps with customizable transparency
- Optionally display place names in English, local, or phonetic spelling
- Different map paint styles

2.4.2.2 Route-Me

Route-Me is an open source library that brings slippy maps to the iPhone. While the native iPhone map library supports Google Maps as the only data source, Route-Me provides functionality to use one of many map data sources including OSM. It supports CloudMade tiles and supports swapping between different cartographic styles. It is a native iPhone library developed in Objective C language. It provides support for fast, smooth panning and zooming actions. Main features included are map data retrieval,

geo-coordinate handling, raster graphics support and offline map data. The library does not support vector maps (Jayathilake et al, 2011). Because Route-Me is an open source project it is being actively developed and the code base changes frequently. It's licensed under the new BSD license so that it can be used for both commercial and non-commercial uses as long as copyright notice and the disclaimer is included in the documentation for the product (Open Street Map, 2011).

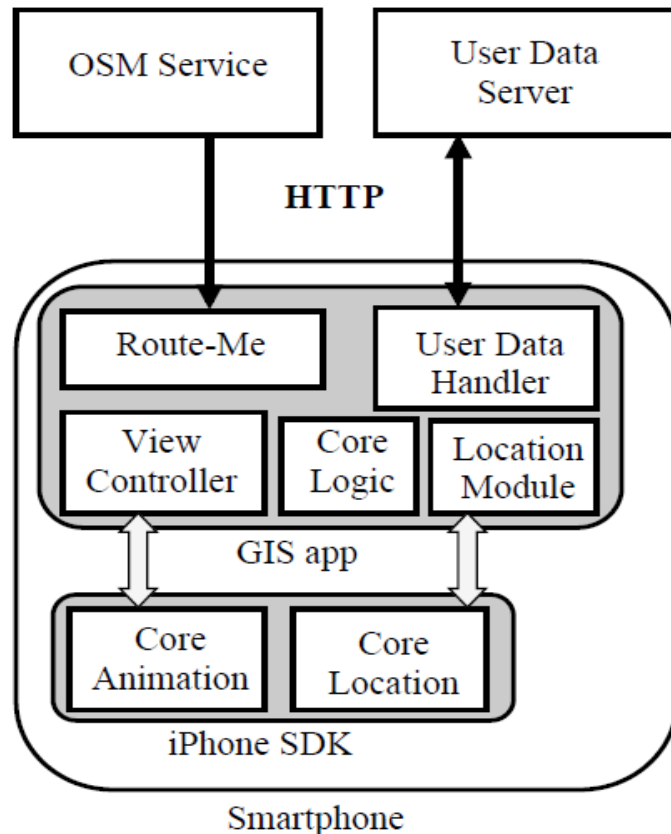


Figure (2. 5): Route app and its connected components to GIS (Jayathilake et al, 2011).

The application connects to OSM Service and the User Data Server. It includes Route-Me as a static library and uses two frameworks from the iPhone SDK, see figure (2.5) (Jayathilake et al, 2011).

2.4.2.3 Tile5

Tile5 is an open source HTML5 mapping and tiling javascript library which is optimized to be implemented in mobile devices. The source for Tile5 is maintained on Github and is released under the MIT license. Tile5 provides a rich HTML5 experience and supports using existing mapping engines such as OSM, deCarta, Cloudmade, etc (Tile5, 2015). The library is targeted primarily at mobile devices that support HTML5.

Primary design decision to use HTML5 is to make it independent from the map provider. Since it makes use of HTML5 it is intended to be compatible with most of the mobile devices independent of their native operating system. That implies the same application would be able to run in many mobile devices. As per the official documentation of Tile5, its objective is to ‘Offer cross-device HTML5 mapping that feels as good as a native device implementation on any mobile device that supports HTML5’ (Tile5, 2015).

Although Tile5 provides some support for adding data on top of the base map, the functionality does not seem to be stable. Therefore the support for user annotations is implemented from scratch using the Canvas API. Offline functionality is provided using the local storage APIs in HTML5. Both the downloaded map data and the client side scripts (Javasripts) are cached locally. While raw map data is cached as files, the metadata associated with them are stored in the local storage database. Nominatim framework, see figure (2.6) (Open Street Map, 2011).

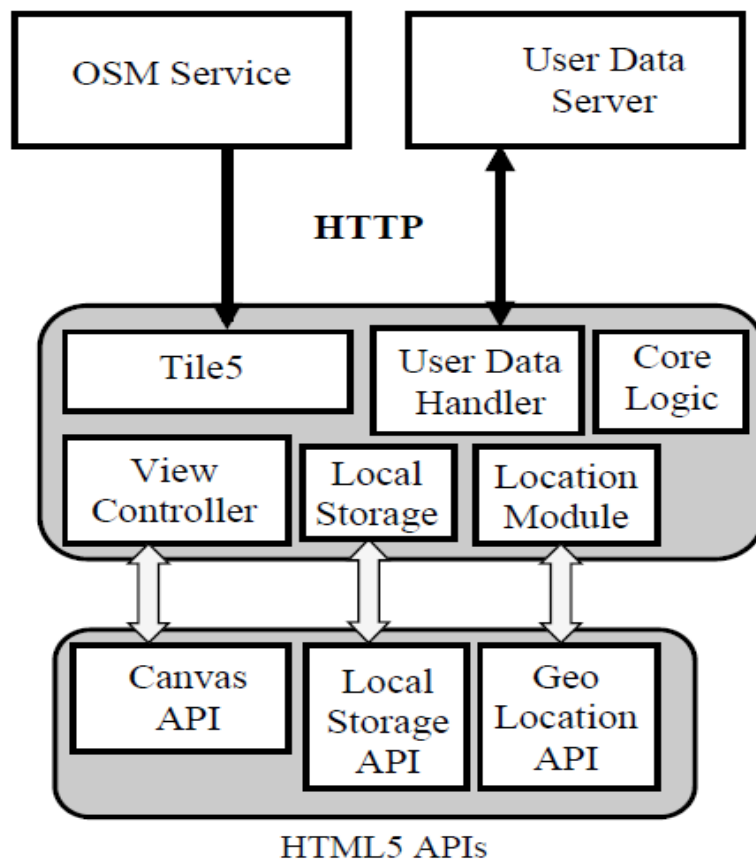


Figure (2. 6): Architecture of the mobile optimized web app and its connected Components. (Jayathilake et al, 2011).

2.5 Road Network Inventory Application for Smartphones:

2.5.1 Roadroid

Roadroid is a Swedish innovation developed since 2002, initially using accelerometer, GPS and a laptop PC - to now using the built in accelerometer in a smartphone. The main screen of the application is illustrated in figure (2.7).

The Android app registers the vibrations from the road and correlates to the International Roughness Index (IRI) – and using the phones GPS to position the data. It also monitors Speed and Altitude and use the camera to take GPS-tagged photos. The web service displays the results on accessible internet maps, and with the user log-in you can work with your data (Roadroid, 2013).

Characteristics of Roadroid application in road network inventory:

- Roadroid is easy to use and highly portable way to collect roughness data.
- It monitors data and makes instant reports on a map, as shown in figure (2.9).
- Roadroid can download the files and create IRI-charts in 100 meter segments.
- Use a road database to generate automatic road condition change reports.
- Roadroid support different cars, speeds and phone models.
- Roadroid method of analyzing the vibration data and estimating an IRI (eIRI) takes into account the current speed, vehicle type and phone model.
- The Roadroid app is using the smartphones built in accelerometer to analyze the road vibrations and its GPS to position the data.
- Data collection can be done by driver – there is no need for a specialized operator.
- Roadroid is a global system, easily accessing remote areas to collect objective data.
- Roadroid saves IRI values with Longitude/Latitude position, Altitude and Vehicle speed each second.
- Roadroid use the phones built in camera to snap GPS-tagged photos that can be transferred to the map tool and shown as clickable thumbnails to view the taken photos.
- Roadroid can also be used together with a stand-alone HD-Video camera with GPS tracking.

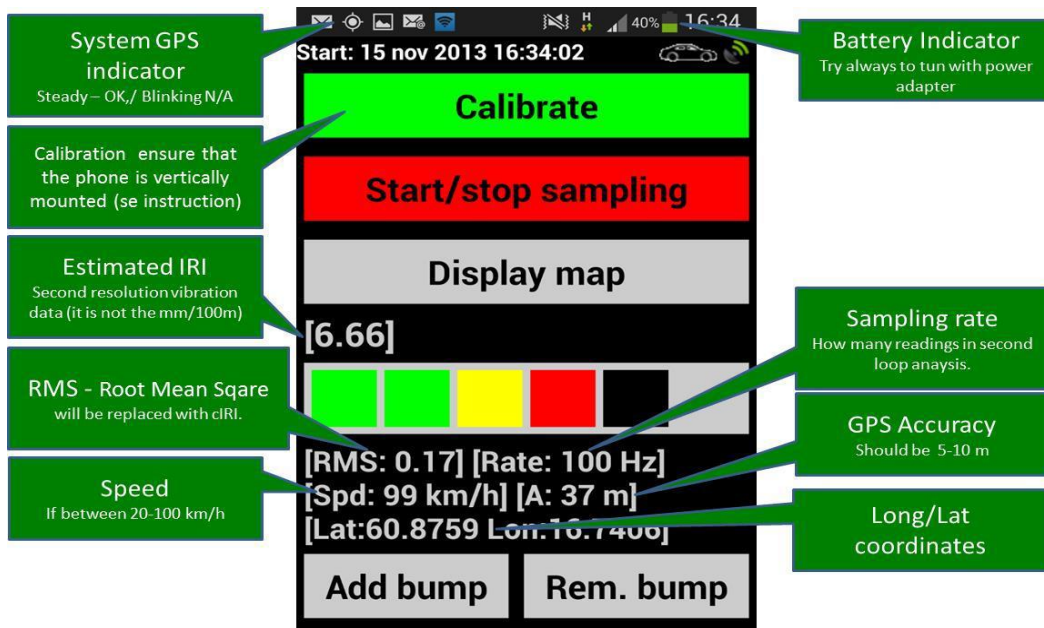


Figure (2. 7): Main screen of Roadroid classic application (Roadroid, 2013)

Roadroid also have a separate **road inventory application** to be used for ocular inspections. This app saves manual input of standard road inventory parameters as rutting, cracks, patching, pothole, bleeding, and edge breaks etc. Instead of using pen and paper you simply add the occurrence of each parameter while inspecting and the data is saved with position data to be viewed on the web maps. See Figure (2.8) (Roadroid, 2015).

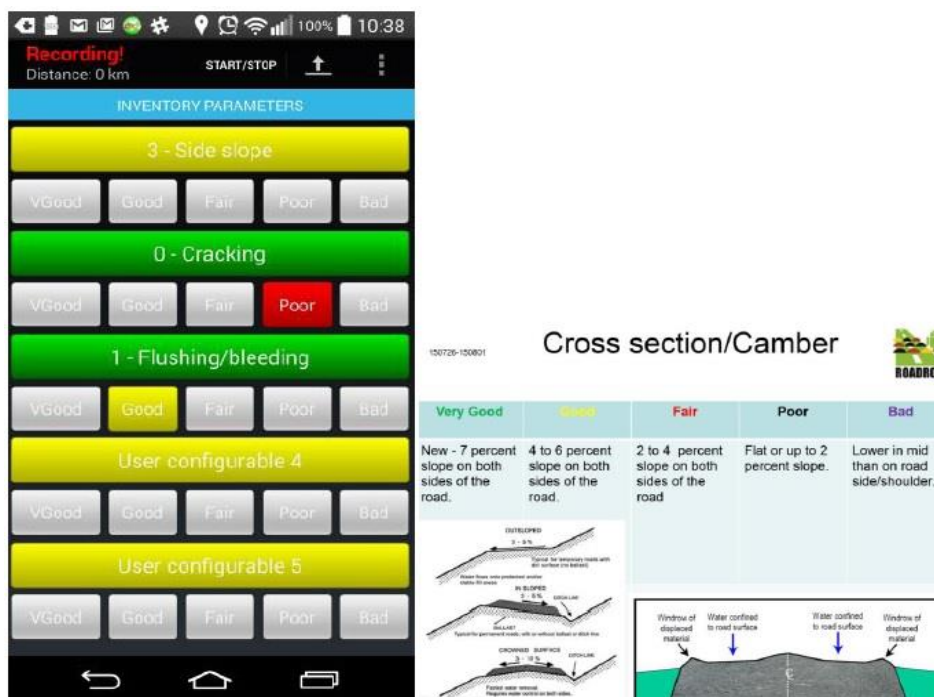


Figure (2. 8): Main screen of Roadroid inventory application (Roadroid, 2015)

Research done by the University of Pretoria in 2013 (Tarr, 2013) was mainly concentrated on finding out if the Roadroid application is consistent enough during |R| measurements with varying vehicle conditions as: speed, road path, loads, tire pressure, etc... The stated conclusion was that Roadroid would be able to produce good results if the mentioned key indicators are standardized.

Research done by the University of Auckland in 2013 (Johnston, 2013) was mainly focused on if the Roadroid application could represented the roughness felt by motorists to a certain level. Both the reports found that the Roadroid application responded to the various road characteristics of the Auckland network in a similar manner to industry accepted systems. To be precise, Roadroid had an 81 % correlation with laser measurement systems.

As most smart phones now have a high quality built-in camera and GPS, Roadroid has developed a function to easily take localized photos and position them on the map (Figure 2.9). The images are often of acceptable quality, but are subject to mounting and light conditions. This is recognized as a very good support for visual inspections, and can also be used to capture dynamic events, such as certain snow conditions or other maintenance contract issues (Lars, 2015).

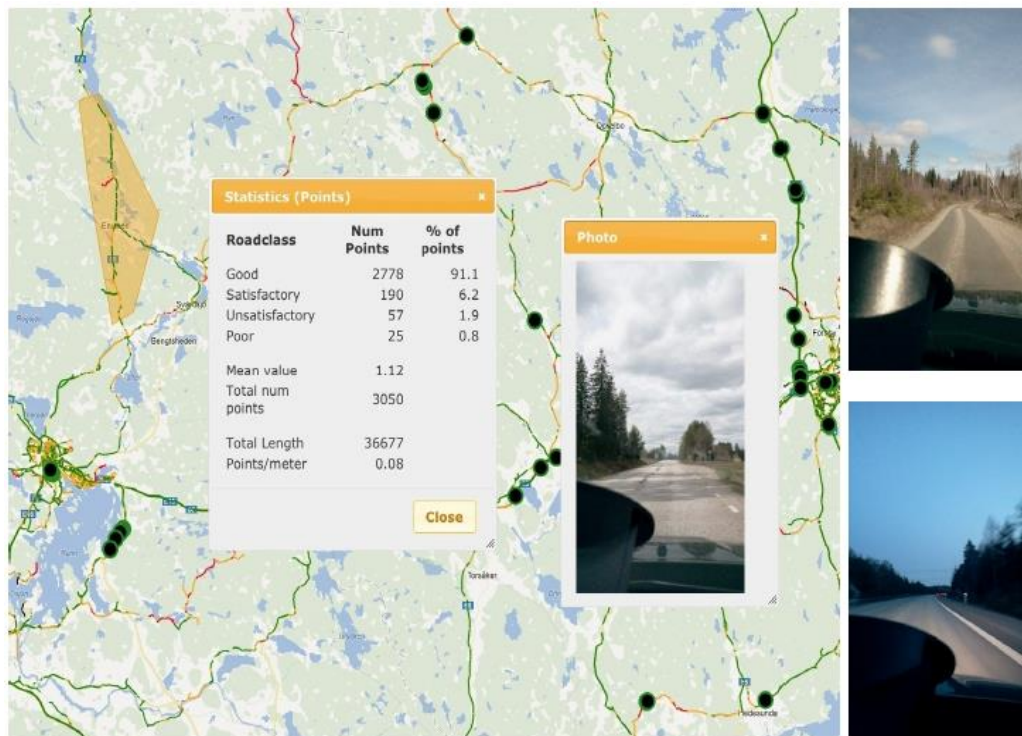


Figure (2. 9): Picture examples of the smart phones built-in camera and support in the web tool (Roadroid, 2013).

2.5.2 Road Recorder:

This is an application for Android that allows users to record video for roads, information from the GPS, and data from both the accelerometer and the pressure sensor. This application is installed on a smartphone and it can put it on a vehicle to records and stores video images from the road along with all the information registered by the smartphone sensors at fixable time intervals. Figure (2.10) shows the main page screen of the Road Recorder android application (Higuera, 2014).

There is a JAVA application for personal computers used to visualize videos recorded with Road Recorder synchronized with the position of the Smartphone on the map along with all values from the sensors throughout the whole vehicle trajectory. This app has editing options specifically designed to create and/or maintain road inventories. Figure (2.11) shows the main page screen of the Road Recorder PC application (Higuera, 2014).



Figure (2. 10): Road Recorder android application (<http://roadrecorder.eu>, 2016)

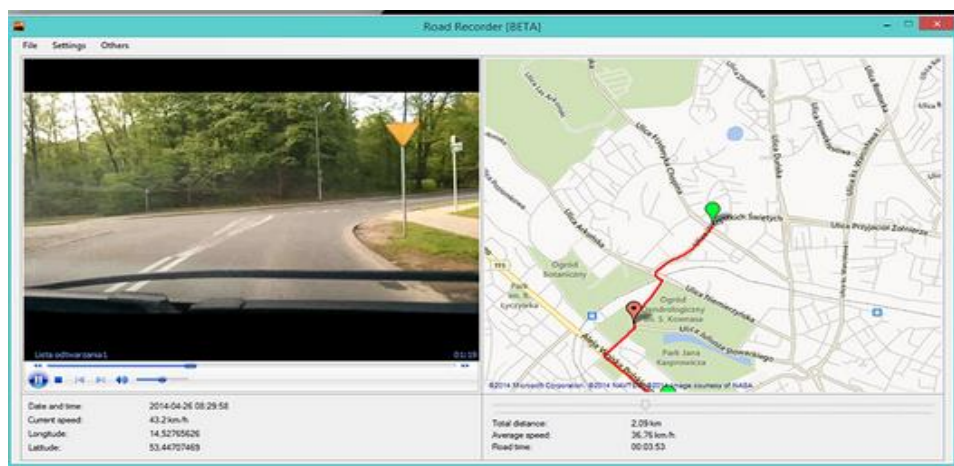


Figure (2. 11): Road Recorder PC application (<http://roadrecorder.eu>, 2016)

2.6 Analytical Hierarchy Process (AHP):

The Analytical Hierarchy Process (AHP) is a decision-aiding method developed by Saaty. It aims at quantifying relative priorities for a given set of alternatives on a ratio scale, based on the judgment of the decision maker, and stresses the importance of the judgments of the decision maker as well as the consistency of the comparison of alternatives in the decision making process (Saaty, 1980). Since the decision maker bases judgments on knowledge and experience, then makes decisions accordingly, the AHP approach agrees well with the behavior of a decision maker. The strength of this approach is that it organizes criteria in a systematic way, and provides a simple solution to the decision-making problems (Skibniewski, 1992). In addition, by breaking a problem down in a logical fashion from the large, descending in gradual steps, to the smaller and smaller, one is able to connect, through simple paired comparison judgments, the small to the large (Kamal, 2001).

In many engineering applications the final decision depends on the evaluation of a set of alternatives in terms of a number of decision criteria, this may be a difficult task. The AHP seems to provide an effective way for properly quantifying the pertinent data. However, there are many critical issues that a decision maker needs to be aware of. To apply AHP in decision problem mainly involve four steps: (Subramanian & Ramanathan, 2012).

- STEP1: Structuring of the decision problem.
- STEP2: Making pair-wise comparisons and obtaining the judgmental matrix.
- STEP3: Computing local weights and consistency of comparisons.
- STEP4: Aggregation of local weights.

2.6.1 Characteristics of AHP

AHP is comprehensive method and the most used widely MCDM method due to its simplicity and great flexibility (Alzober & Yaakub, 2014). AHP has been widely adopted as a powerful MCDM tool. Furthermore, AHP is reliable instrument in decision making, it's easy to apply, more suitable, and very flexible and effective (Safian & Nawawi, 2011).

1. AHP permits group decision-making, it transfers subjective judgment into meaningful weights and ratios on which to base decisions, various judgments

by decision makers can be adapted by this technique, which synthesizes that judgment into a representative outcome and it Identifies inconsistencies made in the judgments (El- Sawalhi et al., 2007).

2. It's permits the decision-maker to compute the consistency of their judgments, because it uses an analytic procedure to process these judgments. Another reason for using this (Topcu, 2004).
3. By breaking a problem down into a logical fashion from the large, descending in gradual steps, to the smaller and smaller, one is able to connect, through simple paired comparison judgments, the small to the large (Saaty, 1990).
4. The strength of this approach is that it organizes tangible and intangible factors in a systematic way, and provides a structured yet relatively simple solution to the decision- making problems (Skibniewski & Choa, 1992).
5. Permits group decision-making where group members can use their experience, values, and knowledge to it is useful in circumstances which necessitate the consideration of different courses of action, which cannot be evaluated by the measurement of a simple, single dimension (Al-Harbi, 2001).
6. Various criteria are included, in order to ensure the quality of the completed product, it is easy to use, because, on the one hand, it requires no prior knowledge of multi-criteria methods from the potential users; and, on the other hand, it minimizes subjective judgments, and the model minimizes the required pairwise comparisons, which is considered to be a major default of AHP (Vavatsikos & Anagnostopoulos, 2006).

2.6.2 Applying AHP Method:

(Saaty, 1990) developed the following steps for applying the AHP method:

1. Define the problem and determine its goal.
2. Structure the hierarchy from the top (the objectives from a decision-maker's viewpoint) through the intermediate levels (criteria on which sub-sequent levels depend) to the lowest level which usually contains the list of alternatives.
3. Construct a set of pair-wise comparison matrices (size $n \times n$) for each of the lower levels with one matrix for each element in the level immediately above by using the relative scale measurement. The pair-wise comparisons are done in terms of which element dominates the other.

4. There are $n(n - 1)$ judgments required to develop the set of matrices in step 3. Reciprocals are automatically assigned in each pair-wise comparison.
5. Hierarchical synthesis is now used to weight the eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.
6. Having made all the pair-wise comparisons, the consistency is determined by using the eigenvalue, λ_{\max} , to calculate the consistency index, CI as follows: $CI = (\lambda_{\max} - n)/(n - 1)$, where n is the matrix size. Judgment consistency can be checked by taking the consistency ratio (CR) of CI with the appropriate value in Table 2. The CR is acceptable, if it does not exceed 0.10. If it is more, the judgment matrix is inconsistent. To obtain a consistent matrix, judgments should be reviewed and improved.
7. Steps 3 - 6 are performed for all levels in the hierarchy.

The research will briefly review the concepts and applications of the Analytical Hierarchy Process (AHP) in comparing between several methods that used in road network inventories.

2.7 Summery:

Road network inventory is very important for effective transportation management. This process is usually done manually by visual inspection survey or from obtained aerial/satellite images. These options are very time consuming and expensive.

As illustrated in this chapter, many previous studies used multiple methods and techniques in road network inventory field such as Aerial/Satellite, road surface laser tester, visual inspection, smartphone applications and other methods that used in road network inventory. These methods range between accuracy, cost, time required, available resources and environmental impact.

In this chapter it can proceed primary objective of this search by comparing between using smartphone application in road network inventory and other method illustrated in this chapter.

Chapter 3

Methodology

Chapter (3): Methodology

3.1 Introduction:

This chapter discusses the methodology which is used in this research. As mentioned before, the main purpose of this research is to present a new method for create road network inventories based on the use of the latest generation of smart-phones that provide a low cost, efficient and adaptable option for the inventory of different types of roads and using GIS software to enhance the road network inventory and using AHP method to compare between smartphone application and other methods used in road network inventory. Methodology is illustrated as a flow chart in figure (3.1).

3.2 Road Network in Deir Al-Balah city:

Deir Al-Balah roads are classified functionally into the following three categories:

1- Arterial Roads

Those roads that pass through the whole city.

2- Main Roads

They are the roads that have large lengths and widths and they are considered as main roads.

3- Local Access Roads

The roads that have small lengths and widths.

Two major roads are selected for this research: Al-Shohadaa Street and Akila Street. The roads are extends from east to west in Deir Al-Balah City (see Figure 3.2).

The roadway network includes the following features: roadway segments or links, road intersections, bridges, rights-of-way, signalization, signage, roadway amenities, and significant parking facilities. This subsection also presents safety-related roadway network data.

A roadway segment or link is a portion of a roadway defined for the purpose of traffic analysis. The segment origination and termination points are typically signaled intersections or the point where the number of lanes on a roadway change. Segments can be classified by lanes, direction, land access, and the type of division between two directions.

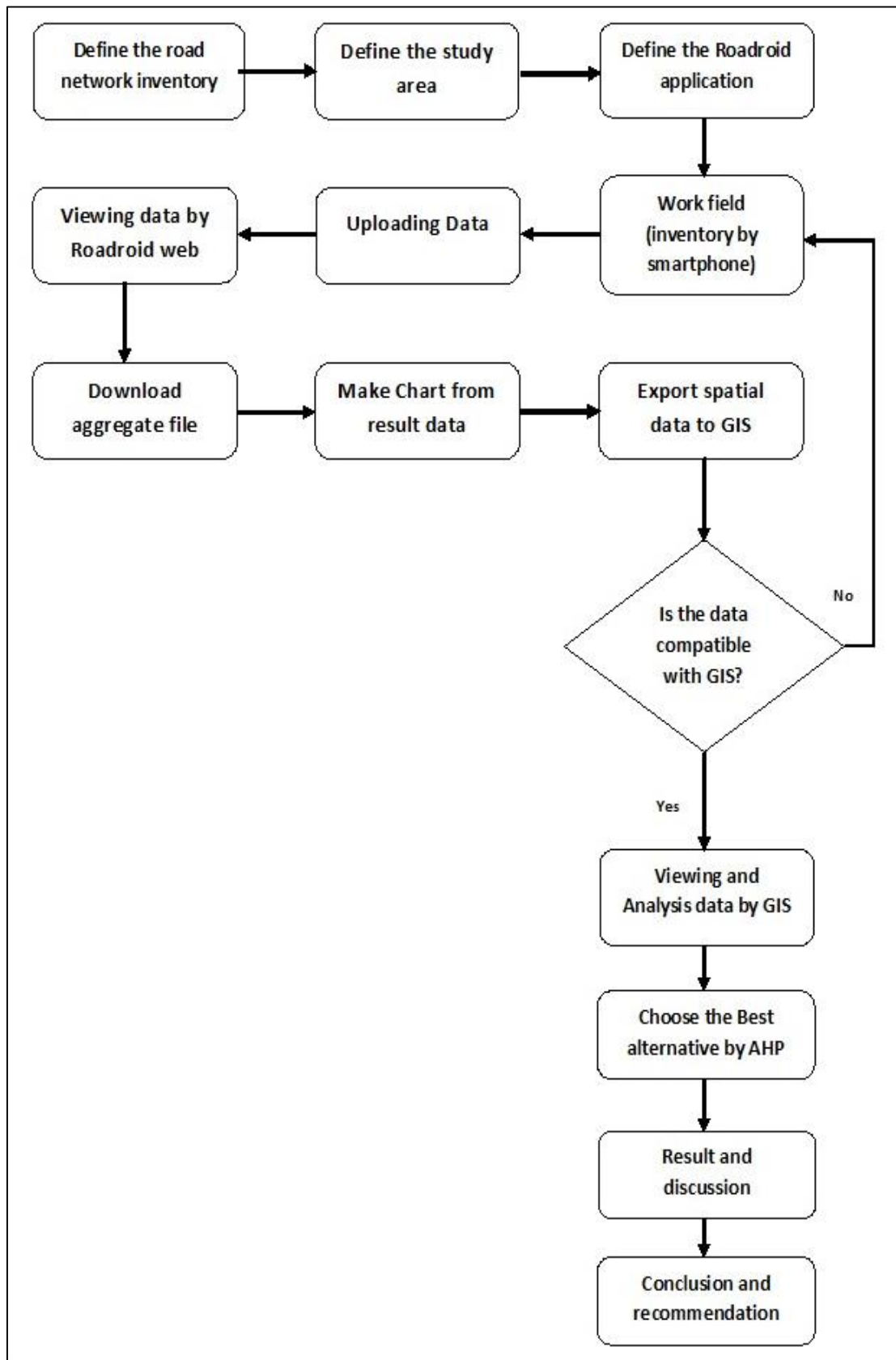


Figure (3. 1): Thesis Methodology

To manage road network inventory system efficiently, it is broken into small components. A branch does not always have consistent characteristics, therefore, it is divided into smaller manageable sections. To identify these sections, they must be measured from one reference point to another.

