

Using smartphone and GIS to measure International Roughness Index (IRI) in Gaza Strip-Palestine Road Network (Deir Balah as case study)

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Abstract—Road network inventory has gain significant importance in last few years especially after wars and natural disasters which make the urgent need for quick and economical ways to do an inventory of roads. The current methods used to create road networks inventories involve high costs and require 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 smartphones that provides 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 methods used in road network inventory. The new method is low cost and gives a good data quality with available resources because most of people have a smartphone today.

Key words— Road Network; Inventory; Roadroid; Smartphone; GIS; AHP.

I INTRODUCTION

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 smartphones 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 [1].

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

Case Study Zone

Two major roads are selected for this research; Al-Shohadaa Street and Akila Street. The roads extend from east to west in Deir Al-Balah-Gaza-Strip-Palestine (see Figure 1).

II 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.

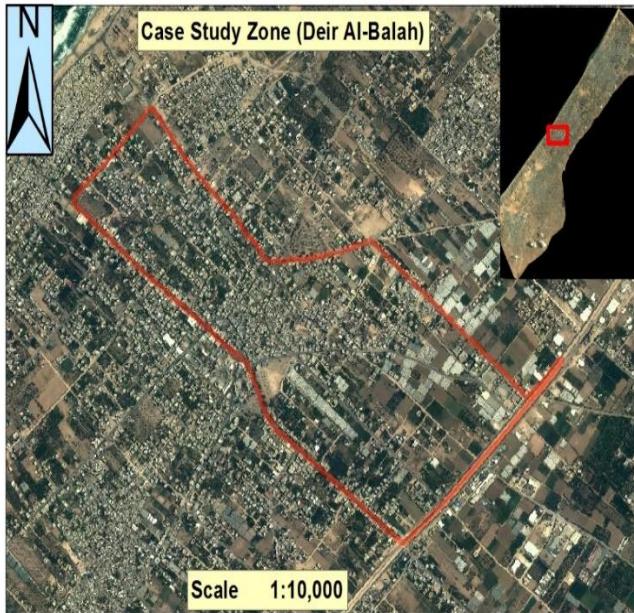


Figure 1: Case Study zone in Deir Al-Balah City

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 application 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 application 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 [2].

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 pothole 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 easures and fixes.

The following steps are performed to construct road network inventory by Roadroid application to collect data in the proposed route of the case study in Deir AL-Balah City [3].

A Collecting Data

For this project, a smartphone Sony Xperia Z3 is used as data logger and video recording device. The test is conducted traveling at average speed as possible between 20 and 100

km/h. Vehicle is adjusted to traffic conditions so that the traffic flow is not impaired. As much as possible, the vehicle is driven following a parallel path to the road centerline.

It is 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 is attached to the windscreen by holder (see Figure 2). The strength of the holder joint provides an extremely accurate orientation of the camera. Furthermore, the smartphone 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 is 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 2: Smartphone on the Windscreen

Different smartphone models return different measuring values (mainly accelerometer sensitivity and sample frequency) and also there are differences between different car models, especially at low speeds. So in the Roadroid application you can choose the smartphone model and the car model (see Figure 3).

While fitting adjustment the phone in Roadroid application 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 4). Measurement starts only if a GPS signal is available.

Driving a car in the proposed route of the case study during smartphone starts sampling (see Figure 5). 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.

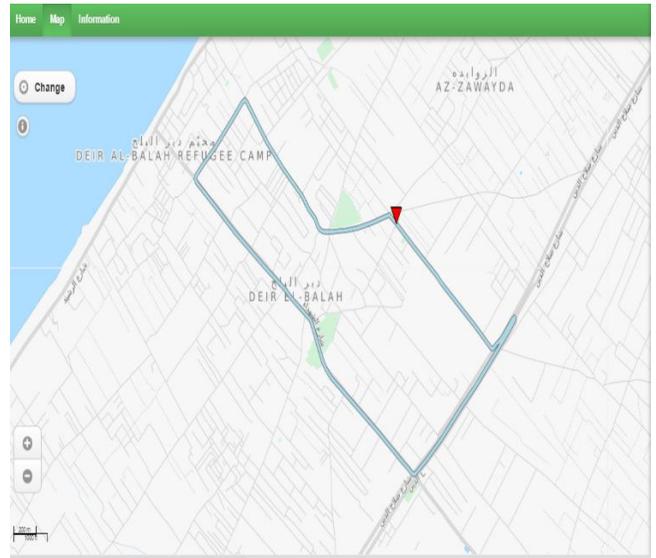


Figure 5: The proposed route of the case study in Deir Al-Balah City illustrated in Roadroid web service.