There is many factors to define the boundary between two sections of a branch in Deir Al-Balah road network:

- Recommended length (every one km, e.g.).
- A change in the number of traffic lanes.
- A change in pavement or surface type.
- Roadway major intersections.
- A change in pavement width.
- Deir Al-Balah Municipality standards.
- Pavement condition.
- Special factor for current situation.

3.3 Inventory Data Collection

The network data collection is the foundation of any pavement management system. Where the network is divided into sections, all the data associated with each section needs to be collected. The needed of collecting date to get enough detailed information about the network to relate it to pavement condition, traffic, cost and funding. The process of collecting general data should be done by determining the types of data needed, which data already exists in office records and the remaining data which must be gathered by a survey team.

The basic purpose of the inventory date is to provide information describing the pavement physical features. A survey team should be selected to conduct the physical inventory. The team members should have a basic knowledge of roadways in the network, the concept of sectioning and reference points and the inventory data collection procedure. As much data, as possible, should be gathered in the office before beginning the field inventory. Generally, the inventory is recorded once and will not be updated unless physical characteristics change.

The minimum required data for each street segment includes (Washington State Department of Transportation, 1994):

- Average Daily Traffic (ADT).
- Date of construction year.
- Street name, number and segment designation.
- Beginning and ending location of the segment.
- Functional classification.
- Number of lanes.
- Pavement type.
- Pavement thickness.
- Pavement length, width and area of the segment.

There is many methods to perform road network inventory including visual inspection survey, automated data collection, hand held computers, tablet computers or pocket inspectors may be developed to facilitate inspection and to eliminate data entry errors. It deals with the identification of pavement distress type, its extent and the level of severity of each type and it is also based on PCI criteria.

For this research smartphone application will be used to perform road network inventory for specific rout in Deir Al-Balah City as a case study. Case study zone illustrated in Figure (3.2).



Figure (3. 2): Case Study zone (Deir Al-Balah)

3.4 The Proposed road network inventory Components:

The software of Roadroid have been used for evaluating the use of smartphones as a very low-cost tool to make road network inventory and GIS software used as a computer system to display, analyze data on maps that results as a shapefile in Roadroid application and exported to GIS.

3.4.1 Roadroid – Smartphone Road Quality Monitoring.

Roadroid is an application that designed for Android smart phones to measure road quality. It can easily measure and monitor the road quality and also use the camera for GPS-tagged photos. Roadroid is developed since 2002, initially using accelerometer, GPS and a laptop PC to now using the built in accelerometer in a smartphone. Roadroid support different cars, speeds and phone models. Roadroid use modern technology and the highest knowledge in Android programming and global mapping services.

Roadroid is a modern, easy and cost efficient way for road roughness data collection. The Roadroid app is using the smartphones built in accelerometer to analyze the road vibrations and its GPS to position the data. Roadroid also have a separate road inventory application to be used for ocular inspections. This app saves manual input of standard road inventory parameters as rutting, cracks, pothole, bleeding Edge breaks etc. in an efficient way. Instead of using pen and paper you simply add the occurrence of each parameter while inspecting and the data is saved with position data to be viewed on the web maps.

Continuous data collection will enable monthly Road condition change reports, with a trend indicator to monitor roughness development over time. The information can directly guide pot-hole fixing and urgent patching. The data can also be given as a dynamic feed to your asset management system or road maintenance management system. Roadroid can work as an early warning system to see when and where a road is changing state and can be an important input for preventive measures and fixes. And we do have specific reports for this purpose.

3.4.1.1 Roadroid application work

The following steps are performed to construct road network inventory by Roadroid application to collect data in the proposed rout of the case study in Deir AL-Balah city.

1. Collecting data

- For this project, a smartphone Sony Xperia Z3 was used as data logger and video recording device. The test was conducted traveling at average speed as possible between 20 and 100 km/h. Vehicle adjusted to traffic conditions so that the traffic flow was not impaired. As much as possible, the vehicle was driven following a parallel path to the road centerline.
- It's important to put the smartphone inside the car in a position very similar to the position of the driver's eyes. This method allows for a more accurate filming of what the driver really sees. The recording will be more suitable to be used to study deficiencies in the road perspective as seen by the driver, for instance, in cases of dips.
- The smartphone attached to the windscreen by holder (see Figure 3.3). The strength of the holder joint provides an extremely accurate orientation of the camera. Furthermore, the smartphone phone location precisely at the driver's line of sight allows the driver to both focus and easily activate and deactivate the recording, if required. Roadroid's interface was designed so that the information on the screen and the activation buttons remain easily accessible by the driver. When sensors, GPS and camera are continuously in use, the smartphone battery barely lasts 1 h. For this reason, the smartphone has to be connected to the car power outlet.



Figure (3. 3): Smartphone on the Windscreen

- Different smart phone models return different measuring values (mainly accelerometer sensitivity and sample frequency) and also there are differences between different car model, especially at low speeds, so in the Roadroid application you can choose the smart phone model and the car model (see Figure 3.4).

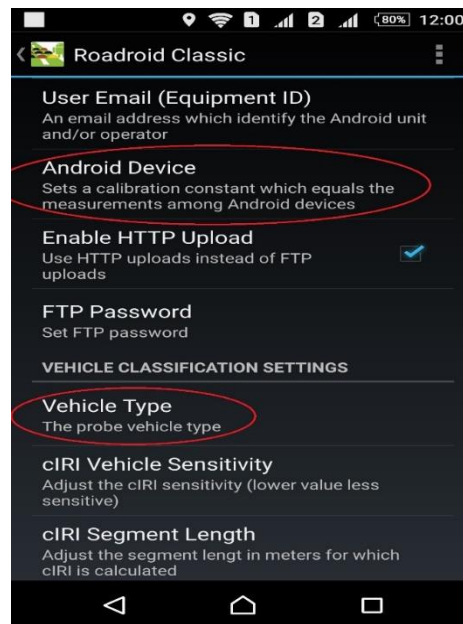


Figure (3. 4): Choose smart phone model and vehicle model in Roadroid application

- Starting the Roadroid application by fitting adjustment (see Figure 3.5). While fitting adjust the phone to X, Y and Z as close to = 0 as possible. The OK button will turn green when you are within the tolerances.
- After fitting adjustment and define android device and vehicle model, the collection data has been started by pressing “Start/stop sampling” (see Figure 3.5). Measurement starts only if a GPS signal is available.

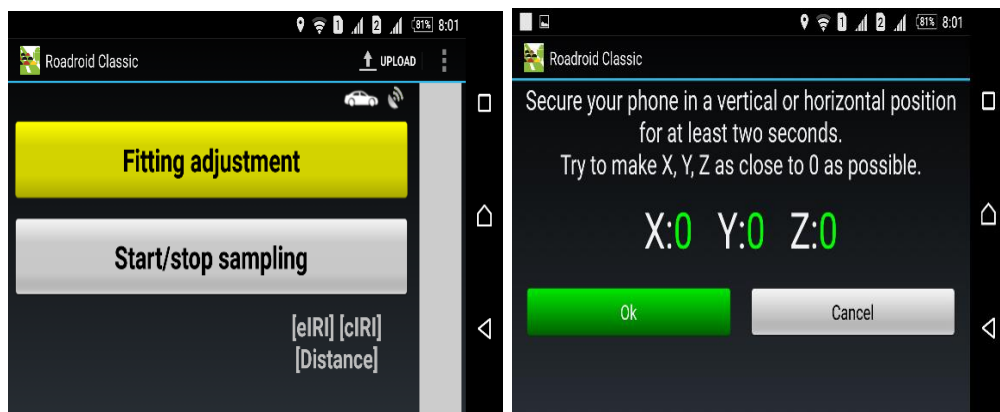


Figure (3. 5): fitting adjustment of Roadroid application and “Start/stop sampling”.

- Driving a car in the proposed route of the case study during smartphone start sampling (see Figure 3.6).
- Estimated IRI values are collected in speeds between 20-100 km/h and Calculated IRI can be adjusted in settings and should be collected in a stable speed of 20-100 km/h.
- Making a note as road section ID/name to keep track of files by Pressing “Start/stop sampling” to stop measurement.
- Making a good plan of how to collect data by pressing start/stop in logical intersections of the road.
- Choosing a preferred auto photo capture length/distance in setting and ensure you got a good view of the road with the camera lens.

Figure (3.6) shows the path that has been followed in Deir Al-Balah city while measurement of IRI by smartphone.

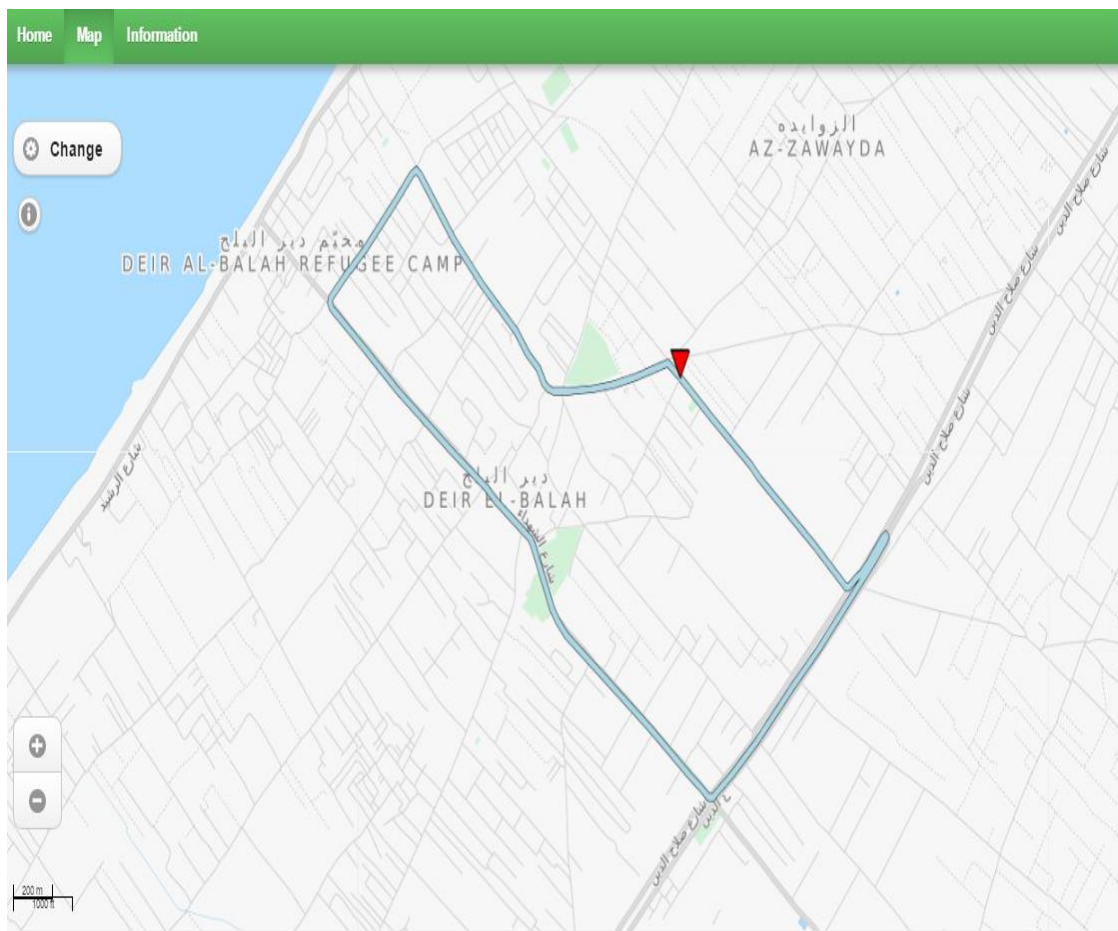


Figure (3. 6): The proposed route of the case study in Deir Al-Balah City illustrated in Roadroid web service.

2. Uploading data

To upload data, Smart-Phone need to be connected to the internet.

- After connecting to the internet, collected roughness data and Media has been uploaded by pressing the “Upload” up and then Choose Data you need to upload (see Figure 3.7). A new roughness survey file and photos is saved each time when pressing Start/stop.

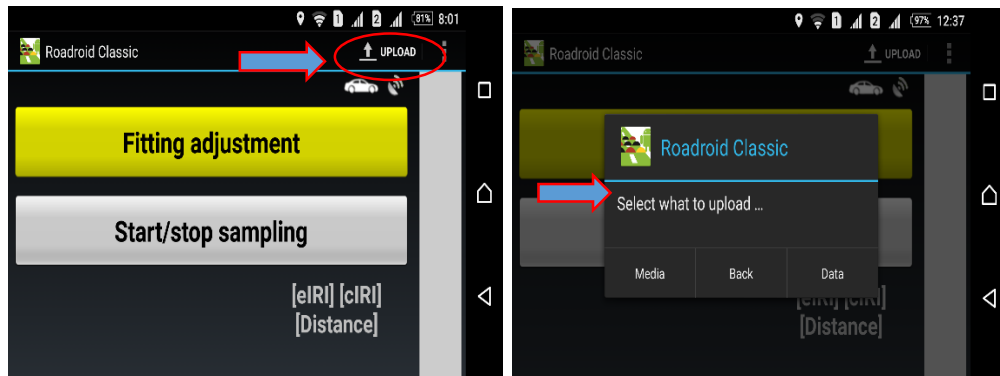


Figure (3. 7): Uploading data collected in Roadroid application.

3. Viewing data by the Roadroid web service

When data is successfully uploaded, it will be imported to the web (www.roadroid.com) within an hour and view the data is through the Import history list (see Figure 3.8).

Import date	User Name	Unit Name	File Name	Import Status	Road Id	Measurement Length (m)	Type	Details
8/6/2016 6:40:10 AM	univ_gaza	Mohammed01	356161066169939-20160806072107-6966c502-RC.zip	Import OK	DB	6769	RoadCondition	Details
8/6/2016 6:40:03 AM	univ_gaza	Mohammed01	356161066169939-20160617182255-6777000-RC.zip	Import OK	aa	0	RoadCondition	Details
8/5/2016 9:40:10 AM	univ_gaza	Mohammed01	356161066169939-20160805101918-25fb3b2b-RI.zip	Import OK	DB	5545	Inventory	Details
8/5/2016 9:40:02 AM	univ_gaza	Mohammed01	356161066169939-20160805103325-f70f41f7-REM.zip	Import OK			RoadEvent	Details

Figure (3. 8): Import aggregated files from Roadroid web service.

Showing the file information by clicking on “Details” and then all the data can now view on the map (See Figure 3.8).

Viewing data on map by clicking “[Zoom to measurement area on map](#)”. (See Figure 3.9 & Figure 3.10).

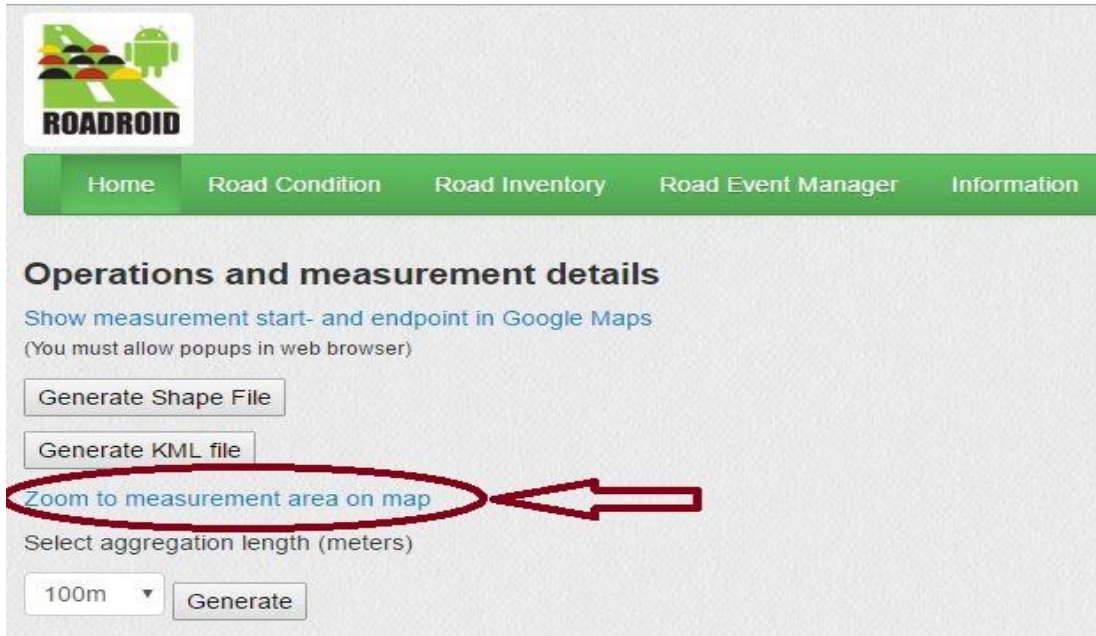


Figure (3. 9): Operation and measurement details

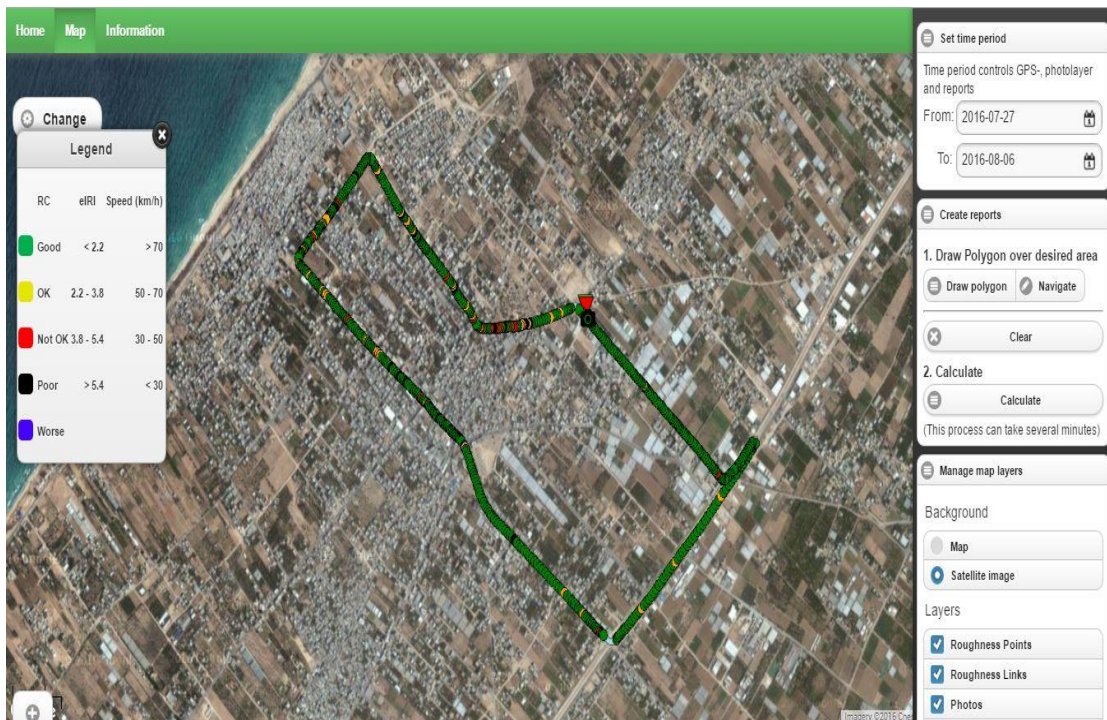


Figure (3. 10): Viewing data on map

eIRI – labels will occur at each dot when zoom in to the map at certain zoom level (See Figure 3.11).

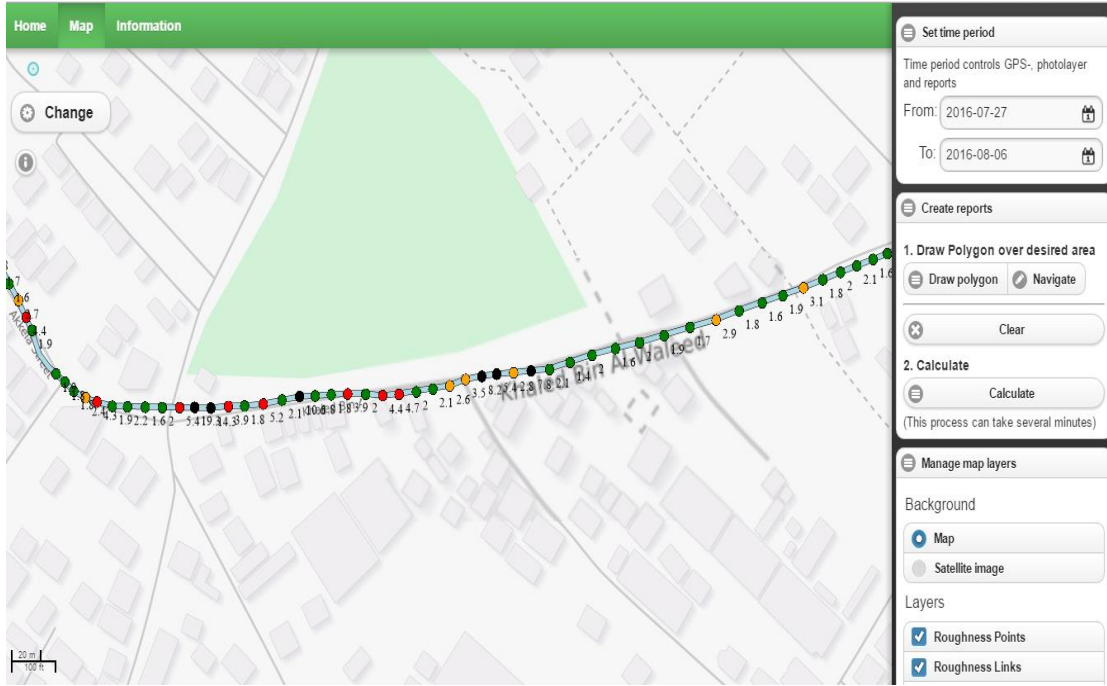


Figure (3. 11): eIRI – labels at each dot when zoom in to the map.

The road condition data are divided into four different levels of road quality (RQ): green for good; yellow for satisfactory/OK; red for unsatisfactory/not OK and black for poor (See Table 3.1).

The mobile app stores a number of data values each second into a CSV (comma-separated value) file. But to get an overview on a larger scale, it is more convenient to use road links with aggregated and averaged measurements than individual sampled dots.

Table (3. 1): Pavement Condition Criteria (Roadroid)

Roughness Category	IRI Value	
	m/km	Color
Good	<2.2	Green
Satisfactory/OK	2.2 – 3.8	Yellow
Unsatisfactory	3.8 – 5.4	Red
Poor	> 5.4	Black

Depending on the spatial road database, there will be many opportunities to refine the data and add attribute information such as road width, traffic volumes, etc. The road condition data can be exported in shape format to other systems.

Roadroid is an application delivering data, but it also needed a viewer, an internet based map tool to present the data. There is dots of quality and coordinates, and this research use the Deir Al-Balah Road network Database as an Open Layer on Google maps and to relate the dots to the Deir Al-Balah Road network Database links. Data was zipped in the smartphone and sent by an FTP service to Roadroid's webserver in the cloud. This operation was performed after finishing measurements and through a Wi-Fi connection. Data files from different Android apps/units ends up on the server directory and in a daily routine they are unzipped and the data placed in a GEO-database for monitoring on the web map.

On the map it could now first see the dots, and then the dots mapped to the Deir Al-Balah Road network Database links. As the single dots are sampled each second, it is hard to get an overview in larger scale and it is therefore much more convenient to use a road geometry.

Getting the percentage of each 4 road classes good – Poor and an average estimated IRI by drawing polygon active for an area to calculate and then clicking "Calculate" (See Figure 3.12).

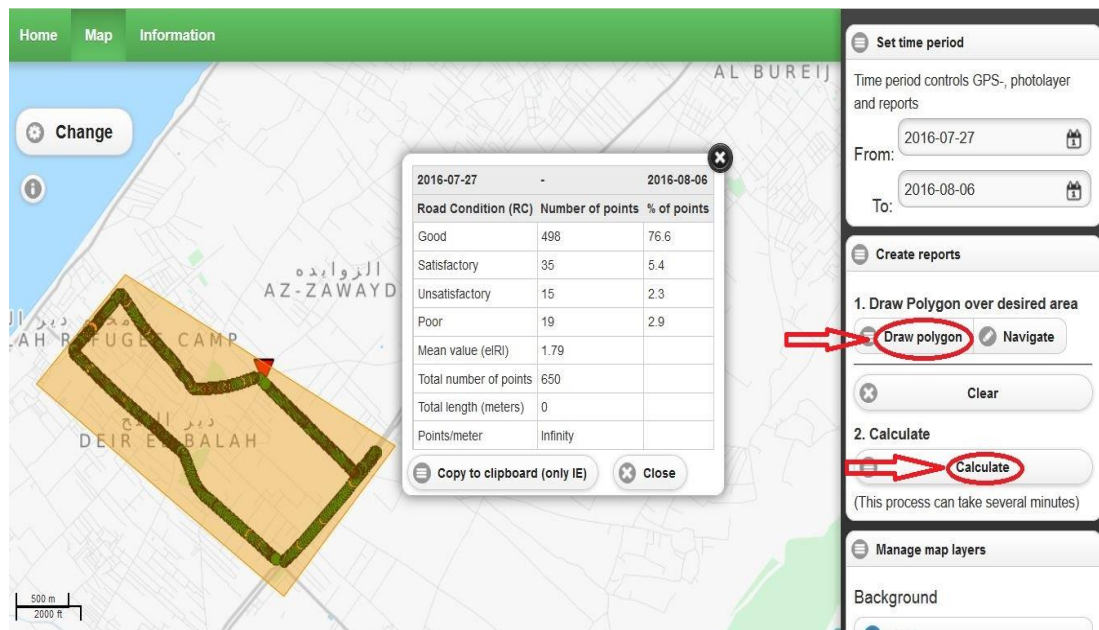


Figure (3. 12): Viewing data by the Roadroid web service

6. Exports spatial data from Roadroid web Service to GIS.

Under file details, data is exported in spatial formats as Shape files form “Generate Shape File” to use it in GIS software (See Figure 3.15). The shapefile exported from Roadroid web service represent the rout which car follow in field work to collect data. This shapefile can inserted in GIS software to use it in analysis and viewing data.

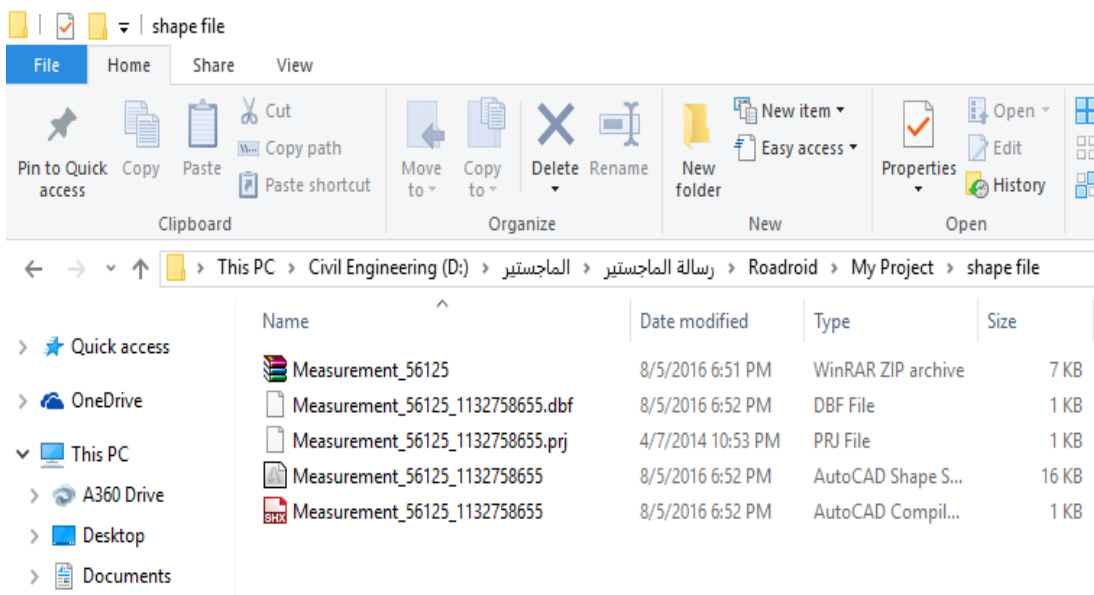
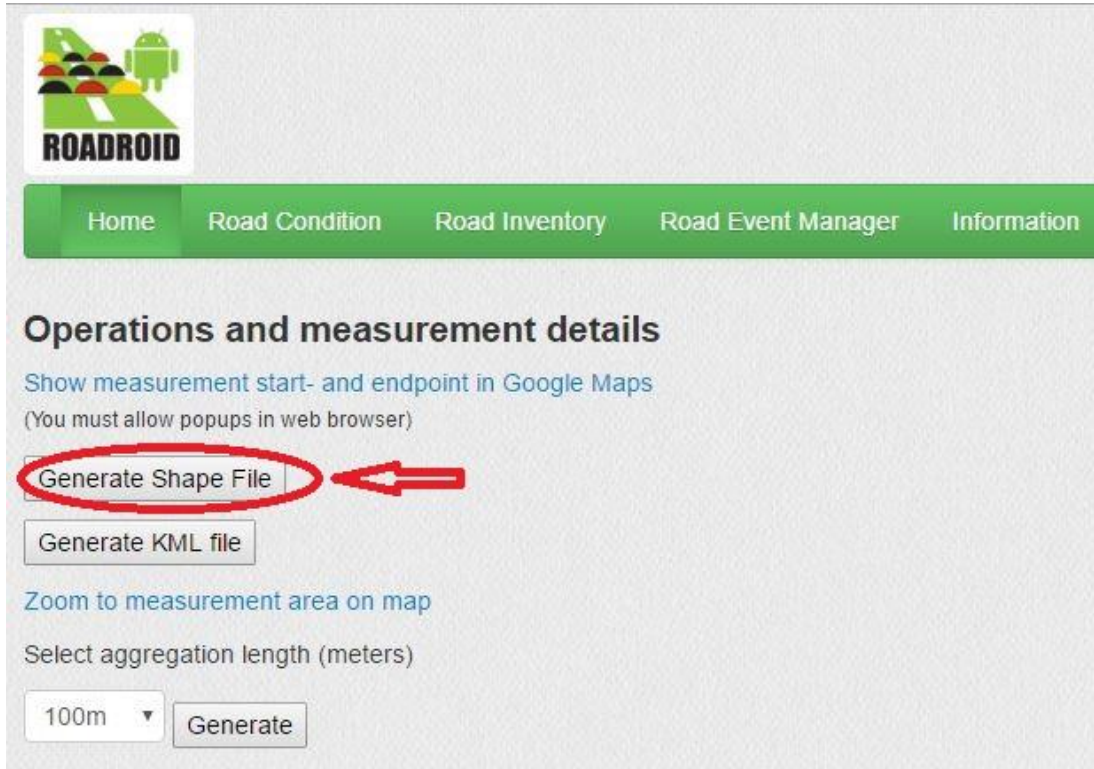


Figure (3. 15): Generate Shape File Format to be used it in GIS

3.4.2 A Geographic Information System (GIS):

It's a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. GIS can show many different kinds of data on one map. This enables people to more easily see, analyze, and understand patterns and relationships.

GIS tool offers a complete set of spatial analysis and provides a high-performance decision support. With GIS technology, people can compare the locations of different things in order to discover how they relate to each other.

GIS can use any information that includes location. The location can be expressed in many different ways, such as latitude and longitude or address. Many different types of information can be compared and contrasted using GIS. The system can include data about people, such as population, income, or education level. It can include information about the land, such as the location of streams, different kinds of vegetation, and different kinds of soil. It can include information about the sites of factories, farms, and schools, or storm drains, roads, and electric power lines. Figure (3.16) shows the main page screen of the ArcGIS- ArcMap.

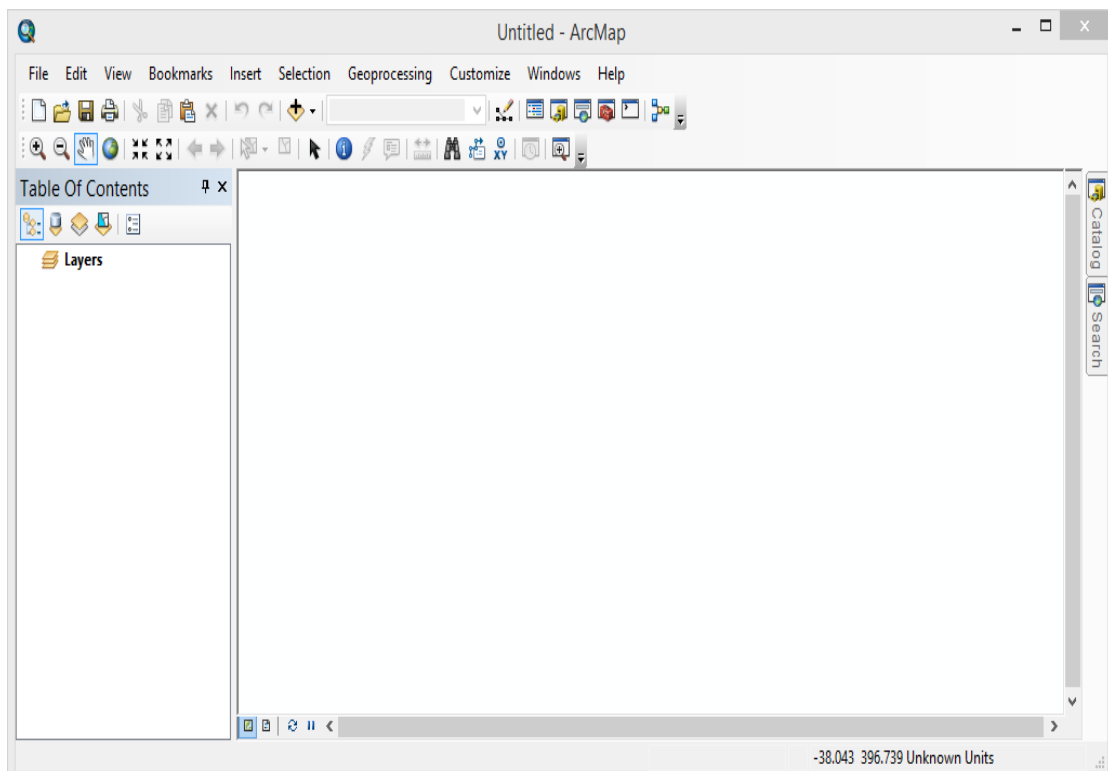


Figure (3. 16): The Main Page Screen of ArcMap.

The following steps are performed to construct GIS work that analysis the data resulting from Roadroid smartphone application:

1. Add shape file that result from Roadroid application, which represents the path of the road in case study in Deir El-Balah. This task is illustrated in Figure (3.17).

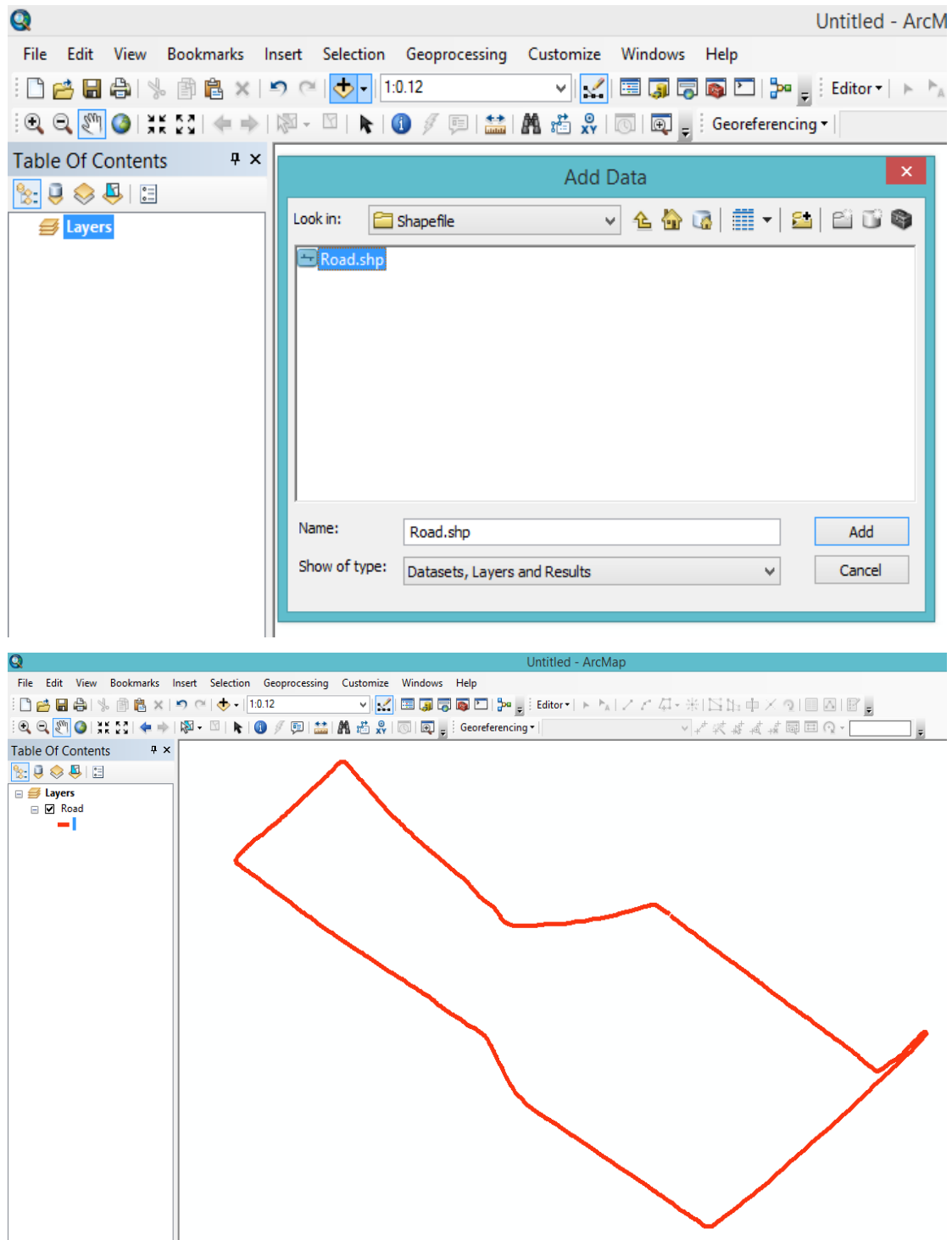


Figure (3. 17): Add shape file that result from Roadroid application.

2. Defining the local coordinate system of Palestine in the GIS for the Road shapefile, "Palestine 1923 Palestine Grid" from "ArcToolbox" > "Projections and Transformations" > "Define Projection". This task is illustrated in Figure (3.18).

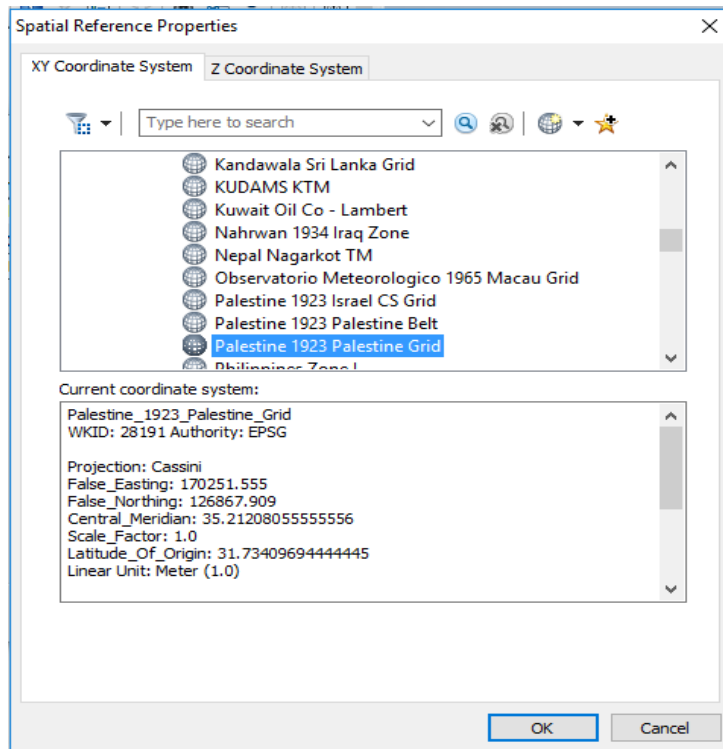
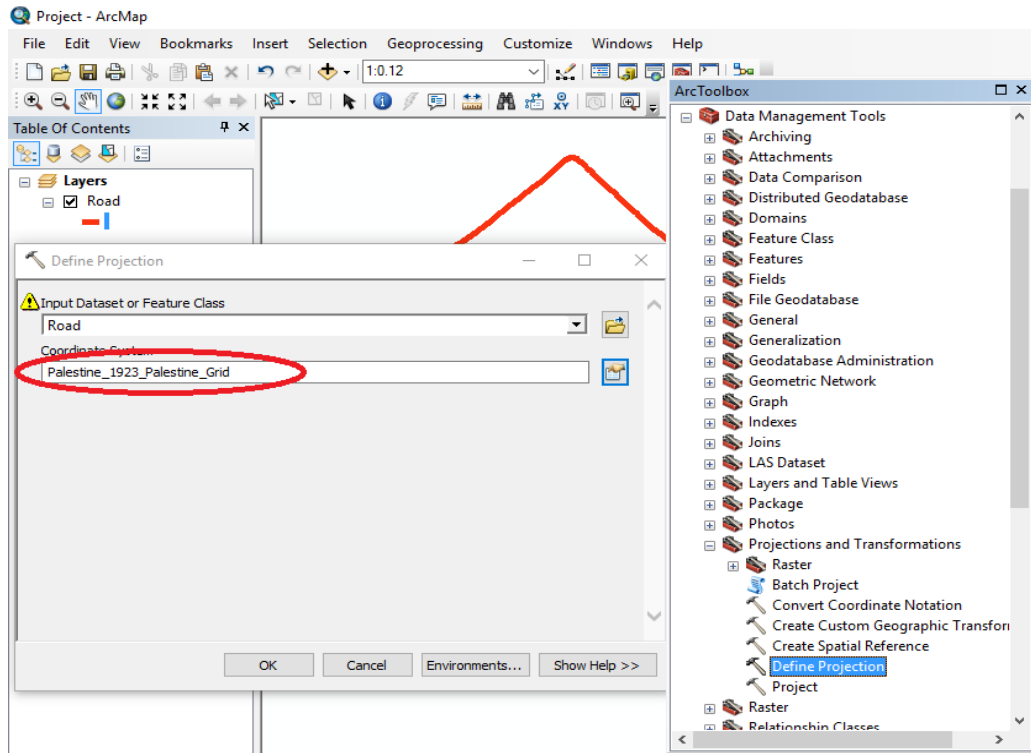


Figure (3. 18): Gaza Coordinate System Definition.

3. Adding Deir al-Balah aerial photo which obtained from the municipality of Deir al-Balah. This task is illustrated in Figure (3.19).

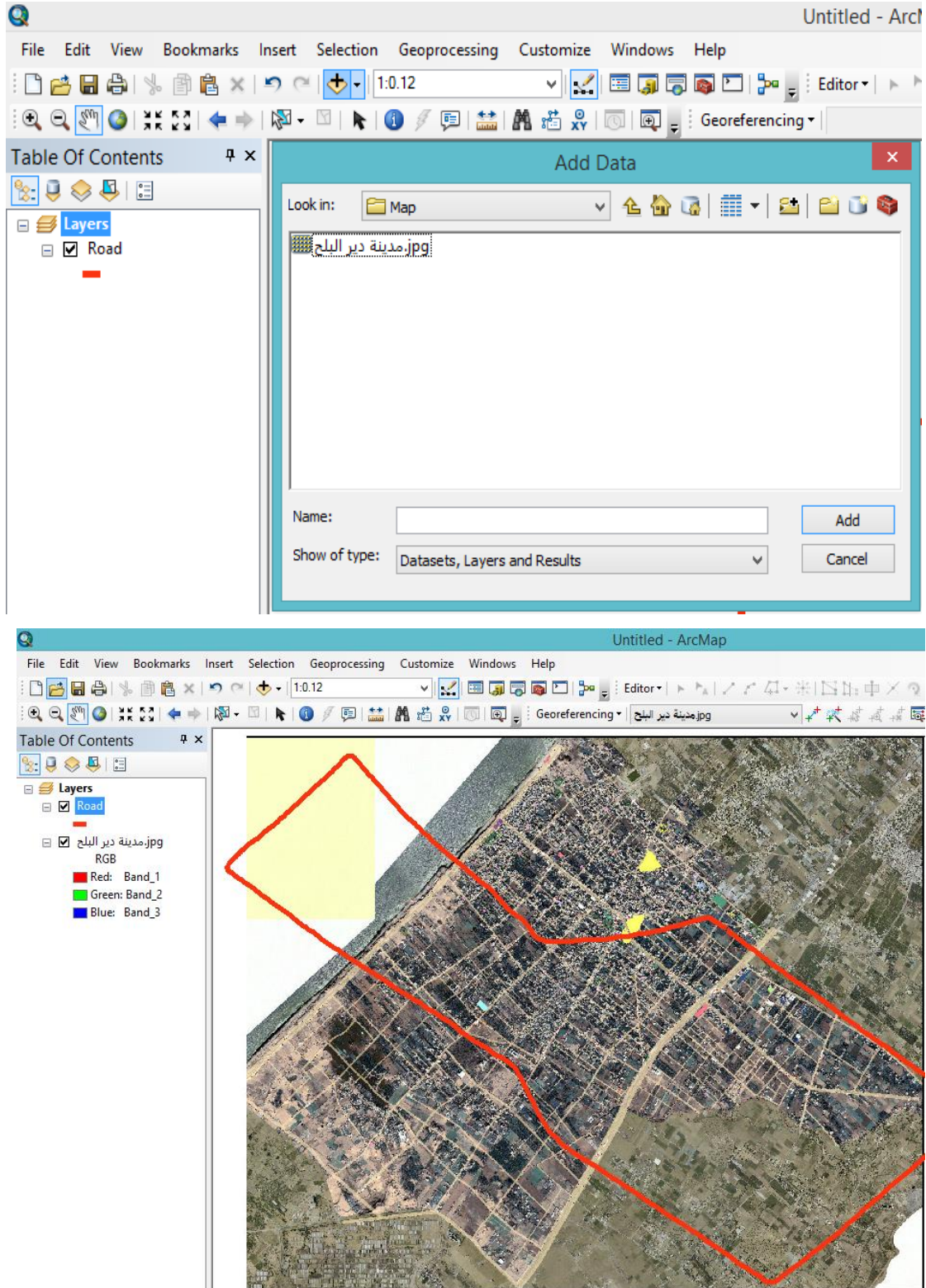


Figure (3. 19): Adding Deir Al-Balah Aerial photo.

4. It's obviously that the aerial image doesn't match with the path of the road imported from Roadroid smartphone application, so it must do Georeferencing to match it. The Georeferencing by linking uncorrected data (Raster) which represents aerial image with corrected data (Vector) which represents the route. This task is illustrated in Figure (3.20).

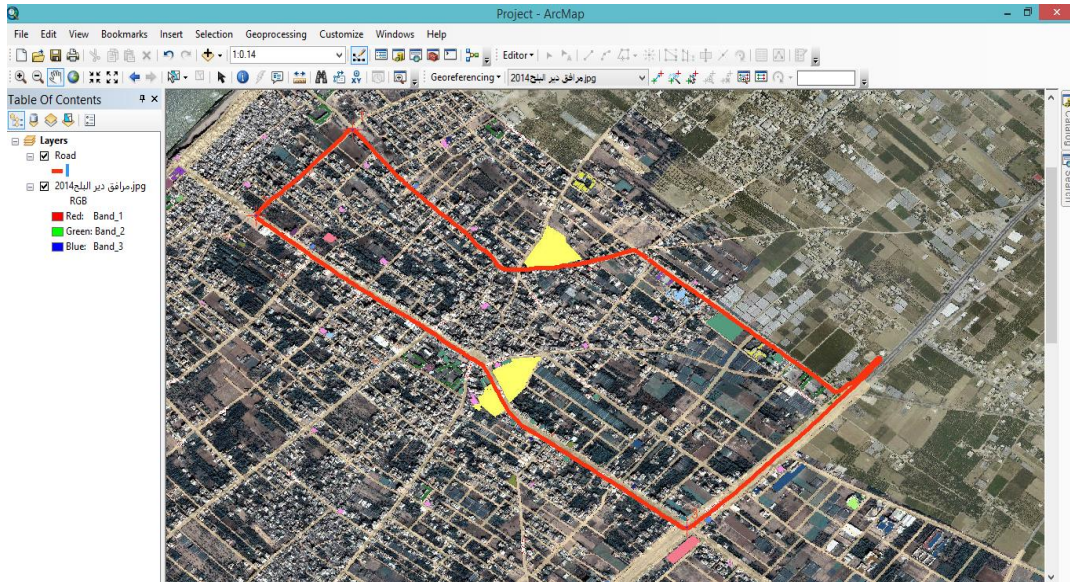


Figure (3. 20): Georeferencing Raster data with Vector data.

5. Adding IRI data that results from Roadroid application and saved as Excel format and set local coordinate system of Palestine from “Edit” > “Palestine 1923 Palestine Grid S”. This task is illustrated in Figure (3.21).

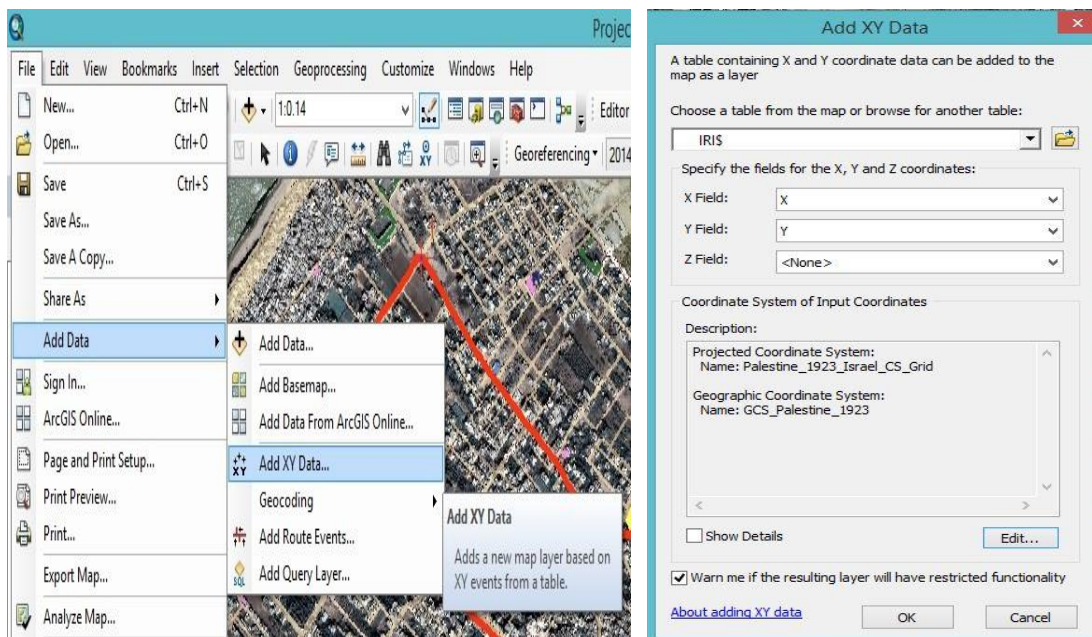


Figure (3. 21): Adding IRI data to ArcMap.