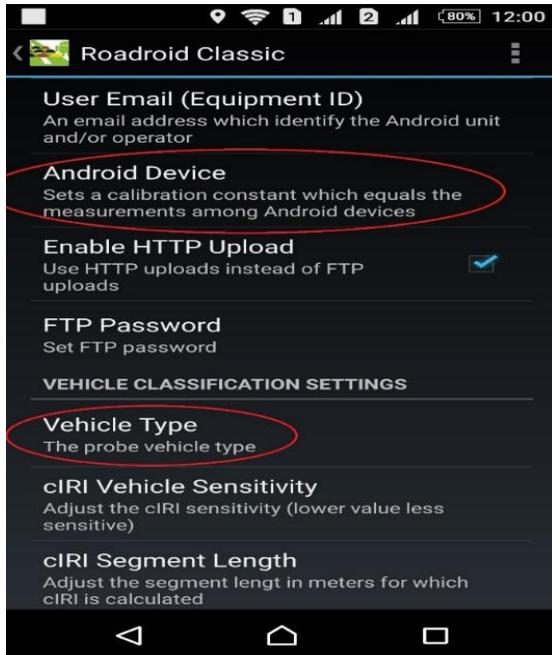


Figure 3: Choose smart phone model and vehicle model in Roadroid application

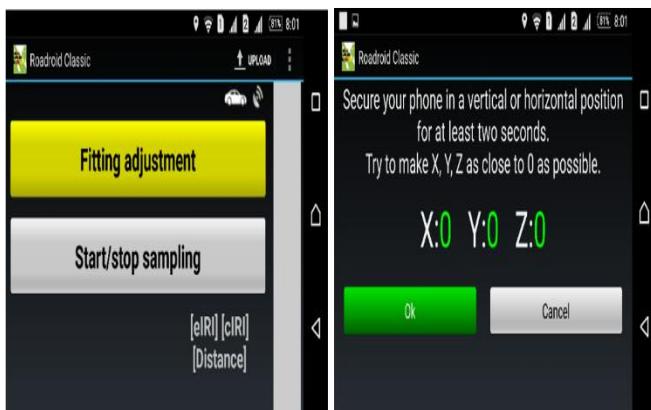


Figure 4: Fitting adjustment of Roadroid application

B Uploading data

To upload data, SmartPhone 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 6). A New roughness survey file and photos are saved each time when pressing Start/stop.

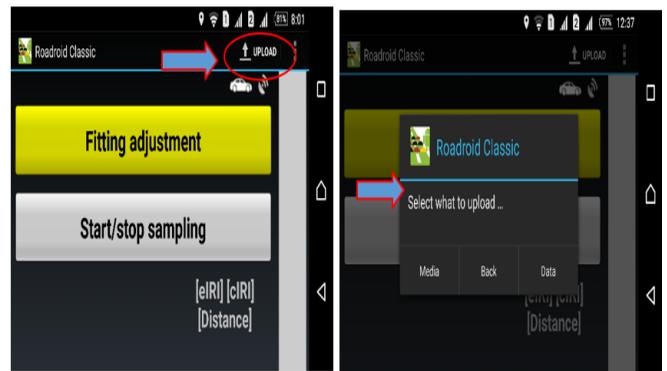


Figure 6: Uploading data collected in Roadroid application.

C 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 7). Showing the file information by clicking on “Details” and then all the data can now view on the map (See Figure 7). Viewing data on map by clicking “Zoom to measurement area on map”. (See Figure 8 & Figure 9).

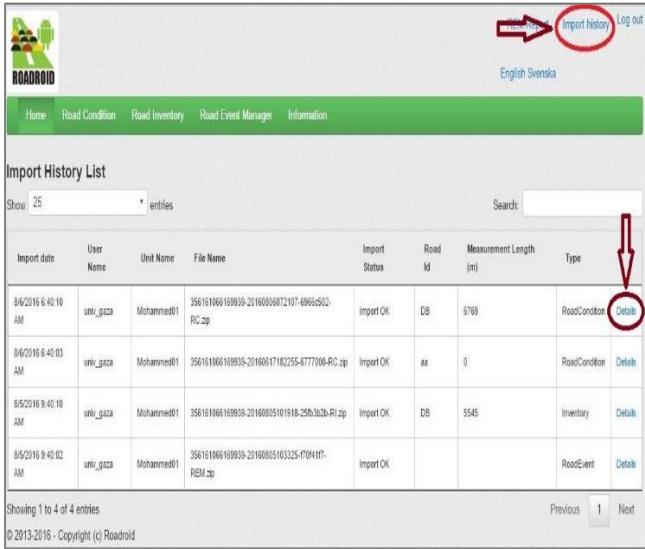


Figure 7: Import aggregated files from Roadroid web service.