6. Convert IRI from text file to Shapefile through “Data” > “Export Data”. This task is illustrated in Figure (3.22).

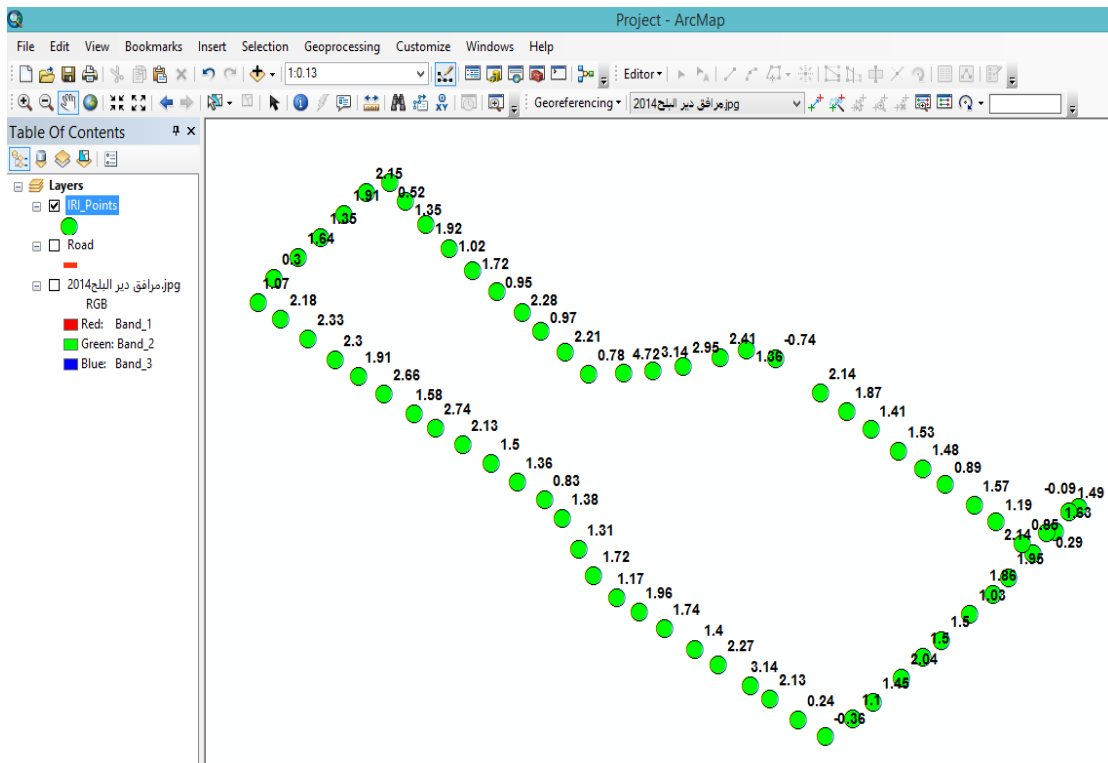
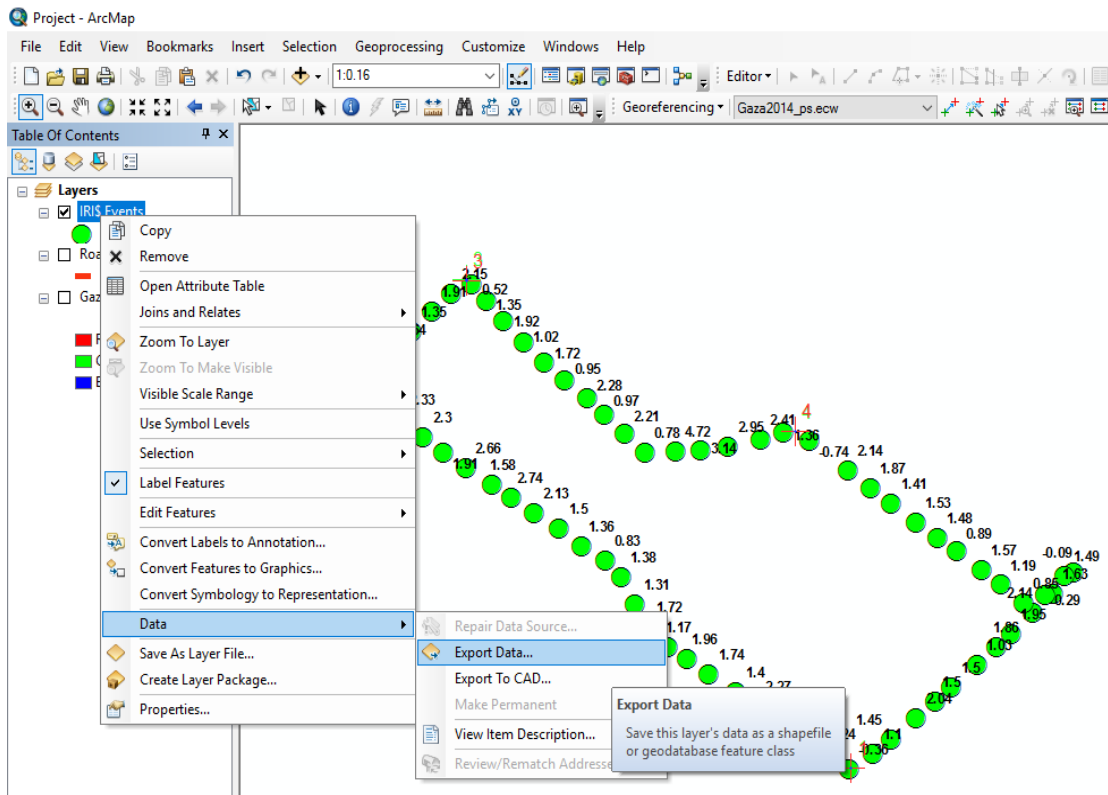


Figure (3. 22): Convert IRI from text file to Shapefile

7. By GIS, geographic data of various levels can be View, Analysis and Visualization. See figure (3.23).

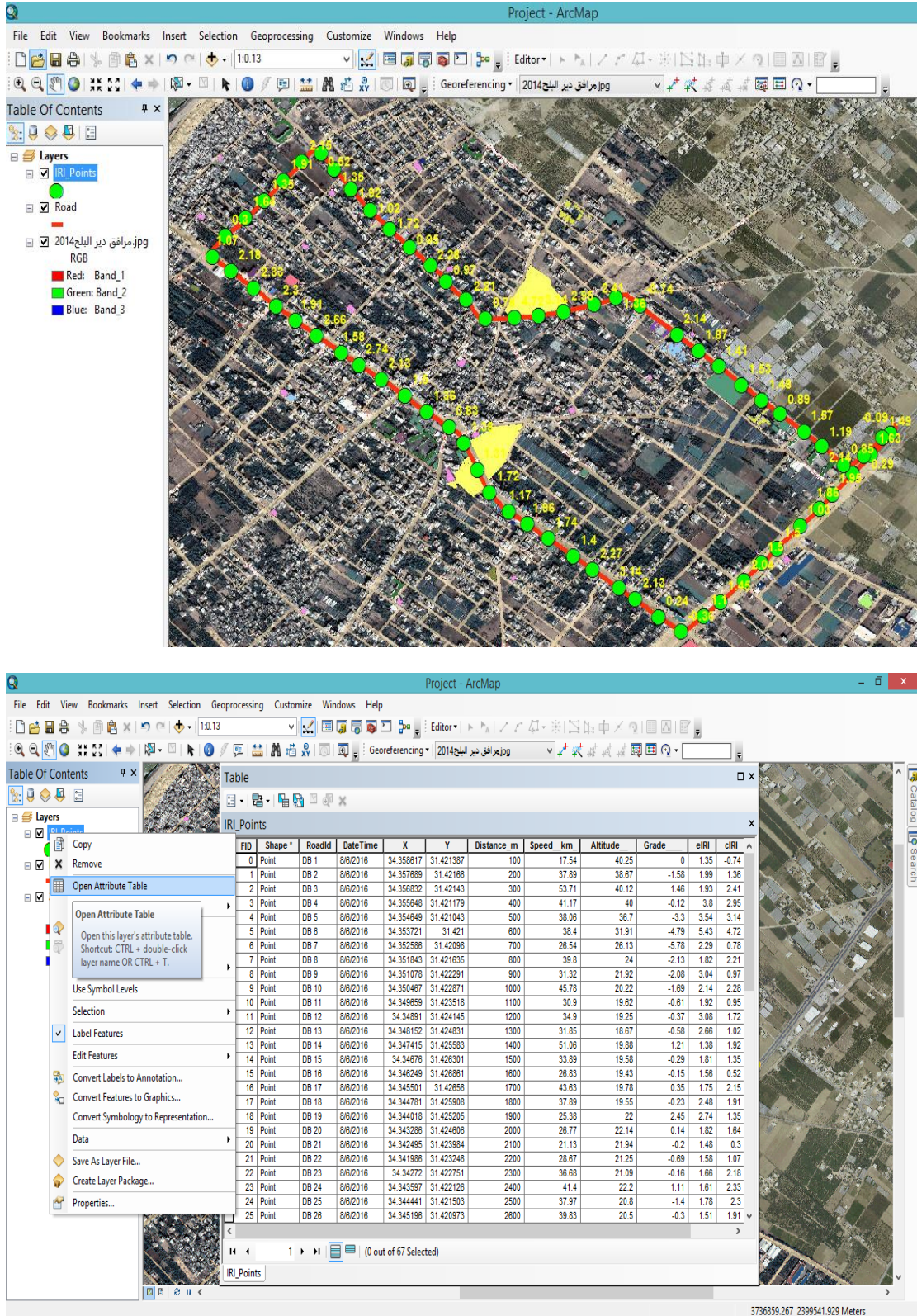


Figure (3. 23): Viewing, analysis and visualization of geographic data by GIS

8. IRI can be classified according to roughness category which has been clarified in table (3.1) through “Properties” > “Symbology” > “Quantities” > “Graduated colors”. This task is illustrated in Figure (3.24).

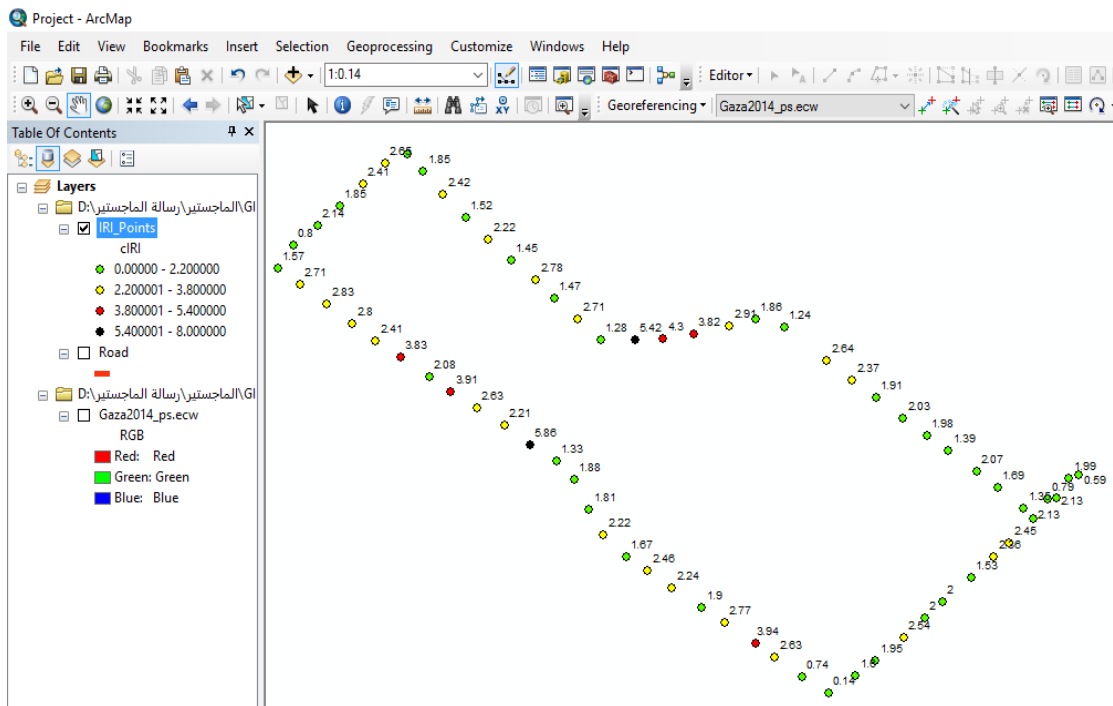
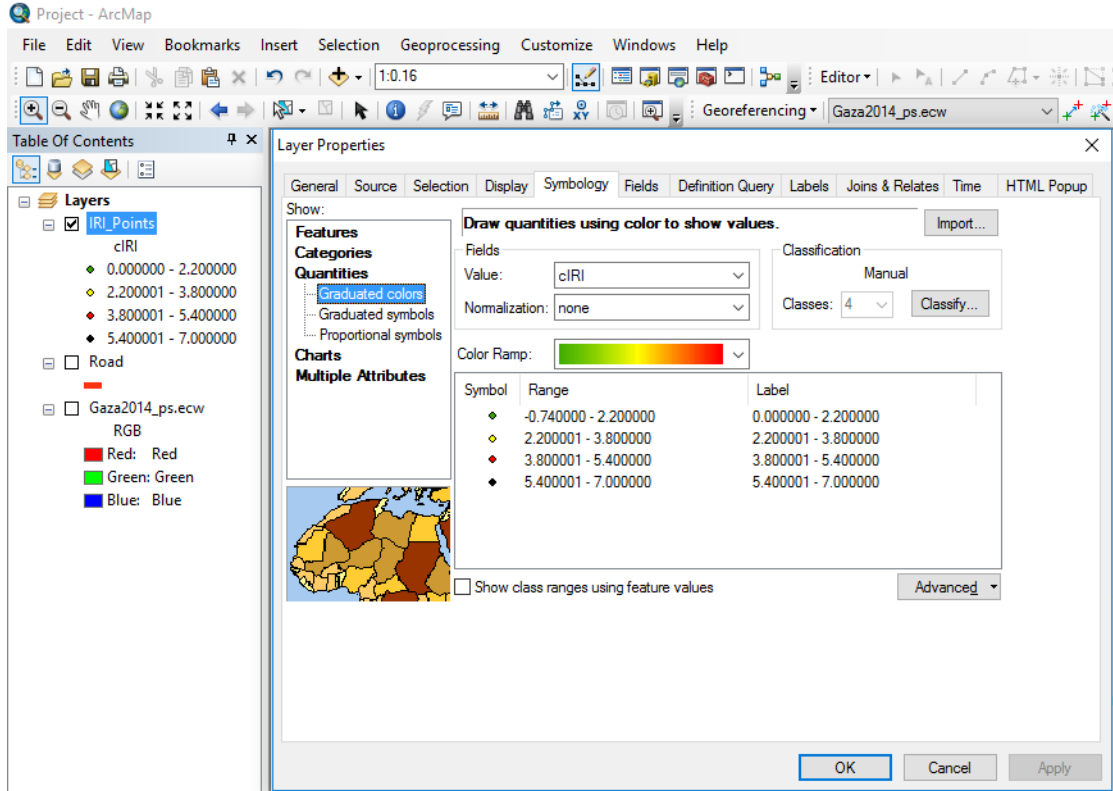


Figure (3. 24): IRI Symbology in ArcMap

9. Roughness Categories can be summarized in separate table to be used in drawing graph. This task is illustrated in Figure (3.25).

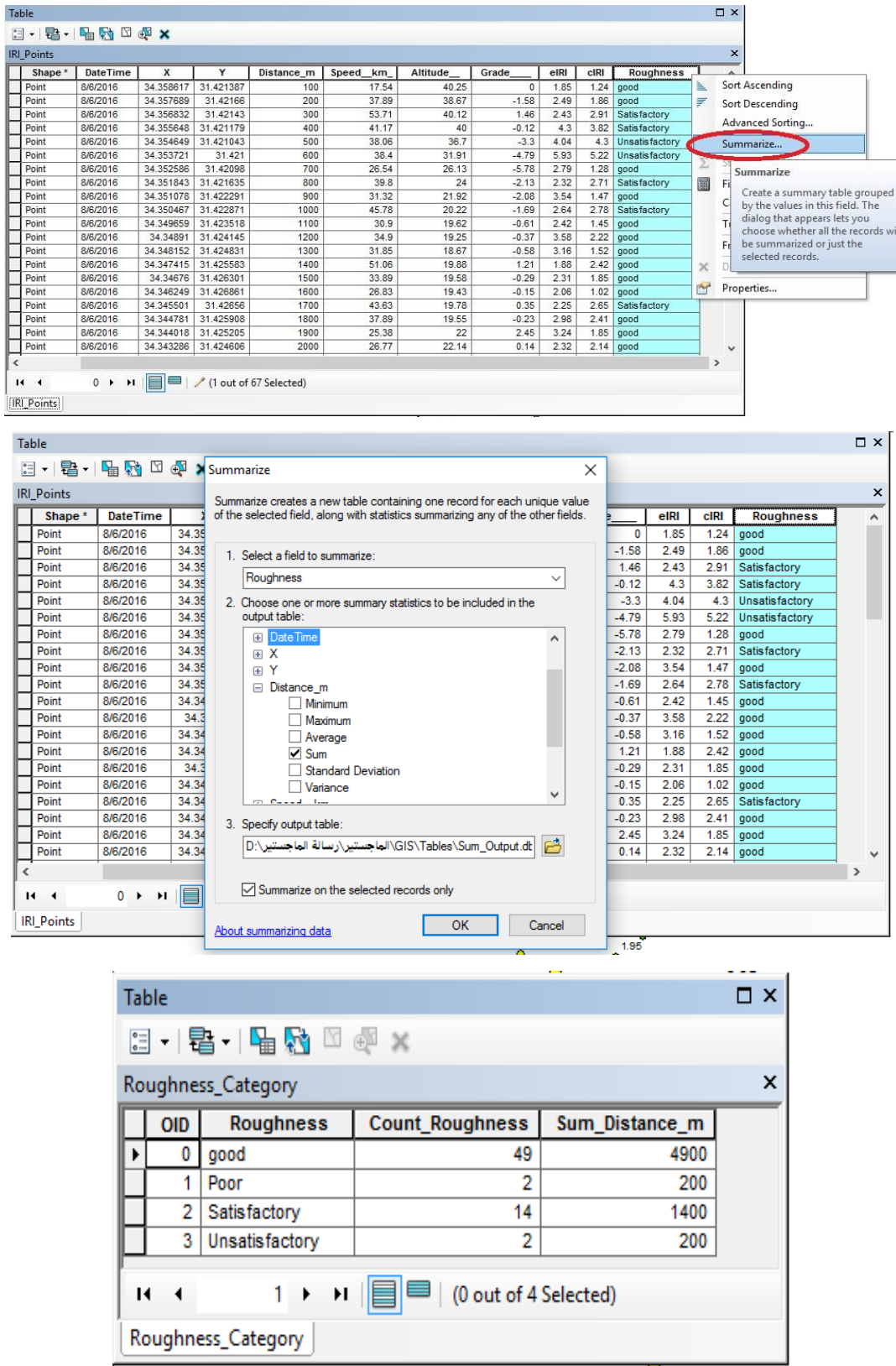


Figure (3.25): Summarize Roughness Categories

10. Roughness Categories can be clarified in diagram through “View” in Toolbar > “Graphs” > “Create Graph”. This task is illustrated in Figure (3.26).

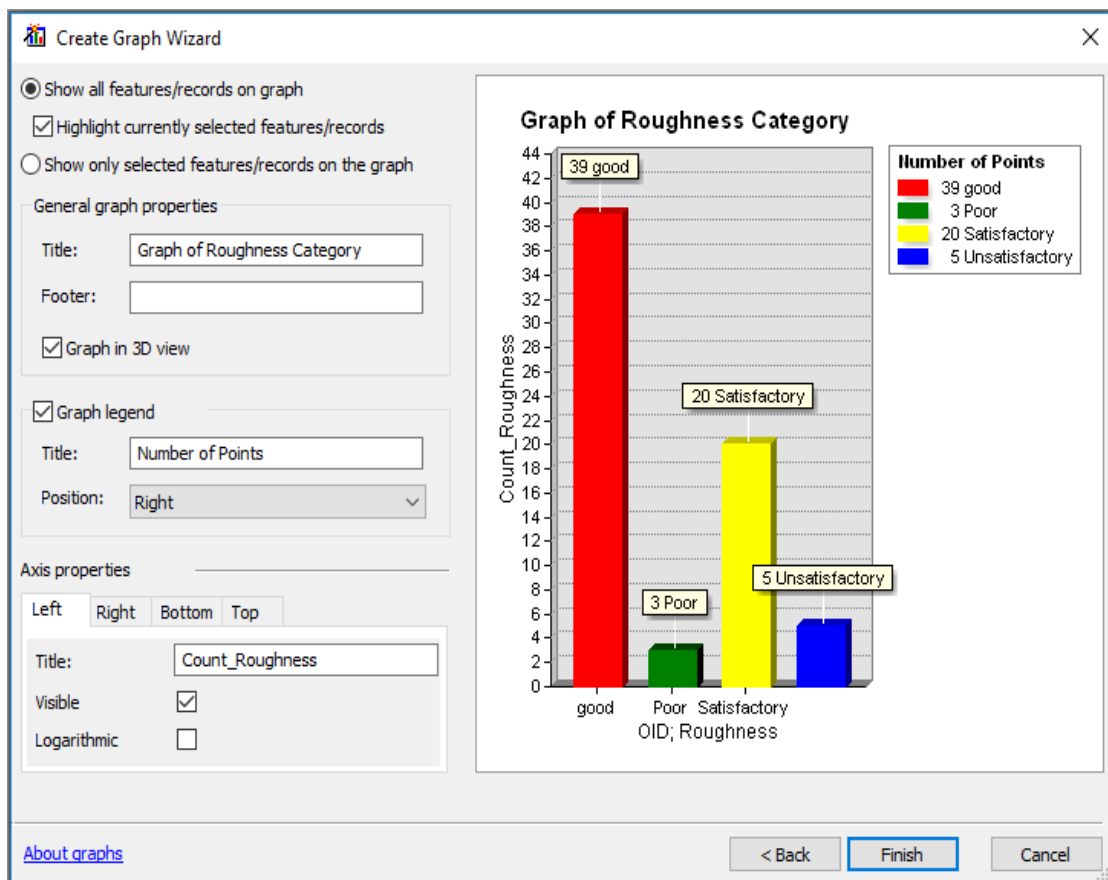
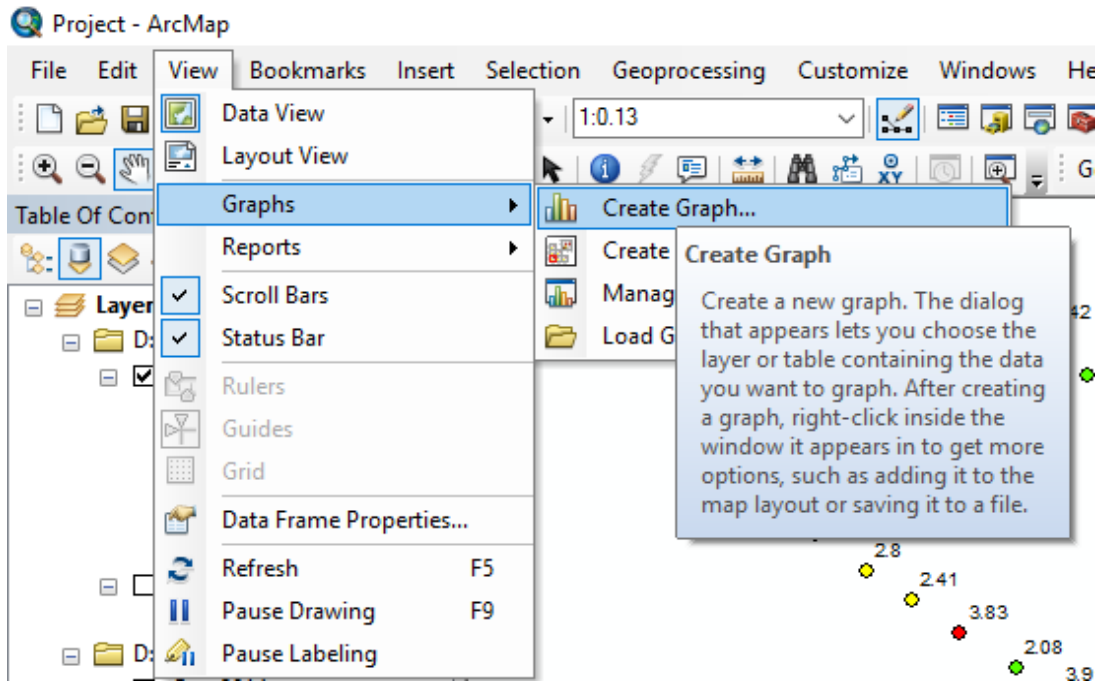


Figure (3. 26): Roughness Categories diagram in ArcMap

3.5 Analytical Hierarchy Process (AHP)

AHP is a multiple criteria decision-making tool. This is an effective tool for dealing with complex decision making, and may aid the decision maker to set priorities and make the best decision. By reducing complex decisions to a series of pairwise comparisons, and then synthesizing the results.

3.5.1 Analytic Hierarchy Process Methodology

There are several steps to reach to the best alternative by AHP, as shown in a flow chart illustrated in Figure (3.27) which explain the methodology of AHP followed in this research.

3.5.1.1 Identify the Alternatives and Criteria.

This step is to identify the problem, the alternatives and evaluation criteria. Which the problem is structured in all its aspects. For this research the alternatives are “visual inspection survey, Smartphone application, aerial/Satellite images” as shown in Table (3.2) and the criteria used to choose best Road Network Inventory method in Gaza Strip are “Cost, Time period, Data Quality and accuracy, Available resources, Environmental Impact” as shown in Table (3.3).

Table (3. 2): alternatives used in AHP method

alternatives	Definition
visual inspection survey	Road network inventory through using of crews to work and collecting data manually. This inventory method need a lot of time and effort.
Smartphone application	Road network inventory using the latest generation of smart-phones application such as Roadroid, Road recorder and other applications. This inventory method is used in this research.
aerial/Satellite images	Road network inventory using aerial/Satellite images. Depending on the availability of aerial/Satellite images, which can be expensive but it can save time in road network inventory.

Table (3. 3): Criteria used in AHP method

criteria	Definition
Cost	The cost of road network inventory include equipment, crew and total needed fund.
Time Period	The period of time it takes to process the road network inventory.
Data Quality and Accuracy	Data are generally considered high quality if, "they are fit for their intended uses in operations, decision making and planning.
Available Recourses	Availability of machines and technology used for road network inventory
Environmental Impacts.	The influence of the surrounding environment on the roads inventory process.

3.5.1.2 Hierarchical structure of the problem:

The final structure of the problem including the goal, criteria, and alternatives is now ready to be evaluated to achieve appropriate Road Network Inventory method. The hierarchical structure is shown in figure (3.27).

The goal is to structure the problem into a hierarchy. A hierarchy is a tree like structure that represents a complex problem on a number of levels. The first level is the goal to be achieved, followed by criteria and so on down to the last level at which alternative are located. The number of levels in any hierarchy depends on the amount of information requested by the decision makers to evaluate the system and the complexity of the problem.

For this research: The hierarchy was consisted of two levels, the first level was the main goal of this research. It was "Selection Appropriate Road Network Inventory method", the second level was the criteria used to choose best Road Network Inventory method "Cost, Time period, Data Quality and accuracy, Available resources, Environmental Impact", and the third level was the alternatives "visual inspection survey, Smartphone application, aerial/Satellite images" as shown in Figure (3.28).

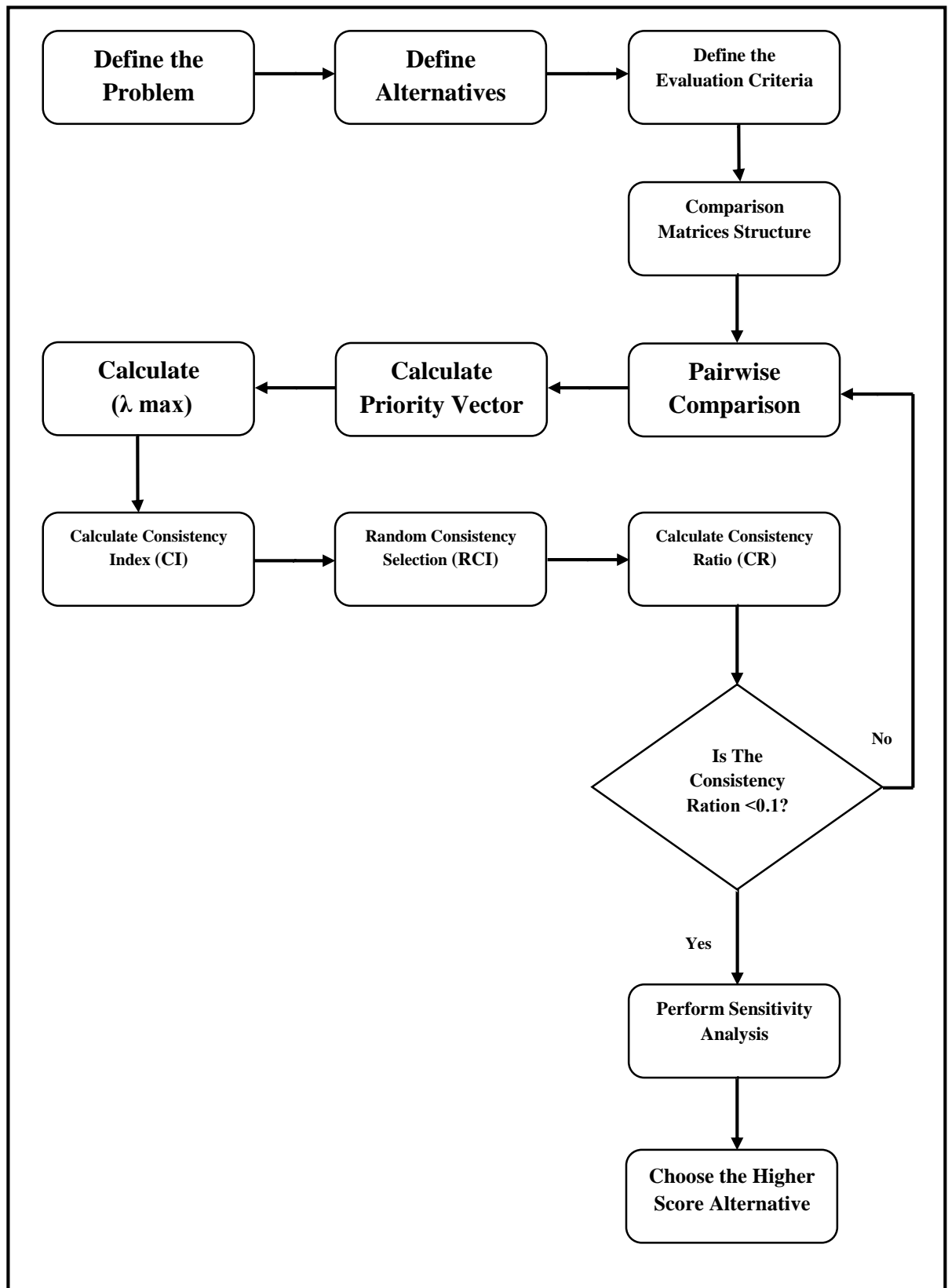


Figure (3. 27): AHP Methodology

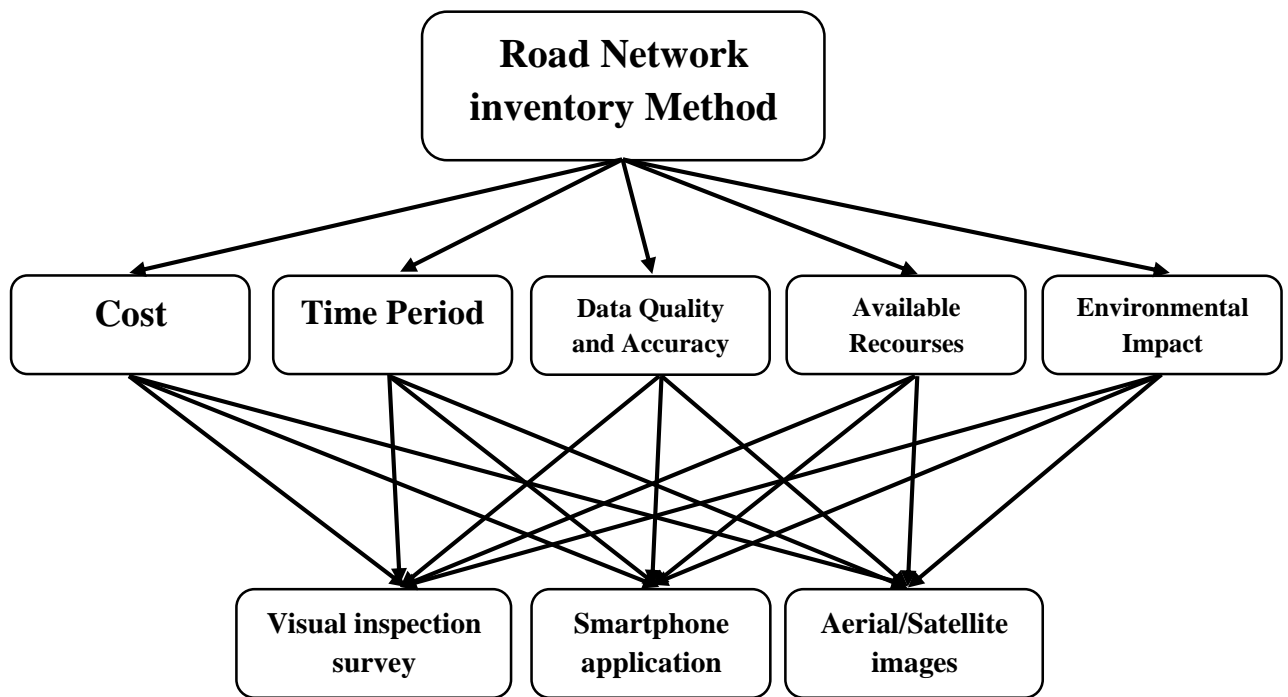


Figure (3. 28): Hierarchy of the research problem

3.5.1.3 Construct Comparison Matrices and Pairwise Comparison

The elements on the second level (criteria level) were arranged into a matrix, and the decision makers made judgments about the relative importance of the element with respect to the overall goal of selecting the most appropriate road inventory method.

The criteria within each hierarchy should be evaluated against their corresponding criteria in the level above, and then compared in pairs between themselves. If there were “n” criteria in one hierarchy, decision makers must conduct paired comparisons by $n \times \frac{n-1}{2}$.

To incorporate their judgments about the various elements in the hierarchy, decision makers compare the elements two by two. The Criteria were compared as to how important they were to the decision makers, with respect to the Goal. The AHP methodology compares criteria, or alternatives with respect to a criterion, in a natural, pairwise mode. To do so, the AHP uses a fundamental scale of absolute numbers developed by Saaty (1980) shown in (Table 3.4).

In this research the questionnaire will be filled by an interview with 10 specialists in road field from various ministries, municipalities and non-governmental organizations (NGO’s). The questionnaire is illustrated in Appendix C.

Table (3. 4): Scale of Relative Importance (according to Saaty (1980))

Intensity of Importance	definition	Explanation
1	equal importance	Two activities contribute Equally to the objective
3	Weak importance of one Over another	Experience and judgment Slightly favor one Activity over another
5	Essential or strong Importance	Experience and judgment Strongly favor one Activity over another
7	Demonstrated Importance	An activity is strongly Favored and its dominance Demonstrated in practice
9	Absolute importance	The evidence favoring one Activity over another is Of the highest possible Order of affirmation
2,4,6,8	Intermediate values Between the two Adjacent judgments	When compromise is needed
Reciprocals of above nonzero	If activity i has one Of the above nonzero Numbers assigned to it When compared with Activity j, then j has The reciprocal value When compared with i.	

Pairwise comparisons are used to determine the relative importance of each alternative in terms of each criterion. In this approach the decision-maker has to express his opinion about the value of one single pairwise comparison at a time. Usually, the decision-maker has to choose his answer among many discrete choices. Each choice is a linguistic phrase. Some examples of such linguistic phrases are: "A is more important than B", or "A is of the same importance as B", or "A is a little more important than B", and so on (see table 3.4).

Pairwise comparisons are quantified by using a scale. Such a scale is a one-to-one mapping between the set of discrete linguistic choices available to the decision maker and a discrete set of numbers which represent the importance, or weight, of the previous linguistic choices. The scale proposed by Saaty is depicted in (table 3.4).

The values of the pairwise comparisons in the AHP are determined according to the scale introduced by Saaty (1980).

According to this scale, the available values for the pairwise comparisons are members of the set: {9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9} (see table 3.1).

In this Research: The tables of the pairwise comparison matrices were developed with its differentiation values mobilized from the survey (data collected by an interviews) for the criteria with each other like the table (3.5) in additional for the alternatives with respect to each criterion separately. The tables of the pairwise comparison matrices presented in the chapter of results individually.

Table (3. 5): Criteria pairwise comparison.

Criteria	Cost	Time Period	Data Quality and Accuracy	Available Recourses	Environmental Impacts
Cost	1	3.50	0.50	4.33	5.40
Time Period	0.29	1	0.28	3.80	4.40
Data Quality and Accuracy	2.00	3.60	1	5.80	6.60
Available Recourses	0.23	0.26	0.17	1	3.30
Environmental Impacts	0.19	0.23	0.15	0.30	1

3.5.1.4 Check Consistency of Matrices

AHP provide a measure of consistency to reduce the inconsistency inherent in the judgment process. This measure is known as the consistency ratio (CR). The value of the consistency ratio should be 10 percent or less. If it is more than 10 percent, the judgments may be somewhat random and should perhaps be revised.

In this Chapter: The CR calculated for each pair wise comparison matrix depending on the following standard steps, with surrounding one example of the calculated CR for the first criterion (COST).

a) Calculating the Priority Vector for a Criterion

After it has been mobilizing the pairwise comparison matrix for the cost criterion as shown in the Table (3. 6). Now comes the role of calculating the priority vector.

Table (3. 6): Pairwise comparison with cost.

<i>Cost</i>	<i>Visual inspection survey</i>	<i>Smartphone application</i>	<i>Aerial/Satellite images</i>
<i>Visual inspection survey</i>	1	0.37	4.30
<i>Smartphone application</i>	2.70	1	6.30
<i>Aerial/Satellite images</i>	0.23	0.159	1

Table (3.7) Show the synthesized matrix for Cost criterion, this matrix was calculated to measure the priority vector through it, the marked value 0.254 in Table (3.7) was obtained by dividing 1 (from Table 3.6) by 3.94 , the sum of the column items in Table (3.6) (1 + 2.7+0.23).

$$0.254 = \frac{1}{1 + 2.7 + 0.23}$$

Table (3. 7): Synthesized matrix for cost.

<i>Cost</i>	<i>Visual inspection survey</i>	<i>Smartphone application</i>	<i>Aerial/Satellite images</i>
<i>Visual inspection survey</i>	0.254	0.242	0.371
<i>Smartphone application</i>	0.687	0.654	0.543
<i>Aerial/Satellite images</i>	0.059	0.104	0.086

The priority vector in Table (3.8) could be obtained by finding the row averages. For example, the priority of *Visual inspection survey* with respect to the criterion “cost uncertainty” in Table (3.8) was calculated by dividing the sum of the rows (0.254+0.242+0.371) by 3 (the number of Alternatives) in order to obtain the value 0.289

Table (3. 8): Priority vector

<i>Cost</i>	
<i>Alternatives</i>	<i>Priority</i>
Visual inspection survey	0.289
Smartphone application	0.628
Aerial/Satellite images	0.083

b) Calculating λ max

To calculate the λ max should calculate the weighted sum matrices, and that was by adding the multiplying of the priority vector in Table (3.8) with each column in of the pair wise comparison matrix in Table (3.6).

Weighted sum matrix =

$$0.289 \times \begin{bmatrix} 1 \\ 2.7 \\ 0.23 \end{bmatrix} + 0.628 \times \begin{bmatrix} 0.37 \\ 1 \\ 0.159 \end{bmatrix} + 0.083 \times \begin{bmatrix} 4.3 \\ 6.3 \\ 1 \end{bmatrix} = \begin{bmatrix} 0.878 \\ 1.932 \\ 0.250 \end{bmatrix}$$

After calculated the weighted sum matrix, each element of the weighted sum matrices divided by their respective priority vector element then the average of these values was computed to obtain λ max.

$$\lambda_{\max} = \frac{\left(\frac{0.878}{0.289} + \frac{1.932}{0.628} + \frac{0.250}{0.083}\right)}{3} = 3.042$$

c) Calculating the Consistency Index (CI)

The calculation of CI was by subtracted n from λ max then divided the result by (n-1) n: is the alternatives in one hierarchy, and equal to 3 here.

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

$$CI = \frac{3.042 - 3}{3 - 1} = 0.021$$

d) Selecting Appropriate Value of the Random Consistency Ratio (RCI)

Appropriate value of random consistency ratio (RCI) was selected from Table (3.9) depending on the matrix size (value of n=3).

$$RCI = 0.58$$

Table (3. 9): RCI values for different values of n. (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

e) Calculate the Consistency Ratio (CR)

CR was calculated by dividing CI by RI as follow:

$$CR = \frac{CI}{RCI} = \frac{0.021}{0.58} = 0.036$$

f) Checking the Consistency of the Pair-Wise Comparison Matrix

It's to check whether the decision maker's comparisons were consistent or not.

$$CR = 0.036 < 0.10 \text{ Ok It's consistent}$$

3.5.1.5 Perform Sensitivity Analysis

Sensitivity analysis allowed verifying the results of the decision. Sensitivity analysis could be performed to see how well the alternatives perform with respect to each of the criteria as well as how sensitive the alternatives are to changes in the importance of the criteria. It should be noted that if a criterion is not sensitive, it would be better to eliminate it from the AHP model.

3.5.1.6 Select the Best Alternative

Comparisons are made by ranking the aggregate scores of each candidate with regard to their performance against each of the criteria, and the candidate associated with the highest scores is the best contractor on this occasion.

In this research was developed an Excel sheet for applying the mythology of AHP step by step through it, the Excel sheet could calculate all the steps illustrated in the AHP mythology section, and also present numerical and graphical information.

Chapter 4

Results and Discussion

Chapter (4) Results and Discussion

4.1 Introduction.

This chapter presented and discussed the results of the research. Firstly, it shows the result of using Roadroid smartphone application for Deir Al-Balah Road inventory and calculate IRI for specific rout in Deir Al-Balah City as a case study. Secondly, it shows the result of analysis and viewing data by Geographic Information System (GIS). Thirdly, show the result of using AHP method to select appropriate road network inventory type in Gaza Strip.

4.2 Deir Al-Balah Road network inventory using Roadroid application.

Roadroid application can be widely used in road inventory parameters, such as International Roughness index (IRI), Rutting, Cracking, Raveling, Flushing/bleeding, Shoving, Patching, Pumping, Corrugation, Sags and humps, Edge breaks, Pothole, Camber/Profile and Widening. But this research collected IRI as a case study in specific rout in Deir Al-Balah City.

4.2.1 Calculated IRI using Roadroid application:

Roadroid is a modern, easy and cost efficient way for road roughness data collection. The Roadroid app is using the smartphones built in accelerometer to analyze the road vibrations and its GPS to position the data. Appendix (A) Illustrates IRI calculated from Roadroid application

The correlation of the estimated IRI (eIRI) towards laser beam measured IRI is about 70-80% depending on road surface type (See Figure 4.1). The accuracy can be increased with some tuning, and the IRI sampling is currently developed with a calculated IRI (cIRI) to enhance the correlation factor (See Figure 4.2).

Inventory have been done which confirm that cIRI, if calibrated correctly, can meet the demands for road condition measurements. However, one needs to maintain a stable speed at around 60~80 km/h for cIRI to work correctly. The quarter-car model uses two swinging weights which can be simulated if the vehicle chassis movement is available as input. The estimation of the chassis movement is based on the accelerometer data and a vehicle calibration variable, which is adjusted between 0.5~4, in small steps by the Roadroid operator.

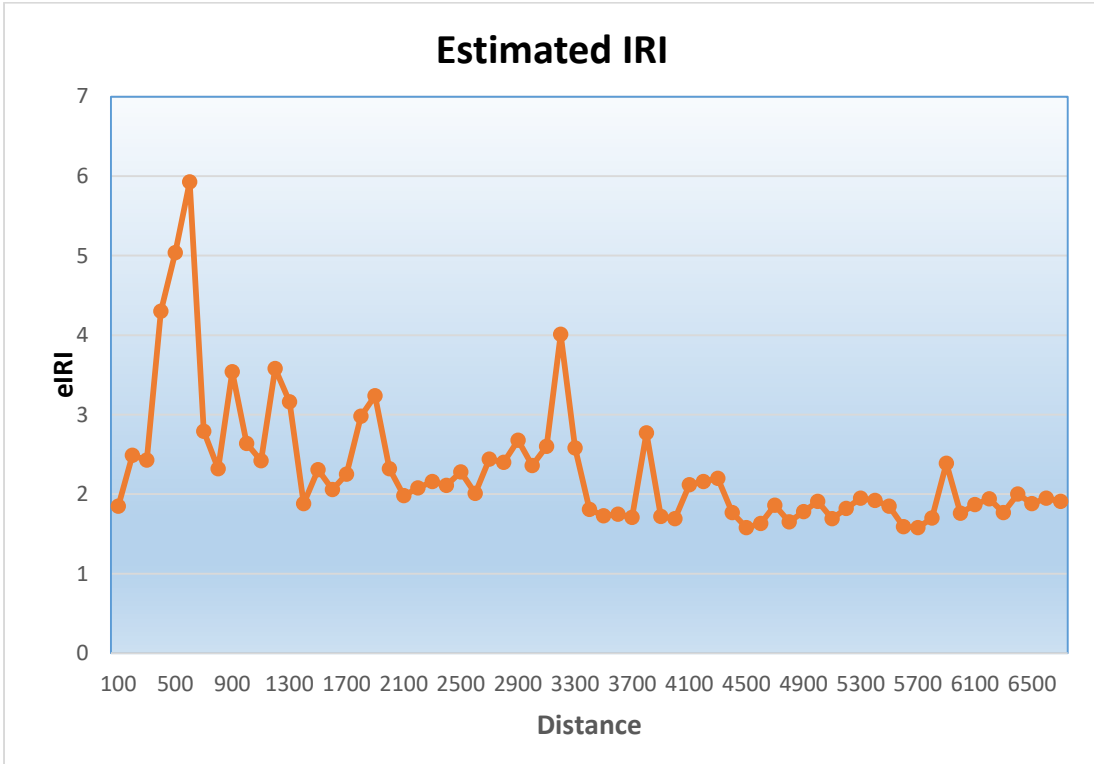


Figure (4. 1): Estimated International Roughness Index (eIRI) in Deir Al-Balah Roads

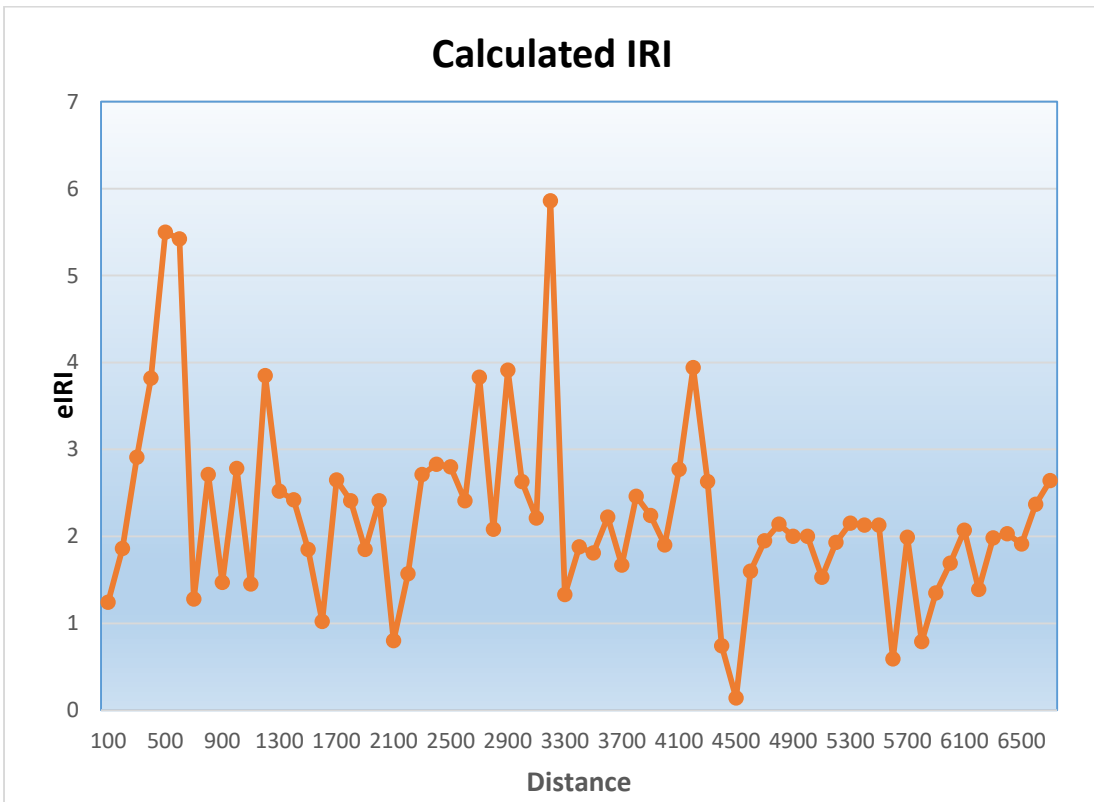


Figure (4. 2): Calculated International Roughness Index (cIRI) in Deir Al-Balah Roads

4.2.2 Characteristics of using smartphone application (Roadroid) to calculate IRI:

- Roadroid is easy and cost efficient, so data collection can be done by driver there is no need of a specific operator.
- The possibility of collecting data continually opens new perspectives performance monitoring. Roughness changes can be monitored on daily, weekly or monthly basis.
- Roadroid is a global system, easily accessing remote areas to collect objective data.
- Roadroid saves IRI values with Longitude /Latitude position, Altitude and Vehicle speed each second.
 - Data is presented on an internet GIS tool and you can extract 100 meter sections of the data.
 - Accept from the roughness data, vertical road profile and speed profile can be mapped.
- Roadroid can give early warnings that something is happening with the roughness, and to find out more about what exactly is happening you can direct when and where to a detailed but expensive laser scanning.

Roadroid is a modern, easy and cost efficient and should be compared with RST, but seen as a great complement to these exact methods. Roadroid can gather big amounts of data over time, make available to see changes from day to day or from months to month. Further work needs to be done in this field. As mobile technologies and sensors get more advanced, suitable distance measuring devices for distance monitoring between the road and chassis might be used in the future.

The needs for using smartphone applications in road network inventory are very different from operational maintenance on developed countries to developing countries.

Internet map solution is a good way to view data gathered by Roadroid, but demands some basic knowledge of GIS and road databases. Roadroid also developed a data aggregator which is able to aggregate and average date/time, coordinates (latitude, longitude), vertical profile (altitude) and speed together with eIRI and cIRI in selectable section lengths (100 m) (See Appendix A).

4.3 Arc GIS output.

Arc GIS maps will make understanding of Deir Al-Balah road network inventory is easy to deal by decision makers and they can take accurate information about accurate place. Colored map will be produced by Arc GIS maps.

4.3.1 IRI map

Colored map produced by Arc GIS software that make easy to deal with Deir Al-Balah city road network inventory. Figure (4.3) Divided IRI values according to pavement surface condition, and that let the decision maker deals directly with any condition they need to maintain.

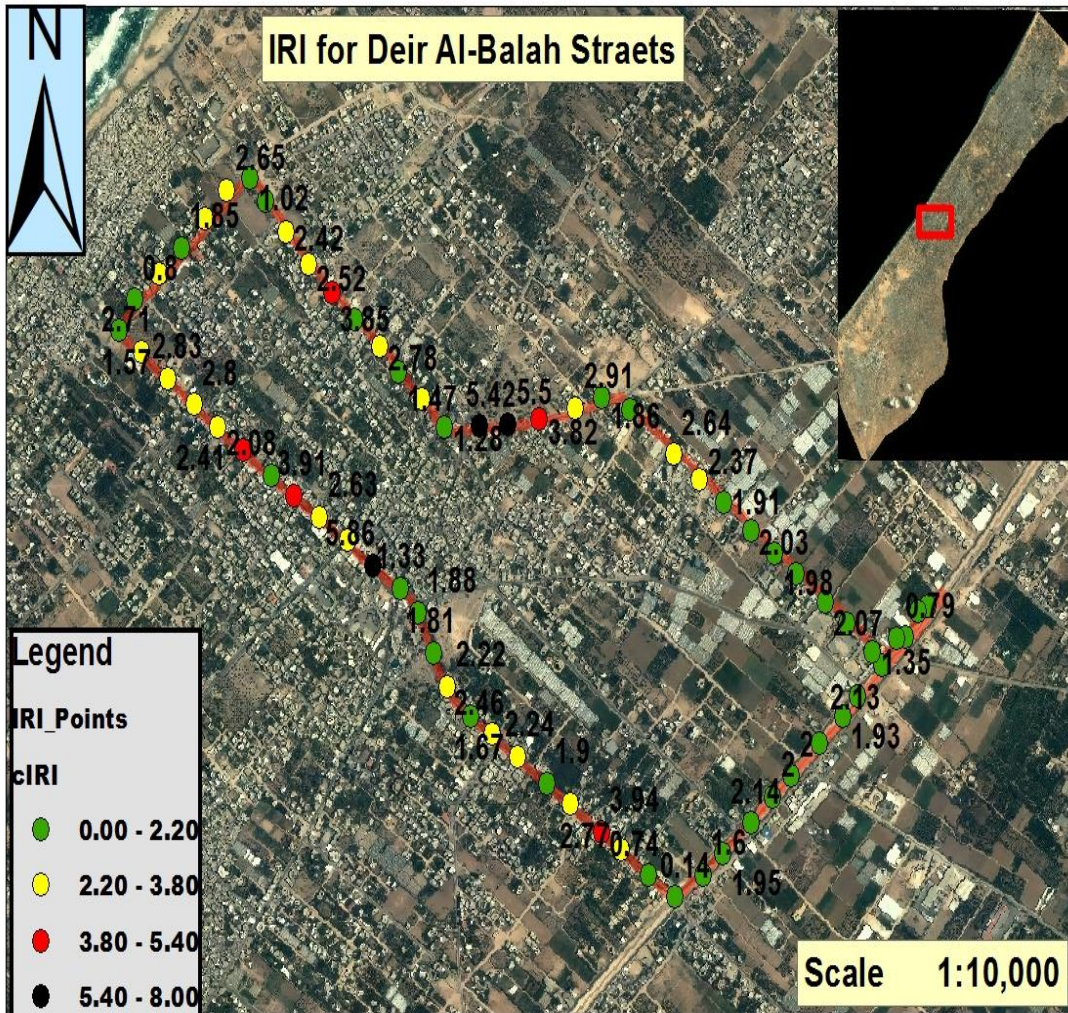


Figure (4. 3): IRI value by Arc GIS software

4.3.2 Roughness Category.

The road condition data are divided into four different levels of road quality (RQ): green for good; yellow for satisfactory/OK; red for unsatisfactory/not OK and black for poor.

- 39 point of IRI in the rout classified as a good, which mean 58.2 % of the rout is a good roughness category.
- 3 points of IRI in the rout classified as a good, which mean 4.5 % of the rout is a poor roughness category.
- 20 point of IRI in the rout classified as a good, which mean 29.85 % of the rout is a satisfactory roughness category.
- 5 points of IRI in the rout classified as a good, which mean 7.46 % of the rout is a unsatisfactory roughness category.

This illustrated in figure (4.4).

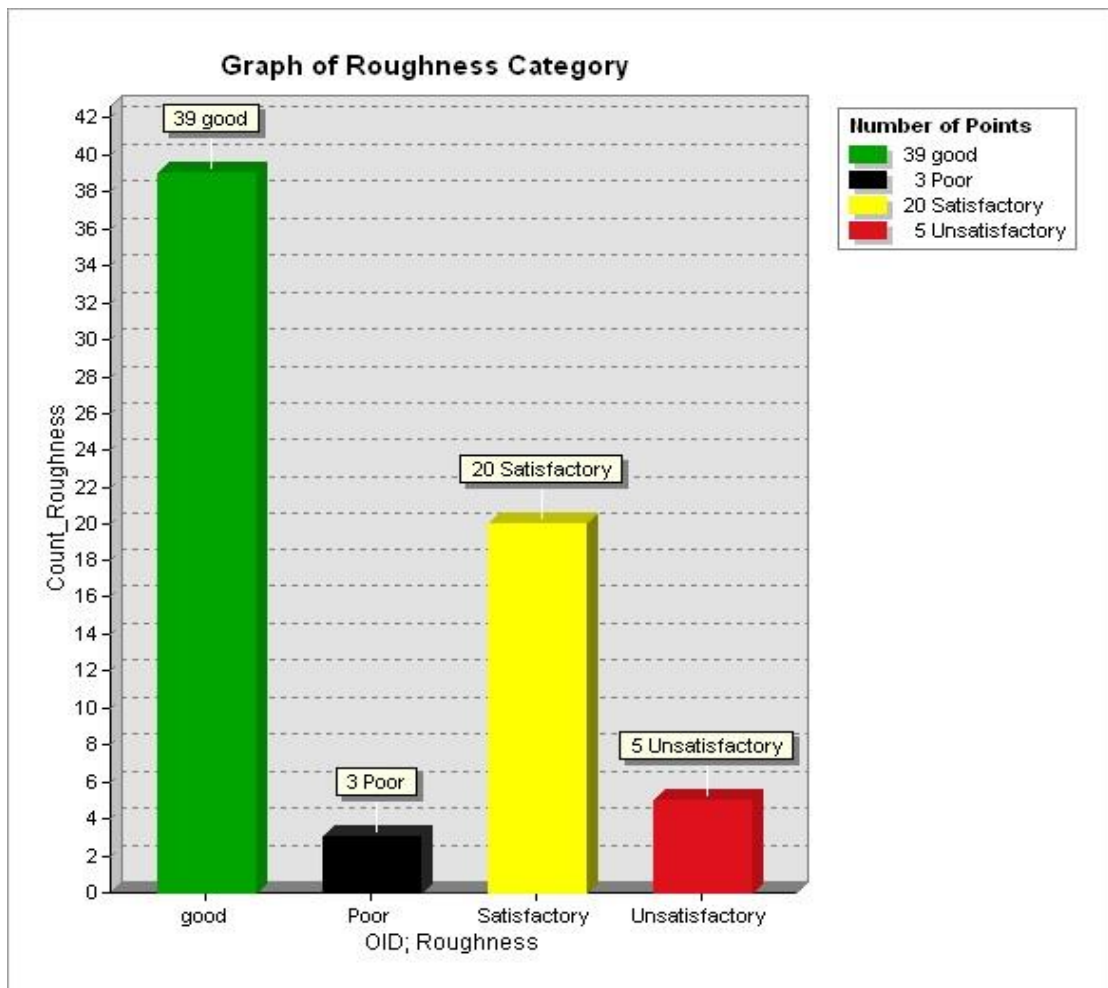


Figure (4. 4): Graph of Roughness Category by Arc GIS software

4.4 Selection Appropriate Road inventory Method using AHP methodology.

The selection appropriate road network inventory method was adapted through the application of the AHP methodology discussed in the previous chapter. In the first step was determined the priority for each criterion with respect to the other, the second step was determined the best road network inventory method achieve each criterion separately, and finally was selected the appropriate road network inventory method that achieve the overall criteria. That's with presented the calculated check (If the CR value smaller than 0.1) through the calculated of the values of λ max, CI, and RCI bellow each table. AHP calculations is illustrated in Appendix B.

4.4.1 Main Criteria Weight.

Figure (4.1) shows graphical presentations for the priorities of each criterion and also show the priorities with numerical values for each criterion. Main criteria weight calculations is illustrated in Appendix B (Table B.1).

As shown in Figure (4.5):

- The “Date Quality and Accuracy” criterion had the top priority; this criterion received a percentage of 42.7 %.
- The “cost” criterion had the second priority with a percentage of 29.2%.
- In the third priority the criterion “Time Period” had received a percentage of 15.8 %.
- The “Available Resources” criterion had the forth priority with a percentage of 8 %.
- The “Environmental Impact” criterion had the fifth priority with a percentage of 4.3%.

From the results it is clear that the paramount goal for road network inventory to achieve the best date quality and accuracy with adequate cost and less time required for accomplishing the inventory process. That's with available recourses and less environmental impact to carry out the road network inventory.

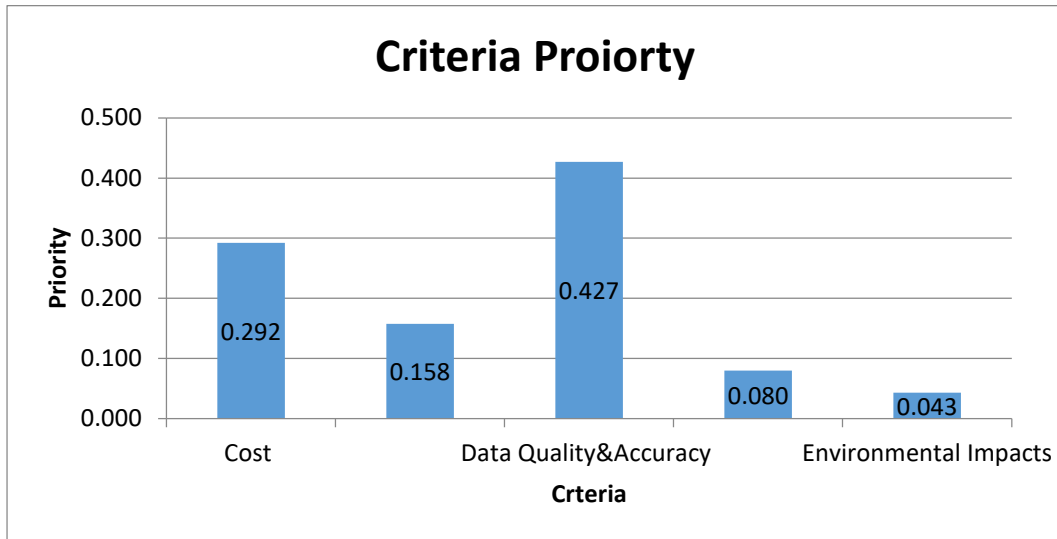


Figure (4. 5): Criteria priority comparison.

Table (4. 1): Check Consistency of Matrices.

$\lambda(\max)$	5.335
<i>CI</i>	0.084
<i>RCI</i>	1.12
<i>CR</i>	0.075
Check $CR < 0.1$	ok

4.4.2 Cost Criterion Weight.

Table (4.2) shows the final results of road network inventories pairwise comparison with cost criterion from the survey of sample in Gaza Strip. Also figure (4.6) shows the priority with numerical presentation for the road network inventory method in achieving the cost criterion and table (4.3) shows the check consistency of matrices with respect to cost criterion.

From the results it's clear that using *smartphone application* for road network inventory was the best with the adequate certainty about the project inventory's cost; it was received a percentage of 62.8 %. While the second road network inventory Method priority for achieving the cost criterion was the *Visual inspection survey* with a percentage of 28.9%, that's due to you need crews to complete the task. The *Aerial/Satellite images* received the lowest priority for achieving the cost criterion which their received a percentage of 8.3%, that's due to that Aerial photographs need to be considerable cost to buy them especially that you need to image with high accuracy.

Table (4. 2): Pairwise comparison and priority with respect to cost criterion.

<i>Cost</i>	<i>Visual inspection survey</i>	<i>Smartphone application</i>	<i>Aerial/Satellite images</i>
<i>Visual inspection survey</i>	<i>1</i>	<i>0.37</i>	<i>4.30</i>
<i>Smartphone application</i>	<i>2.70</i>	<i>1</i>	<i>6.30</i>
<i>Aerial/Satellite images</i>	<i>0.23</i>	<i>0.159</i>	<i>1</i>

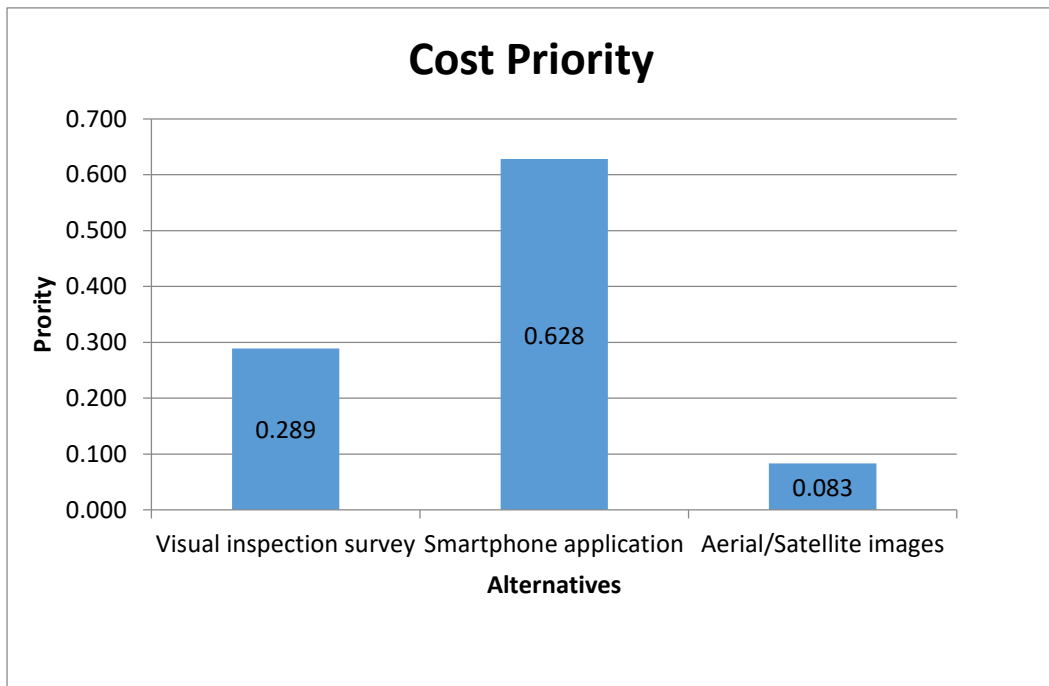


Figure (4. 6): Pairwise priority with respect to cost criterion.

Table (4. 3): Check Consistency of Matrices with respect to cost criterion.

$\lambda(\max)$	<i>3.042</i>
<i>CI</i>	<i>0.021</i>
<i>RCI</i>	<i>0.580</i>
<i>CR</i>	<i>0.036</i>
<i>Check</i>	<i>CR<0.10</i>

4.4.3 Time Period Criterion Weight.

Table (4.4) shows the final results of road network inventories pairwise comparison with time period criterion from the survey of sample in Gaza Strip. Also figure (4.7) shows the priority with numerical presentation for the road network inventory method in achieving the time period criterion and table (4.5) shows the check consistency of matrices with respect to time period criterion.

From the results it's clear that using *smartphone application* for road network inventory was the best with the adequate certainty about the project inventory's time period; it was received a percentage of 40.7%. While the second road network inventory method priority for achieving the time period criterion was the *Aerial/Satellite images* with a percentage of 39.2%. The *Visual inspection survey* received the lowest priority for achieving the cost criterion which their received a percentage of 20.1%, that's due to the time you need to make Visual inspection survey.

Table (4. 4): Pairwise comparison and priority with respect to time period criterion.

<i>Time Period</i>	<i>Visual inspection survey</i>	<i>Smartphone application</i>	<i>Aerial/Satellite images</i>
<i>Visual inspection survey</i>	1	0.45	0.56
<i>Smartphone application</i>	2.222	1	0.95
<i>Aerial/Satellite images</i>	1.786	1.053	1

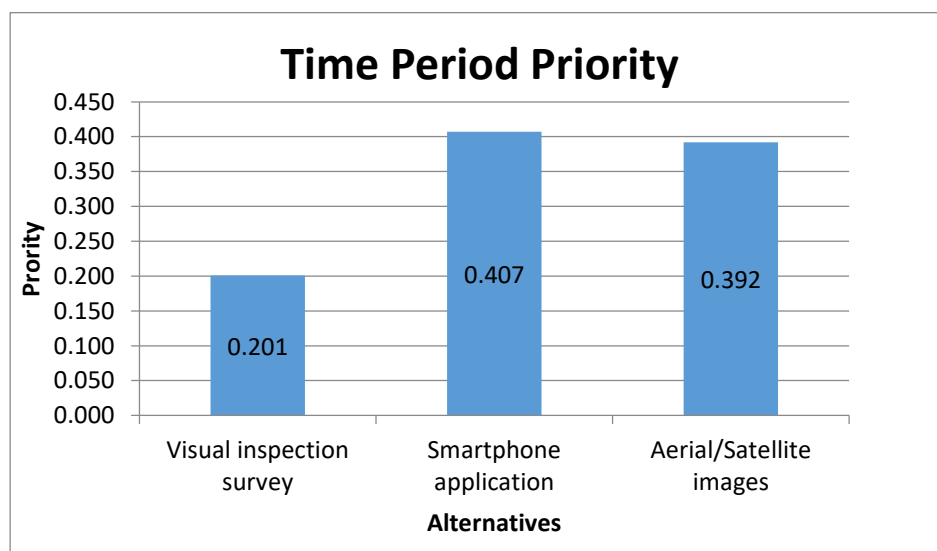


Figure (4. 7): Pairwise priority with respect to time period criterion.

Table (4. 5): Check Consistency of Matrices with respect to time period criterion.

$\lambda(\max)$	3.008
CI	0.004
RCI	0.580
CR	0.007
Check	CR<0.10

4.4.4 Data Quality and Accuracy Criterion Weight.

Table (4.6) shows the final results of road network inventories pairwise comparison with Data Quality and Accuracy criterion from the survey of sample in Gaza Strip. Also figure (4.8) shows the priority with numerical presentation for the road network inventory method in achieving the Data Quality and Accuracy criterion and table (4.7) shows the check consistency of matrices with respect to Data Quality and Accuracy criterion.

From the results it's clear that using *smartphone application* for road network inventory was the best with the adequate certainty about the project inventory's Data Quality and Accuracy; it was received a percentage of 42.8%. While the second road network inventory method priority for achieving the Data Quality and Accuracy criterion was the *Aerial/Satellite images* with a percentage of 30.1%. The *Visual inspection survey* received the lowest priority for achieving the cost criterion which their received a percentage of 27.1%.

Table (4. 6): Pairwise comparison and priority with respect to Data Quality and Accuracy criterion.

<i>Data Quality and Accuracy</i>	<i>Visual inspection survey</i>	<i>Smartphone application</i>	<i>Aerial/Satellite images</i>
<i>Visual inspection survey</i>	1	0.667	0.85
<i>Smartphone application</i>	1.50	1	1.5
<i>Aerial/Satellite images</i>	1.18	0.67	1

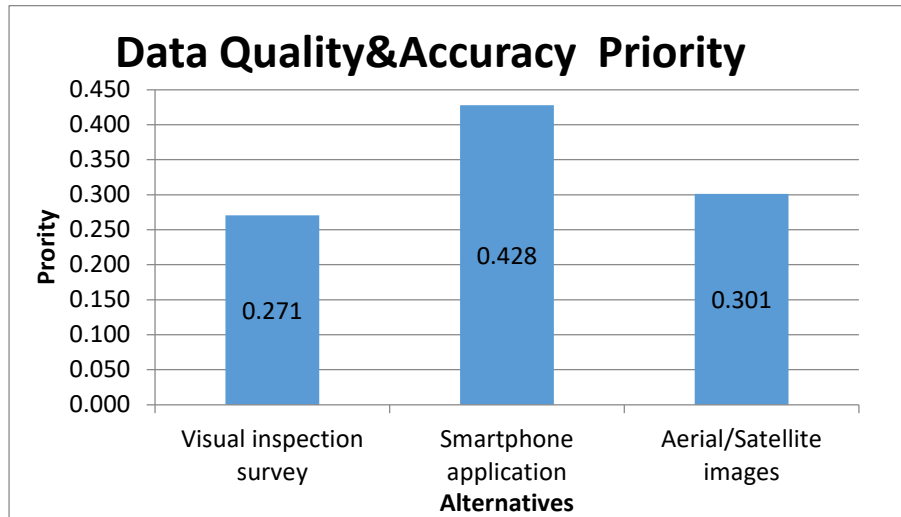


Figure (4. 8): Pairwise priority with respect to Data Quality and Accuracy criterion.

Table (4. 7): Check Consistency of Matrices with respect to Data Quality and Accuracy criterion.

$\lambda(\max)$	3.003
CI	0.001
RCI	0.580
CR	0.003
Check	CR < 0.10

4.4.5 Available Resources Criterion Weight.

Table (4.8) shows the final results of road network inventories pairwise comparison with Available Resources criterion from the survey of sample in Gaza Strip. Also figure (4.9) shows the priority with numerical presentation for the road network inventory method in achieving the Available Resources criterion and table (4.9) shows the check consistency of matrices with respect to Available Resources criterion.

From the results it's clear that using *smartphone application* for road network inventory was the best with the adequate certainty about the project inventory's Available Resources; it was received a percentage of 48.1 %. While the second road network inventory method priority for achieving the Available Resources criterion was the *Visual inspection survey* with a percentage of 44.3%. The *Aerial/Satellite images* received the lowest priority for achieving the Available Resources criterion which their received a percentage of 7.6%, that's due to that Aerial photographs doesn't available in Gaza Strip.

Table (4. 8): Pairwise comparison and priority with respect to Available Resources criterion.

<i>Available Resources</i>	<i>Visual inspection survey</i>	<i>Smartphone application</i>	<i>Aerial/Satellite images</i>
<i>Visual inspection survey</i>	<i>1</i>	<i>0.95</i>	<i>5.66</i>
<i>Smartphone application</i>	<i>1.05</i>	<i>1</i>	<i>6.56</i>
<i>Aerial/Satellite images</i>	<i>0.18</i>	<i>0.15</i>	<i>1</i>

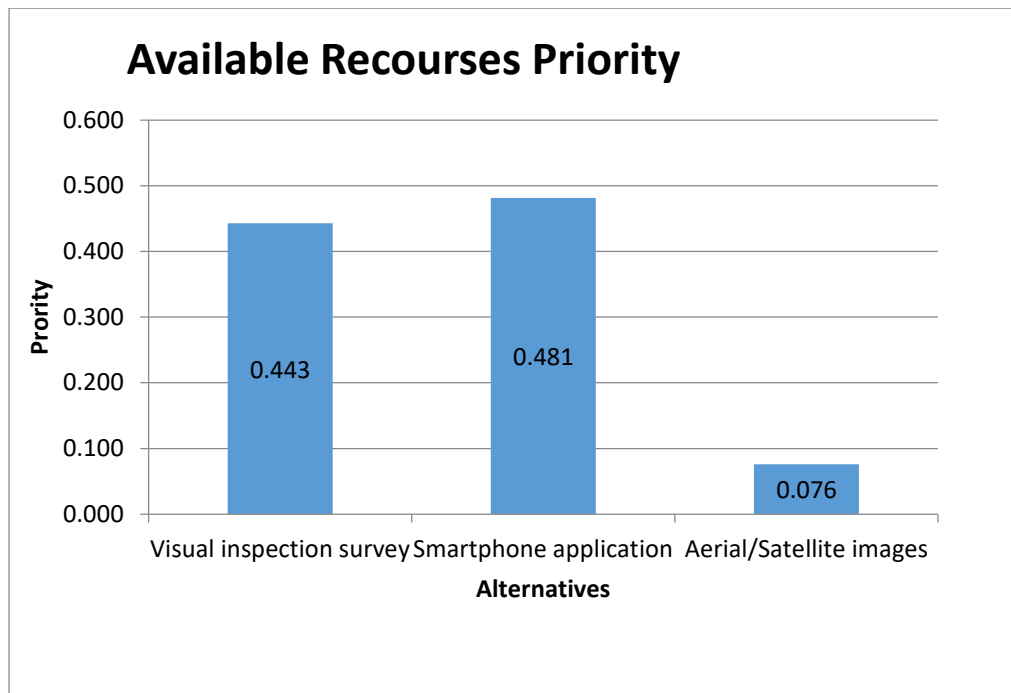


Figure (4. 9): Pairwise priority with respect to Available Resources criterion.

Table (4. 9): Check Consistency of Matrices with respect to Available Resources criterion.

$\lambda(\max)$	<i>3.001</i>
<i>CI</i>	<i>0.001</i>
<i>RCI</i>	<i>0.580</i>
<i>CR</i>	<i>0.001</i>
<i>Check</i>	<i>CR<0.10</i>

4.4.6 Environmental Impact Criterion Weight.

Table (4.10) shows the final results of road network inventories pairwise comparison with Environmental Impact criterion from the survey of sample in Gaza Strip. Also figure (4.10) shows the priority with numerical presentation for the road network inventory method in achieving the Environmental Impact criterion and table (4.10) shows the check consistency of matrices with respect to Environmental Impact criterion.

From the results it's clear that using *Aerial/Satellite images* for road network inventory was the best with the adequate certainty about the project inventory's Environmental Impact; it was received a percentage of 37.3 %. While the second road network inventory method priority for achieving the Environmental Impact criterion was the *smartphone application* with a percentage of 34.2%. The *Visual inspection survey* received the lowest priority for achieving the Environmental Impact criterion which their received a percentage of 28.5%.

Table (4. 10): Pairwise comparison and priority with respect to Environmental Impact criterion.

<i>Environmental Impact</i>	<i>Visual inspection survey</i>	<i>Smartphone application</i>	<i>Aerial/Satellite images</i>
<i>Visual inspection survey</i>	1	0.83	0.77
<i>Smartphone application</i>	1.2	1	0.91
<i>Aerial/Satellite images</i>	1.3	1.1	1

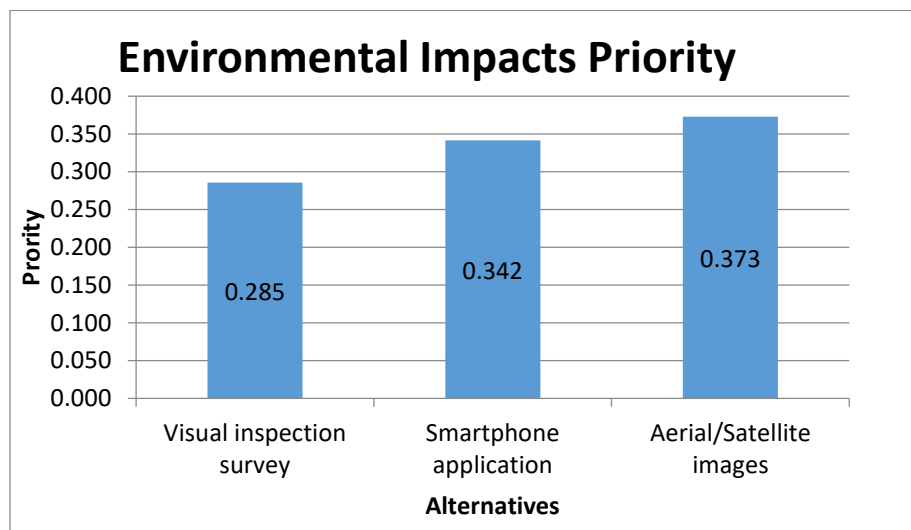


Figure (4. 10): Pairwise priority with respect to Environmental Impact criterion.

Table (4. 11): Check Consistency of Matrices with respect to Environmental Impact criterion.

$\lambda(\max)$	3.000
CI	0.000
RCI	0.580
CR	0.000
Check	CR<0.10

4.4.7 Over All Priority Weight for Road Network Inventory.

As shown in figure (4.11): The best road network inventory method achieving all criteria was *smartphone application*, with priority of 48.3%. That's due to several reasons:

- Smartphone Application inventory method is less expensive compared to other methods.
- It needs a less period of time in comparison with other inventory methods.
- Smartphone Application gives an acceptable level of data quality and accuracy in road network inventory.
- Available resources because it just needs an Android mobile, car and the person who will make inventory, the person who is working on the application knowing that the application does not require high expertise.
- Environmental impact doesn't affect significantly in roads inventory process while using smartphone application.

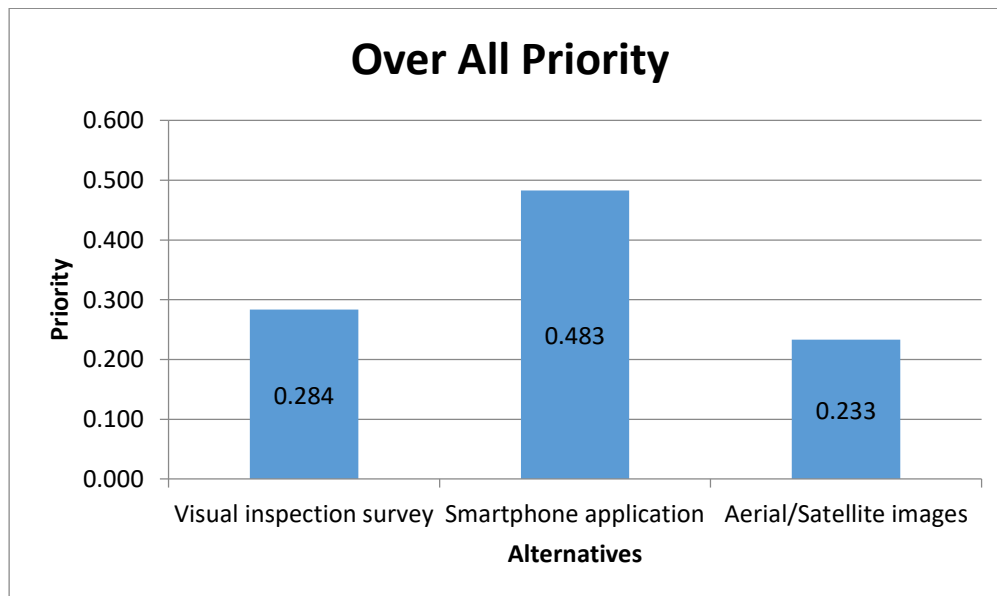


Figure (4. 11): Road network inventories priority comparison with overall criteria.

Visual inspection survey method received second rank with a percentage of 28.4% which is a common method used in the Gaza Strip and *Aerial/Satellite images* method received third rank with a percentage of 23.3%, this is because the aerial/satellite images with high accuracy is difficult to provide in the Gaza Strip.

Table (4.12) shows the final results of inventory methods pairwise comparison with overall criteria in Gaza Strip. Also it shows the priority with numerical presentation for the inventory methods in achieving the overall criteria.

Table (4. 12): Road network inventories priority comparison with overall criteria.

<i>Criteria</i>	<i>Cost</i>	<i>Time Period</i>	<i>Data Quality & Accuracy</i>	<i>Available Recourses</i>	<i>Environmental Impacts</i>	<i>Over All Priority</i>
<i>Alternatives</i>	0.292	0.158	0.427	0.080	0.043	
<i>Visual inspection survey</i>	0.289	0.201	0.271	0.443	0.384	0.284
<i>Smartphone application</i>	0.628	0.407	0.428	0.481	0.322	0.483
<i>Aerial/Satellite images</i>	0.083	0.392	0.301	0.076	0.294	0.233

4.4.8 Sensitivity Analysis.

AHP sensitivity analysis is to investigate how sensitive the rankings of the alternatives are to changes in the importance of the criteria.

A sensitivity analysis was carried out to study the impact of the different criteria on deciding the appropriate road network inventory method. This analysis had measured from two sides. In first side, the relative importance of one criterion was changed from the value recorded as the basis of survey to be the only criterion in deciding the appropriate road network inventory type (by increase its weight to be the maximum, equaled 9 with respect to other criteria). The second side revealed the appropriate road network inventory method that when a criterion is not considered by (by decrease its weight to be the minimum, equaled 0.1 with respect to other criteria).

The result in this case revealed that the *smartphone application* remained the dominant in most criteria but changed when the weight of “Environmental Impact” criterion maximize. Other criteria play a role to change the priority of inventory method without change their rank. The results of sensitivity analysis showed in the figure (4.12).

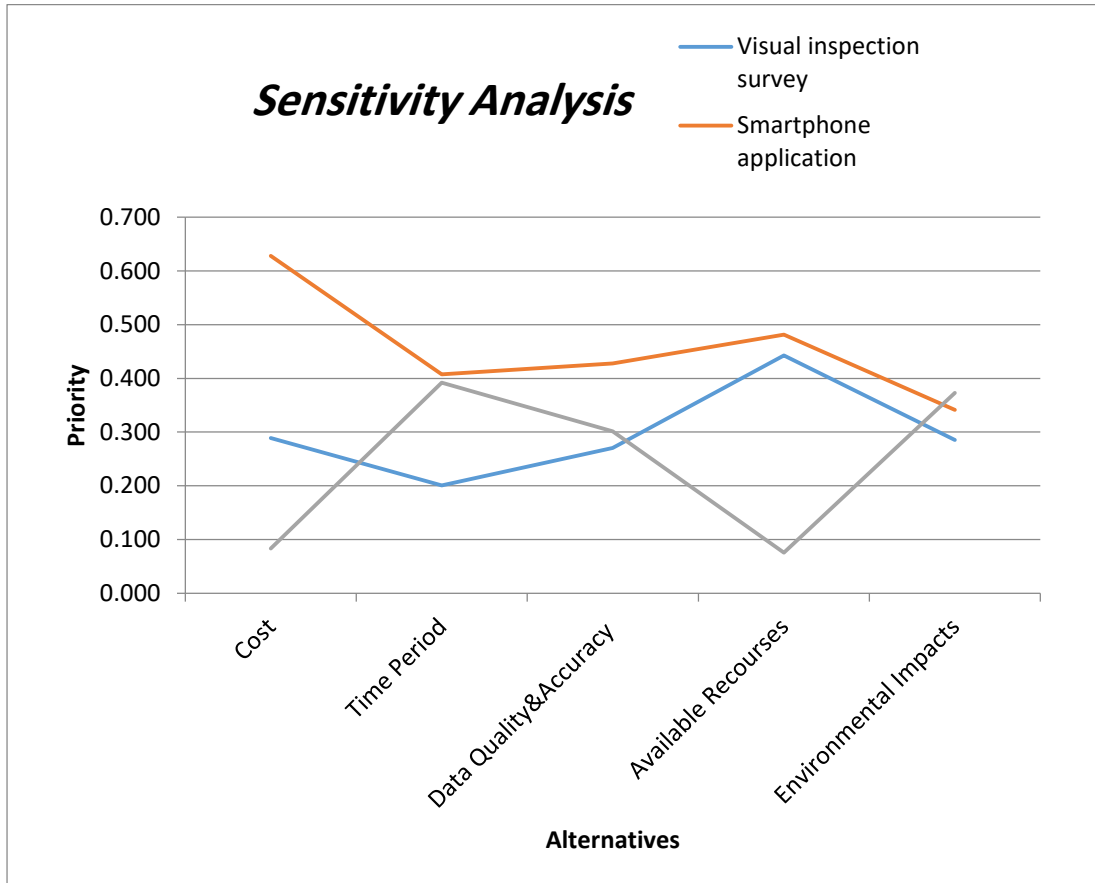


Figure (4. 12): Result of sensitivity Analysis.

Figure (4.12) shows that the criteria are represented by vertical bars, and the alternatives are displayed as horizontal line graphs. The intersection of the alternative line graphs with the vertical criterion lines shows the priority of the alternative for the given criterion. The criterion’s priority is represented by the height of its bar. The overall priority of each alternative is represented on the overall line.

Chapter 5

Conclusion and Recommendations

Chapter (5) Conclusion and Recommendations

5.1 Conclusions

At the end of this study, the following points can be concluded:

1. Roads Network inventory with smart phones can provide an efficient, scalable, and cost-effective way for road organizations to deliver road condition data. This research illustrated this with the use of android software “Roadroid”.
2. Roads Network inventory with smart phones can gather big amounts of data over time, make available to see changes from day to day or from months to month.
3. Roads Network inventory with smart phones provides an effective solution to some challenges that would be difficult to overcome under certain circumstances, such as road networks in developing countries, forestry and mountain roads, biking or pedestrian trails, and touristic routes across nature reserves and parks.
4. Different smart phone models return different measuring values (mainly accelerometer sensitivity and sample frequency).
5. The choice of Android rather than iPhone was made considering the open architecture and hardware price/performance relation.
6. Roads are needed to be monitored continuously for roughness and other anomalies to avoid inconvenience to the road users.
7. Continuous data collection will enable monthly Road condition change reports, with a trend indicator to monitor roughness development over time. The information can directly guide pot-hole fixing and urgent patching. The data can also be given as a dynamic feed to your asset management system or road maintenance management system.
8. Smartphone sensors are gaining importance in road network inventory field as they are cost effective and also increase scalability. Analyzing form the research activities, it is certain that this area will gain more importance in recent future.

5.2 Advantage of using Smartphone in road network inventory.

1. Smartphone is a modern, easy and cost efficient way for road network inventory.
2. Smartphone can gather big amounts of data over a short time, make available to see changes from day to day or from months to month.
3. Smartphone can do inventories of all types of road networks that are not accessible to cars.
4. Smartphone can manage the routine maintenance of road networks with less time period and available resources.
5. Using smartphone in road network inventory creates a unique opportunity for developing countries where advanced methods will not work such as RST and Aerial/ Satellite images.
6. Financers can be encouraged as they can monitor the situation and results of their efforts visually by internet. Whereas in Roadroid application you can view all the data collected through the internet.

5.3 Recommendation

Based on the results of this research the following points are recommended:

1. There is a great need to improve the way of presentation the comprehensive level of information being collected from road network inventory flexibility and scalability.
2. There is need to be able to add data from several road inventory measurements over time and compare results over time in a flexible way.
3. There is need to automatically generate reports for a specific road and to compare roads with each other and to do comparisons within whole regions.
4. Municipalities, ministries like (MPWH), Companies and institutions working in the road field decision makers in Gaza Strip are recommended to use the results of this research in any future road network inventory works.
5. There is need to do continuous monitoring to view development of roads condition over time, especially when using smartphones in the field of road network inventory, Inventory process seemed to be easier, faster and less expensive. The IRI seemed to be a suitable way to also make reports from the road condition data and trend changes over time.

6. Roadroid should be used in a **continuous data collection** to be a good support for developed roads. Roadroid can also feed different asset management software with IRI values. Roadroid can monitor day to day roughness changes and can guide load restrictions, so it clearly can see when and where the problems occur.
7. Smartphone can used as a basis for future research projects on road design and outline.

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Appendices

Appendix (A)

International Roughness Index (IRI) calculation by Roadroid

cIRI-sensitivity: 1.5**Table (A.1): International Roughness Index (IRI) calculation by Roadroid (Smartphone application)**

DateTime	Latitude	Longitude	Distance(m)	Speed (km/h)	Altitude (m)	Grade (%)	eIRI	cIRI	Roughness Category
8/6/2016 7:21	31.4213871586325	34.3586168547569	100	17.54	40.25	0	1.85	1.24	good
8/6/2016 7:21	31.4216596040719	34.3576887250085	200	37.89	38.67	-1.58	2.49	1.86	good
8/6/2016 7:21	31.4214296808539	34.3568317750882	300	53.71	40.12	1.46	2.43	2.91	Satisfactory
8/6/2016 7:21	31.4211794475765	34.3556481563576	400	41.17	40	-0.12	4.3	3.82	Unsatisfactory
8/6/2016 7:21	31.4210431788562	34.3546493320364	500	38.06	36.7	-3.3	5.04	5.5	Poor
8/6/2016 7:22	31.4210004012053	34.3537209747690	600	38.4	31.91	-4.79	5.93	5.42	Poor
8/6/2016 7:22	31.4209798805283	34.3525861488263	700	26.54	26.13	-5.78	2.79	1.28	good
8/6/2016 7:22	31.4216351718980	34.3518426655994	800	39.8	24	-2.13	2.32	2.71	Satisfactory
8/6/2016 7:22	31.4222914098358	34.3510783661205	900	31.32	21.92	-2.08	3.54	1.47	good
8/6/2016 7:22	31.4228707662210	34.3504669792371	1000	45.78	20.22	-1.69	2.64	2.78	Satisfactory
8/6/2016 7:22	31.4235176683227	34.3496585815531	1100	30.9	19.62	-0.61	2.42	1.45	good
8/6/2016 7:23	31.4241451928163	34.3489098857606	1200	34.9	19.25	-0.37	3.58	3.85	Unsatisfactory
8/6/2016 7:23	31.4248314119137	34.3481516861006	1300	31.85	18.67	-0.58	3.16	2.52	Satisfactory
8/6/2016 7:23	31.4255825703727	34.3474151994521	1400	51.06	19.88	1.21	1.88	2.42	Satisfactory
8/6/2016 7:23	31.4263014199334	34.3467595010633	1500	33.89	19.58	-0.29	2.31	1.85	good
8/6/2016 7:23	31.4268605728847	34.3462488067771	1600	26.83	19.43	-0.15	2.06	1.02	good
8/6/2016 7:24	31.4265596020472	34.3455013781018	1700	43.63	19.78	0.35	2.25	2.65	Satisfactory
8/6/2016 7:24	31.4259081717453	34.3447811138731	1800	37.89	19.55	-0.23	2.98	2.41	Satisfactory
8/6/2016 7:24	31.4252051869501	34.3440183449198	1900	25.38	22	2.45	3.24	1.85	good
8/6/2016 7:24	31.4246061389227	34.3432864577138	2000	26.77	22.14	0.14	2.32	2.41	Satisfactory
8/6/2016 7:24	31.4239841840157	34.3424945898810	2100	21.13	21.94	-0.2	1.98	0.8	good
8/6/2016 7:25	31.4232461688404	34.3419857944152	2200	28.67	21.25	-0.69	2.08	1.57	good
8/6/2016 7:25	31.4227511113912	34.3427198996219	2300	36.68	21.09	-0.16	2.16	2.71	Satisfactory

8/6/2016 7:29	31.4135259178616	34.3647771481342	5100	70.53	44.83	1.83	1.69	1.53	good
8/6/2016 7:29	31.4141508196924	34.3655128763264	5200	75.29	44.2	-0.63	1.82	1.93	good
8/6/2016 7:29	31.4146159490801	34.3660171149593	5300	76.61	43.83	-0.37	1.95	2.15	good
8/6/2016 7:29	31.4153469752437	34.3668103795337	5400	72.98	43.33	-0.5	1.92	2.13	good
8/6/2016 7:30	31.4160137794932	34.3675577038733	5500	66.01	44.71	1.38	1.85	2.13	good
8/6/2016 7:30	31.4167537163231	34.3683068110720	5600	24.51	43.41	-1.3	1.59	0.59	good
8/6/2016 7:30	31.4166240047370	34.3679761883027	5700	36.08	43.73	0.32	1.58	1.99	good
8/6/2016 7:30	31.4159906080338	34.3672748124735	5800	23.82	43.31	-0.41	1.7	0.79	good
8/6/2016 7:30	31.4156737220928	34.3664890372096	5900	27.87	41.93	-1.38	2.39	1.35	good
8/6/2016 7:31	31.4163375714609	34.3656447080342	6000	41.57	41.22	-0.71	1.76	1.69	good
8/6/2016 7:31	31.4168484954102	34.3649428164012	6100	43.78	41.3	0.08	1.87	2.07	good
8/6/2016 7:31	31.4175055086498	34.3640193783170	6200	30.14	41.25	-0.05	1.94	1.39	good
8/6/2016 7:31	31.4179786196669	34.3633165873168	6300	44.29	40.67	-0.58	1.77	1.98	good
8/6/2016 7:31	31.4185347878999	34.3625308297369	6400	35.36	38.75	-1.92	2	2.03	good
8/6/2016 7:31	31.4191858395044	34.3616428596516	6500	38.63	38.4	-0.35	1.88	1.91	good
8/6/2016 7:32	31.4197368225985	34.3608658410248	6600	39.88	38	-0.4	1.95	2.37	good
8/6/2016 7:32	31.4203273828287	34.3600277402670	6700	44.22	39.44	1.44	1.91	2.64	Satisfactory

Appendix (B)

Analytical Hierarchy Process (AHP) Calculations

Table (B. 1): Main Criteria Weight Calculations.

AHP Methodology fo Road Network Inventory

Criteria	Alternatives
Cost	Visual inspection survey
Time Period	Smartphone application
Data Quality&Accuracy	Aerial/Satellite images
Available Recourses	
Environmental Impacts	

Criteria	Cost	Time Period	Data Quality&Accuracy	Available Recourses	Environmental Impacts	Proiorty	
<i>Cost</i>	1	3.500	0.50	4.33	5.40	0.292	1.638
<i>Time Period</i>	0.29	1	0.28	3.80	4.40	0.158	0.855
<i>Data Quality&Accuracy</i>	2.00	3.60	1	5.80	6.60	0.427	2.328
<i>Available Recourses</i>	0.23	0.26	0.17	1	3.30	0.080	0.406
<i>Environmental Impacts</i>	0.19	0.23	0.15	0.30	1	0.043	0.222
<i>sum</i>	3.702	8.588	2.102	15.236	20.700	1.000	

Criteria	Cost	Time Period	Data Quality&Accuracy	Available Recourses	Environmental Impacts	sum
<i>Cost</i>	0.270	0.408	0.238	0.284	0.261	1.461
<i>Time Period</i>	0.077	0.116	0.132	0.249	0.213	0.788
<i>Data Quality&Accuracy</i>	0.540	0.419	0.476	0.381	0.319	2.134
<i>Available Recourses</i>	0.062	0.031	0.082	0.066	0.159	0.400
<i>Environmental Impacts</i>	0.050	0.026	0.072	0.020	0.048	0.217

<i>Criteria</i>	
<i>Criteria</i>	<i>Proiorty</i>
Cost	0.292
Time Period	0.158
Data Quality&Accuracy	0.427
Available Recourses	0.080
Environmental Impacts	0.043

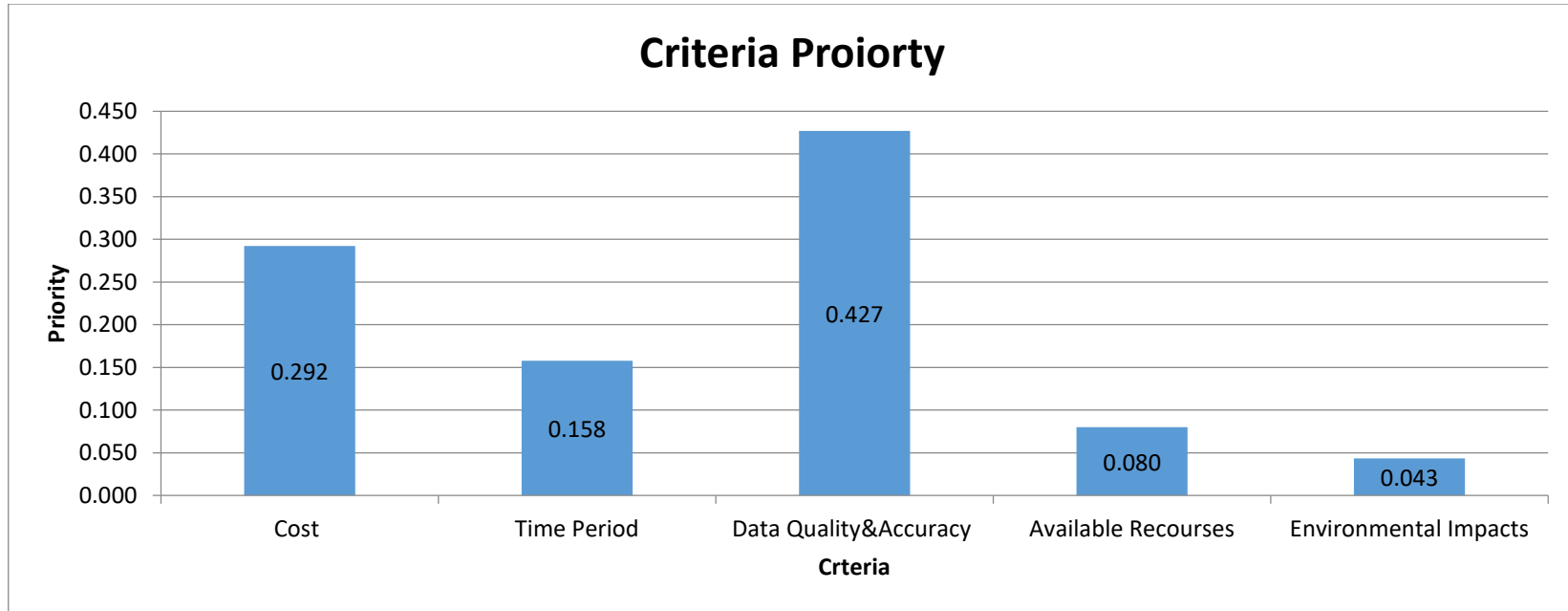


Figure (B. 1): Main Criteria Priority Comparison.

Table (B. 2): Pairwise comparison and priority with respect to “Cost” criterion.

Cost

<i>Cost</i>	<i>Visual inspection survey</i>	<i>Smartphone application</i>	<i>Aerial/Satellite images</i>
<i>Visual inspection survey</i>	1	0.37	4.30
<i>Smartphone application</i>	2.70	1	6.30
<i>Aerial/Satellite images</i>	0.23	0.159	1
<i>sum</i>	3.94	1.53	11.60

<i>Cost</i>	<i>Visual inspection survey</i>	<i>Smartphone application</i>	<i>Aerial/Satellite images</i>	<i>sum</i>
<i>Visual inspection survey</i>	0.254	0.242	0.371	0.867
<i>Smartphone application</i>	0.687	0.654	0.543	1.884
<i>Aerial/Satellite images</i>	0.059	0.104	0.086	0.249

<i>Cost</i>	
<i>Alternatives</i>	<i>Priority</i>
<i>Visual inspection survey</i>	0.289
<i>Smartphone application</i>	0.628
<i>Aerial/Satellite images</i>	0.083

0.878

1.932

0.250

$\lambda(\max)$	3.042	
<i>CI</i>	0.021	
<i>RCI</i>	0.580	
<i>CR</i>	0.036	
<i>Check</i>	<i>CR</i> <0.10	OK

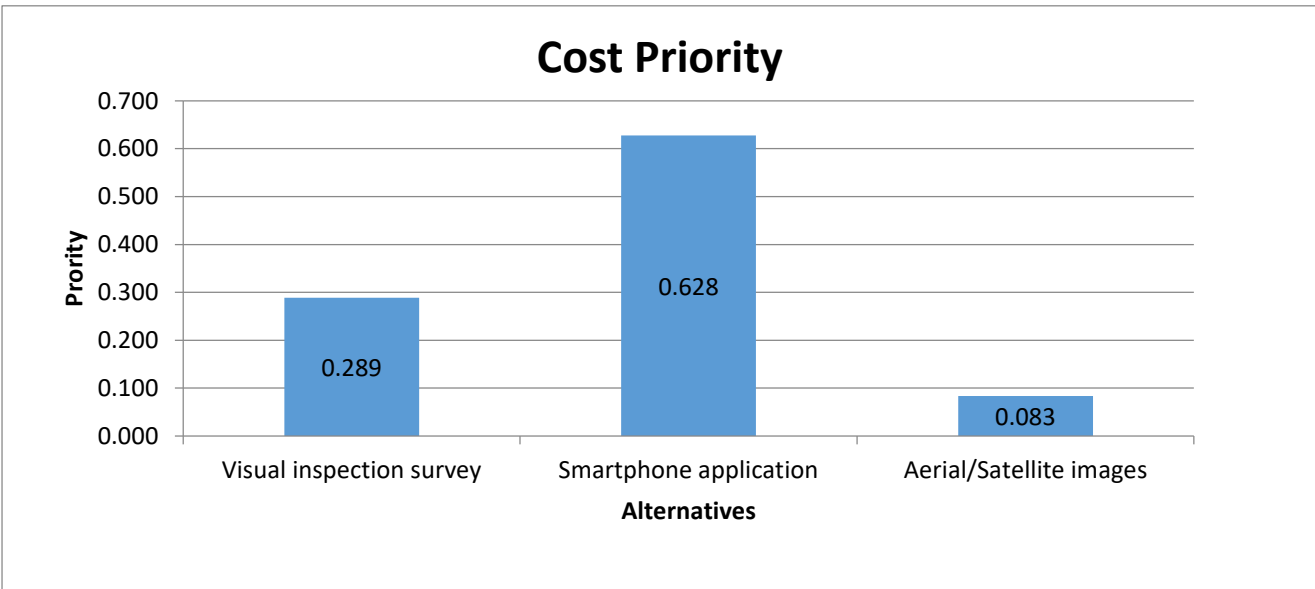


Figure (B. 2): Pairwise comparison and priority with respect to cost criterion.

Table (B. 3): Pairwise comparison and priority with respect to “Time Period” criterion.

Time Period

<i>Time Period</i>	<i>Visual inspection survey</i>	<i>Smartphone application</i>	<i>Aerial/Satellite images</i>
<i>Visual inspection survey</i>	1	0.45	0.56
<i>Smartphone application</i>	2.222	1	0.95
<i>Aerial/Satellite images</i>	1.786	1.053	1
<i>sum</i>	5.01	2.50	2.51

<i>Time Period</i>	<i>Visual inspection survey</i>	<i>Smartphone application</i>	<i>Aerial/Satellite images</i>	<i>sum</i>
<i>Visual inspection survey</i>	0.200	0.180	0.223	0.603
<i>Smartphone application</i>	0.444	0.400	0.378	1.222
<i>Aerial/Satellite images</i>	0.357	0.421	0.398	1.176

<i>Time Period</i>	
<i>Alternatives</i>	<i>Priority</i>
<i>Visual inspection survey</i>	0.201
<i>Smartphone application</i>	0.407
<i>Aerial/Satellite images</i>	0.392

0.604

1.226

1.179

$\lambda(\max)$	3.008	
<i>CI</i>	0.004	
<i>RCI</i>	0.580	
<i>CR</i>	0.007	
<i>Check</i>	<i>CR</i> <0.10	OK

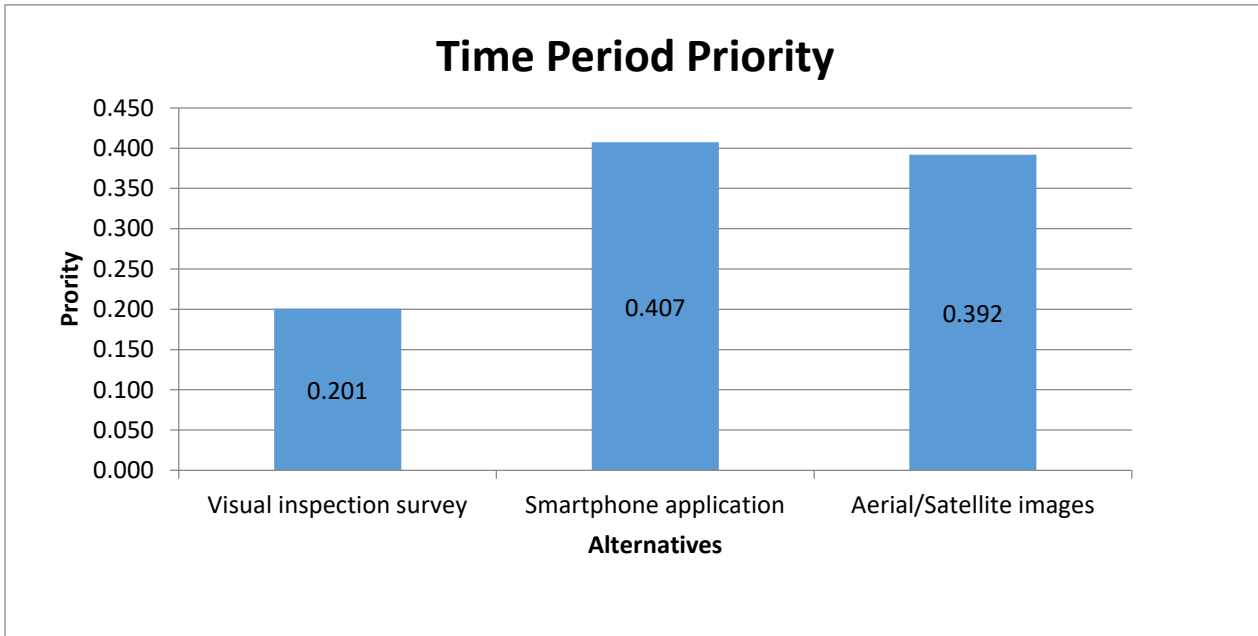


Figure (B. 3): Pairwise comparison and priority with respect to “Time Period” criterion.

Table (B. 4): Pairwise comparison and priority with respect to “Data Quality and Accuracy” criterion.

Data Quality & Accuracy

<i>Data Quality&Accuracy</i>	<i>Visual inspection survey</i>	<i>Smartphone application</i>	<i>Aerial/Satellite images</i>
<i>Visual inspection survey</i>	1	0.667	0.85
<i>Smartphone application</i>	1.50	1	1.5
<i>Aerial/Satellite images</i>	1.18	0.67	1
sum	3.68	2.33	3.35

<i>Data Quality&Accuracy</i>	<i>Visual inspection survey</i>	<i>Smartphone application</i>	<i>Aerial/Satellite images</i>	<i>sum</i>
<i>Visual inspection survey</i>	0.272	0.286	0.254	0.812
<i>Smartphone application</i>	0.408	0.429	0.448	1.284
<i>Aerial/Satellite images</i>	0.320	0.286	0.299	0.904

<i>Data Quality&Accuracy</i>	
<i>Alternatives</i>	<i>Priority</i>
<i>Visual inspection survey</i>	0.271
<i>Smartphone application</i>	0.428
<i>Aerial/Satellite images</i>	0.301

0.812
1.286
0.905

$\lambda(\max)$	3.003	
<i>CI</i>	0.001	
<i>RCI</i>	0.580	
<i>CR</i>	0.003	
<i>Check</i>	<i>CR</i> <0.10	OK

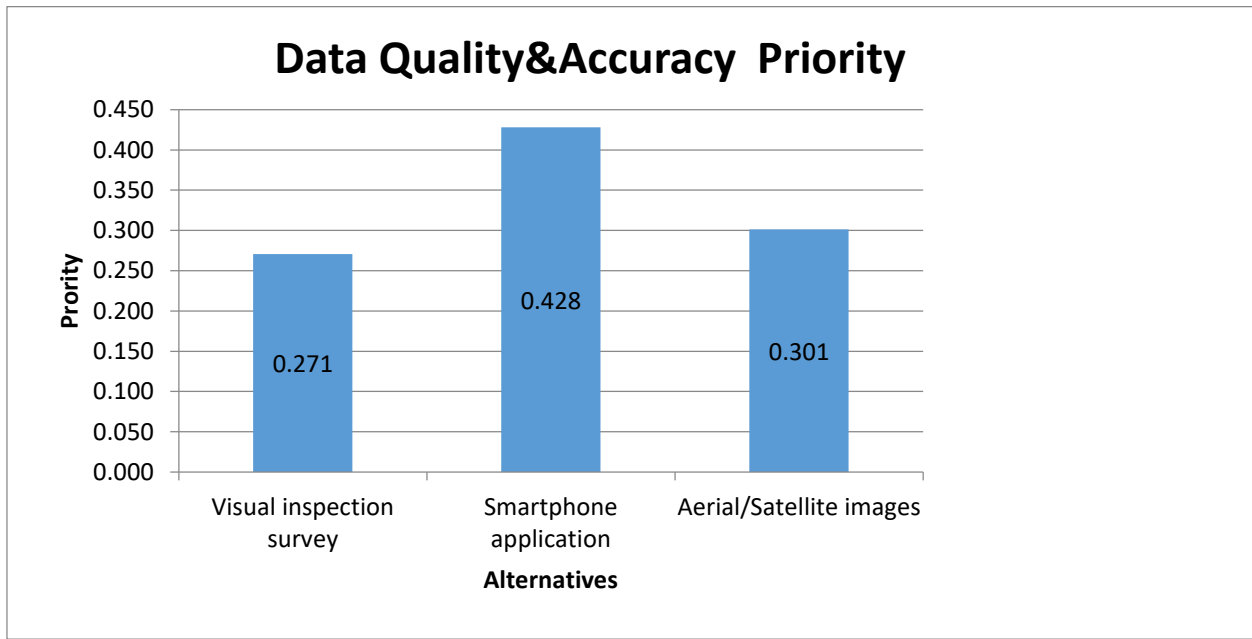


Figure (B. 4): Pairwise comparison and priority with respect to “Data Quality and Accuracy” criterion.

Table (B. 5): Pairwise comparison and priority with respect to “Available Recourse” criterion.

Available Recourses

<i>Available Recourses</i>	<i>Visual inspection survey</i>	<i>Smartphone application</i>	<i>Aerial/Satellite images</i>
<i>Visual inspection survey</i>	1	0.95	5.66
<i>Smartphone application</i>	1.05	1	6.56
<i>Aerial/Satellite images</i>	0.18	0.15	1
<i>sum</i>	2.23	2.10	13.22

<i>Available Recourses</i>	<i>Visual inspection survey</i>	<i>Smartphone application</i>	<i>Aerial/Satellite images</i>	<i>sum</i>
<i>Visual inspection survey</i>	0.449	0.452	0.428	1.329
<i>Smartphone application</i>	0.472	0.476	0.496	1.444
<i>Aerial/Satellite images</i>	0.079	0.073	0.076	0.227

<i>Available Recourses</i>	
<i>Alternatives</i>	<i>Priority</i>
<i>Visual inspection survey</i>	0.443
<i>Smartphone application</i>	0.481
<i>Aerial/Satellite images</i>	0.076

1.329

1.445

0.227

$\lambda(\max)$	3.001	
<i>CI</i>	0.001	
<i>RCI</i>	0.580	
<i>CR</i>	0.001	
<i>Check</i>	<i>CR<0.10</i>	OK

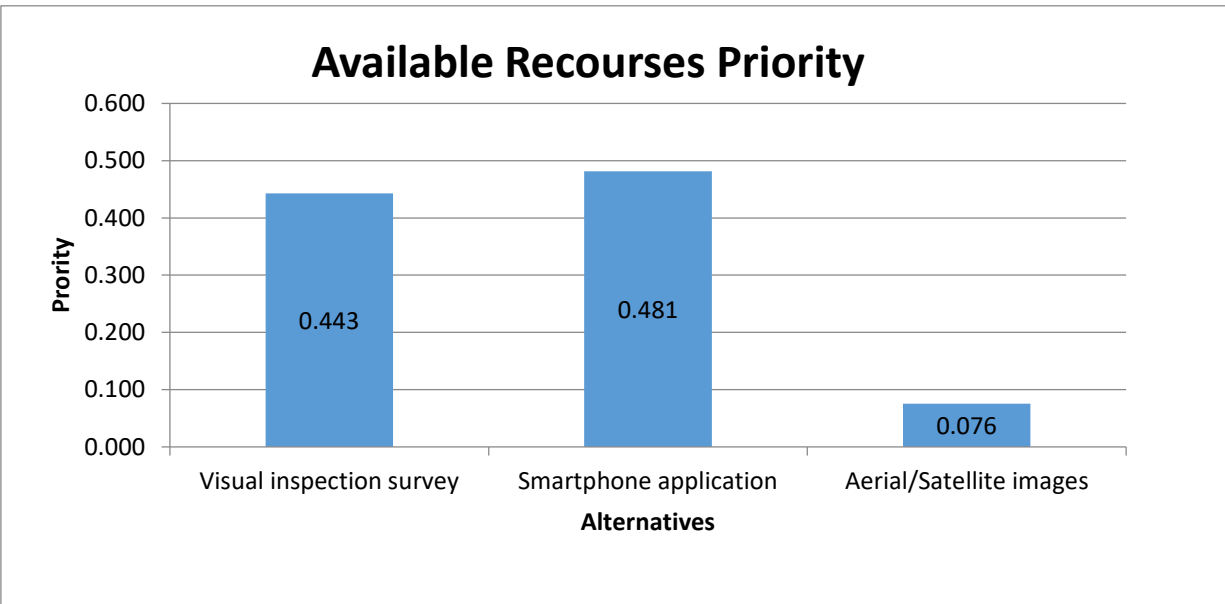


Figure (B. 5): Pairwise comparison and priority with respect to “Available Recourse” criterion.

Table (B. 6): Pairwise comparison and priority with respect to “Environmental Impacts” criterion.

Environmental Impacts

<i>Environmental Impacts</i>	<i>Visual inspection survey</i>	<i>Smartphone application</i>	<i>Aerial/Satellite images</i>
<i>Visual inspection survey</i>	1	0.83	0.77
<i>Smartphone application</i>	1.20	1	0.91
<i>Aerial/Satellite images</i>	1.30	1.10	1
<i>sum</i>	3.50	2.93	2.68

<i>Environmental Impacts</i>	<i>Visual inspection survey</i>	<i>Smartphone application</i>	<i>Aerial/Satellite images</i>	<i>sum</i>
<i>Visual inspection survey</i>	0.285	0.283	0.287	1.856
<i>Smartphone application</i>	0.344	0.341	0.340	0.025
<i>Aerial/Satellite images</i>	0.371	0.375	0.373	0.119

<i>Environmental Impacts</i>	
<i>Alternatives</i>	<i>Priority</i>
<i>Visual inspection survey</i>	0.285
<i>Smartphone application</i>	0.342
<i>Aerial/Satellite images</i>	0.373

0.856
1.025
1.119

$\lambda(\max)$	3.000	
<i>CI</i>	0.000	
<i>RCI</i>	0.580	
<i>CR</i>	0.000	
<i>Check</i>	<i>CR < 0.10</i>	OK

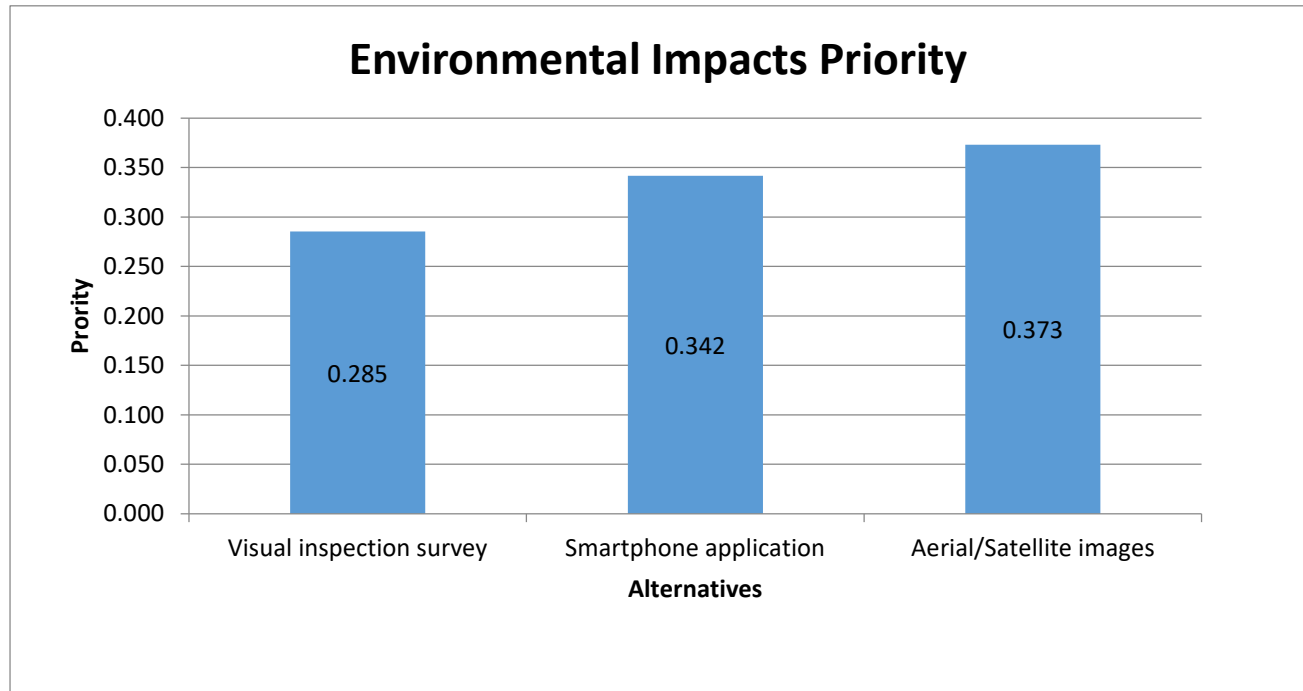


Figure (B. 6): Pairwise comparison and priority with respect to “Environmental Impacts” criterion.

Table (B. 7): Road network inventories priority comparison with overall criteria.

Over All Priority						
<i>Criteria</i>	<i>Cost</i>	<i>Time Period</i>	<i>Data Quality & Accuracy</i>	<i>Available Recourses</i>	<i>Environmental Impacts</i>	<i>O. A. Priority</i>
<i>Alternatives</i>	0.292	0.158	0.427	0.080	0.043	
<i>Visual inspection survey</i>	0.289	0.201	0.271	0.443	0.283	0.279
<i>Smartphone application</i>	0.628	0.407	0.428	0.481	0.342	0.484
<i>Aerial/Satellite images</i>	0.083	0.392	0.301	0.076	0.373	0.237
					<i>Sum</i>	1.000

Final Results	
<i>Over All</i>	
<i>Alternatives</i>	<i>Priority</i>
<i>Visual inspection survey</i>	0.279
<i>Smartphone application</i>	0.484
<i>Aerial/Satellite images</i>	0.237

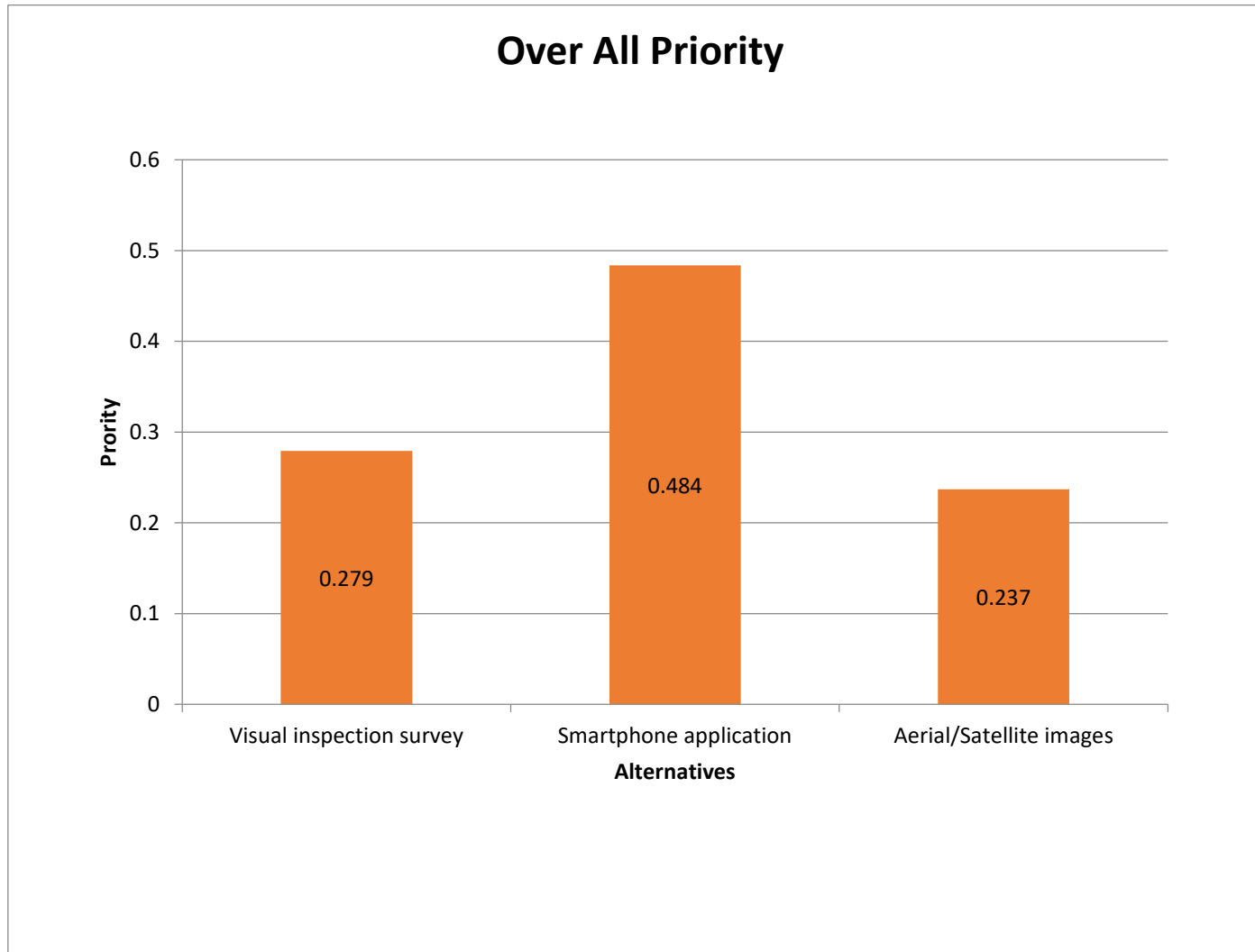


Figure (B. 7): Road network inventories priority comparison with overall criteria.

Table (B. 8): Sensitivity Analysis.

Sensitivity Analysis			
Criteria	Visual inspection survey	Smartphone application	Aerial/Satellite images
Cost	0.289	0.628	0.083
Time Period	0.201	0.407	0.392
Data Quality & Accuracy	0.271	0.428	0.301
Available Recourses	0.443	0.481	0.076
Environmental Impacts	0.285	0.342	0.373

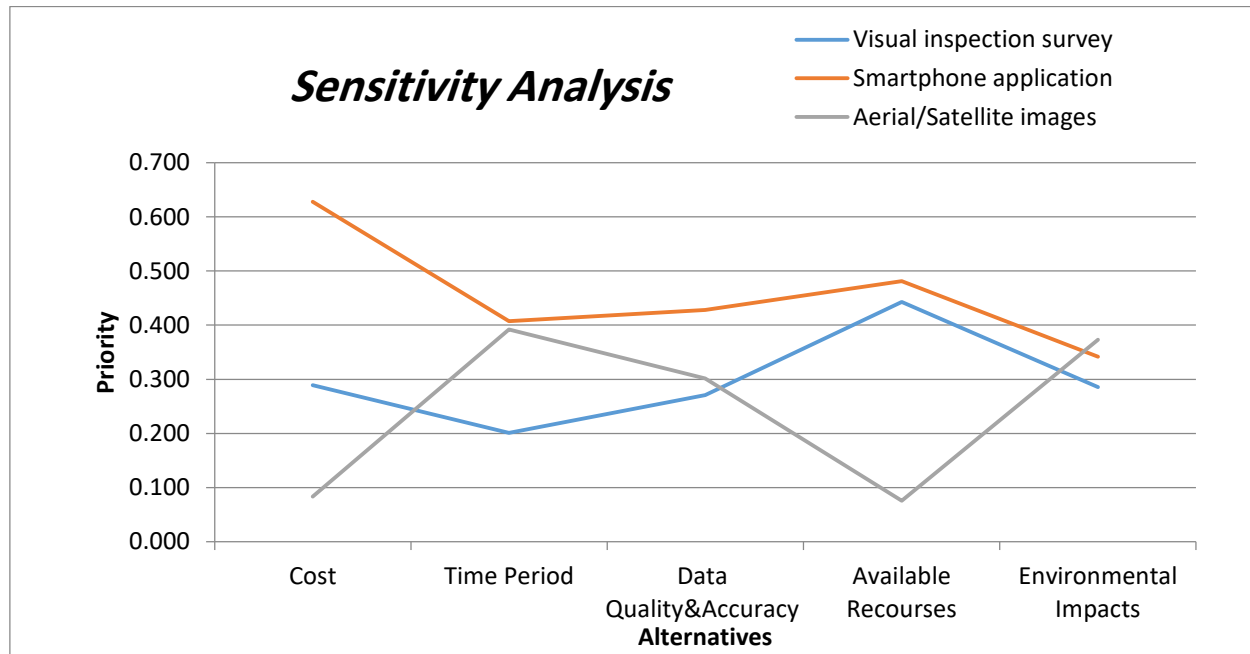


Figure (B. 8): Sensitivity Analysis.

Appendix (C)

Questionnaire

**The Islamic University of Gaza
Deanery of High Studies
Faculty of Engineering
Civil Engineering Department
Infrastructure Engineering**



Questionnaire about:

**USING SMARTPHONE AND GIS AS A TOOL FOR
GAZA ROAD NETWORK INVENTORY**

Dear Sir,

The aim of this questionnaire is to compare between several methods that used in road network inventories based on several criteria using AHP method.

In order to achieve this aim, we hope from you, please to fill the questionnaire by giving your own opinions of the importance of each criterion and remembering that you can add other important criteria and sub criteria in your opinion.

All of data collected from you will be used only for scientific purpose which the researcher needs for his MBA degree thesis.

Thanks for your help in advance for enriching this research which by its turn will be used in the fulfillment of the master dissertation in the infrastructure engineering specialization.

All thanks and appreciation for contribution in enhancement of scientific research process.

**Researcher:
Mohammed S. Naji**

**Supervisor:
Dr. Alaeddinne Daoud Eljamassi**

Part I: General Information

1- Organization Type

Municipality	
Ministers	
INGO's	
Other, determine.....	

2- Work Experience (Years)

1-5 years	
5-10 years	
10-15 years	
More than 15 years	

3- Education.

Diploma	
Bachelor B.Sc.	
Master M.Sc.	
Doctorate (Ph.D.)	

4- Specialization.

Civil Engineer	
Architect Engineer	
Electrical Engineer	
Mechanical Engineer	

5- Respondent Gender

Male	
Female	

Part II: Current Road Network Inventory situation in Gaza strip:

Field	Importance					
	5	4	3	2	1	0
Visual inspection survey are commonly used in Gaza Strip.						
Smartphone application are commonly used in Gaza Strip.						
Aerial/Satellite images are commonly used in Gaza Strip.						
A sufficient knowledge in the details of the Visual inspection survey method.						
A sufficient knowledge in the details of the Smartphone application method.						
A sufficient knowledge in the details of the Aerial/Satellite images method.						
Cost criterion affects the decision of choose road network inventory method.						
Time Period criterion affects the decision of choose road network inventory method.						
Data Quality and Accuracy criterion affects the decision of choose road network inventory method.						
Available Resources criterion affects the decision of choose road network inventory method.						
Environmental Impacts criterion affects the decision of choose road network inventory method.						

Part III: Criteria importance table

Please determine the relative importance for each criteria relative to other criterion in a couple comparison in order to compare all the criterion with the others. Knowing that this importance will be measured in accordance to the Hierarchical Analysis process in according to the digital classification for couple comparison as revealed in the following table:

Intensity of importance	Verbal judgment of preference
1	Equally preferred
2	Equally to moderately
3	Moderately preferred
4	Moderately to strongly
5	Strongly preferred
6	Strongly to very strongly
7	Very strongly preferred
8	Very strongly to extremely
9	Extremely preferred

criteria	Definition
Cost	The cost of road network inventory include equipment, crew and total needed fund.
Time Period	The period of time it takes to process the inventory.
Data Quality and Accuracy	Data are generally considered high quality if, "they are fit for their intended uses in operations, decision making and planning.
Available Resources	Availability of machines and technology.
Environmental Impacts.	The influence of the surrounding environment on the roads inventory process.

Determine the importance of each criterion with respect to the road network inventory:

Criteria	Very important	important	Moderately important	Little important	Not important
Cost					
Time Period					
Data Quality and Accuracy					
Available Recourses					
Environmental Impacts					

Determine the importance of each criterion with respect to each other for using specific method of road network inventory.

The next example explain how to fill the next table:

Criteria	Cost	Time Period	Data Quality and Accuracy	Available Recourses	Environmental Impacts
Cost	1	5	1/4	1/9	3

In this example, the criterion in the vertical column at the left of the table is compared with all the criteria at the top row according the numerical rating in pairwise comparison as follows:

- If the Cost is more important than the Time Period with moderate grade, number 3 is placed in the white cell.
- If the Cost is strongly important than the Data Accuracy of the company, number 5 is placed in the white cell.
- If the Cost is less important than the Quality of the company with moderate grade, fraction 1/3 is placed in the white cell.

Criteria	Cost	Time Period	Data Quality and Accuracy	Available Recourses	Environmental Impacts
Cost	1				
Time Period		1			
Data Quality and Accuracy			1		
Available Recourses				1	
Environmental Impacts					1

Determine the importance of each road network inventory method with respect to each other for using **Cost** criterion.

Cost	Visual inspection survey	Smartphone application	Aerial/Satellite images
Visual inspection survey	1		
Smartphone application		1	
Aerial/Satellite images			1

Determine the importance of each road network inventory method with respect to each other for using **Time Period** criterion.

Time Period	Visual inspection survey	Smartphone application	Aerial/Satellite images
Visual inspection survey	1		
Smartphone application		1	
Aerial/Satellite images			1

Determine the importance of each road network inventory method with respect to each other for using **Data Quality and Accuracy** criterion.

Data Quality and Accuracy	Visual inspection survey	Smartphone application	Aerial/Satellite images
Visual inspection survey	1		
Smartphone application		1	
Aerial/Satellite images			1

Determine the importance of each road network inventory method with respect to each other for using **Available Recourses** criterion.

Available Recourses	Visual inspection survey	Smartphone application	Aerial/Satellite images
Visual inspection survey	1		
Smartphone application		1	
Aerial/Satellite images			1

Determine the importance of each road network inventory method with respect to each other for using **Environmental Impacts** criterion.

Environmental Impacts	Visual inspection survey	Smartphone application	Aerial/Satellite images
Visual inspection survey	1		
Smartphone application		1	
Aerial/Satellite images			1

Appendix (D)

Experts Names and Their Positions

Experts Names and Their Positions

1. Hisham A. Alderawi. Manager of the planning Department of the Deir el-Balah Municipality.
2. Eng. Eyad Abu Samra. Manager of the GIS Department of the Deir el-Balah Municipality.
3. Ahmed Ben Said. General Manager of Roads in MPWH.
4. Ahmed Mater. Vice Manager of MPWH.
5. Hassan Barrak. Manager of CMWU in the Middle Area.
6. Eng. Yusuf Al-Buhisi. Water Engineer in the CMWU.
7. Salah Abu Abdo. Vice Manager of the Municipality of Khan Younes and University lecturer in the Faculty of Science and Technology.
8. Eng. Ahmed Kullab. Head of supervision and implementation department of the Khan Younes Municipality.
9. Eng. Zakaria Helles. Senior Civil Engineer in MA'AN Development Center.
10. Abd Albaset Qawwash. Project Engineer at UNRWA.