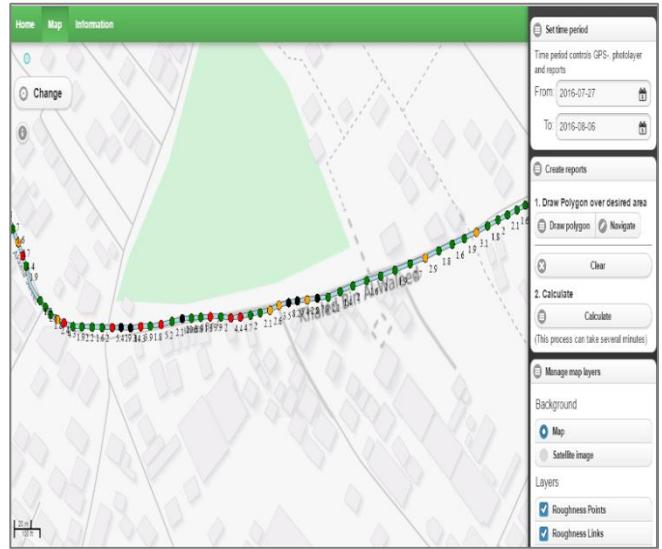


Figure 10: eIRI - labels at each dot when zoom in to the map

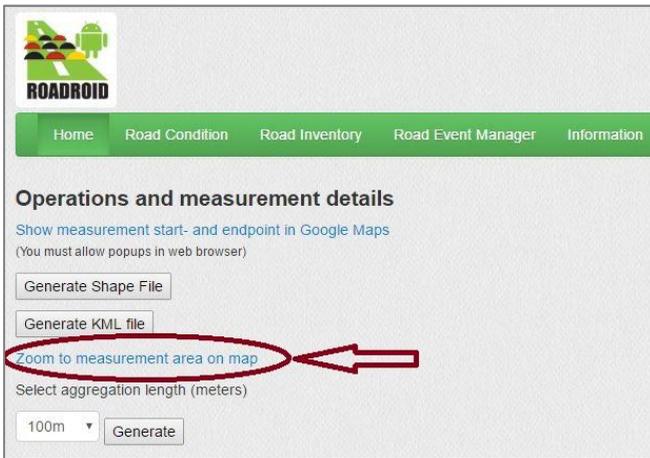


Figure 8: Operation and measurement details

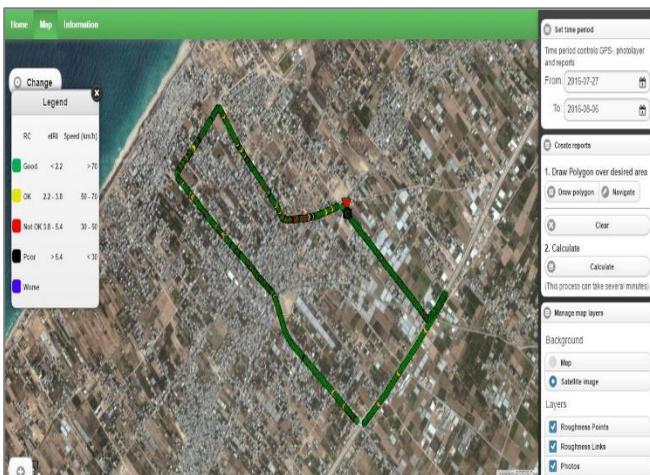


Figure 9: Viewing data on map

IRI – labels will occur at each dot when zoom in to the map at certain zoom level (See Figure 10).

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 1). The mobile application 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 1
Control Pavement Condition Criteria [1].

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 uses 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 webservice in the cloud. This operation is 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 dot is 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 11).

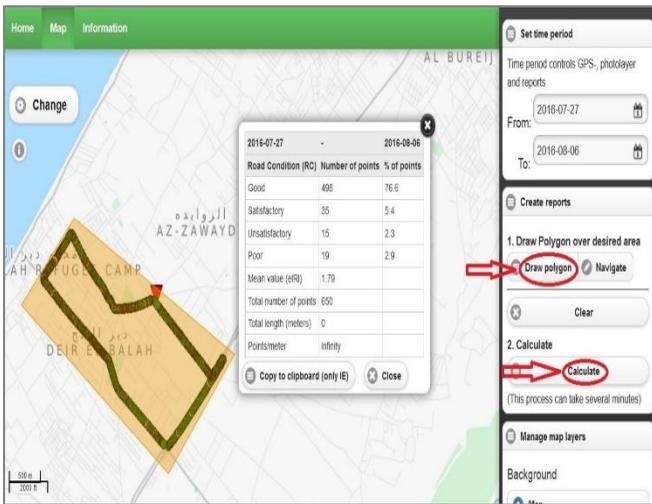


Figure 11 Viewing data by the Roadroid web service

D Download aggregated files

Data is saved in the phone every second between 20-100 km/h - the distance between the “dots” will vary depending on the speed. The data aggregated in a 100 meter section can be downloaded through the “Generate” as text files (See Figure 12).

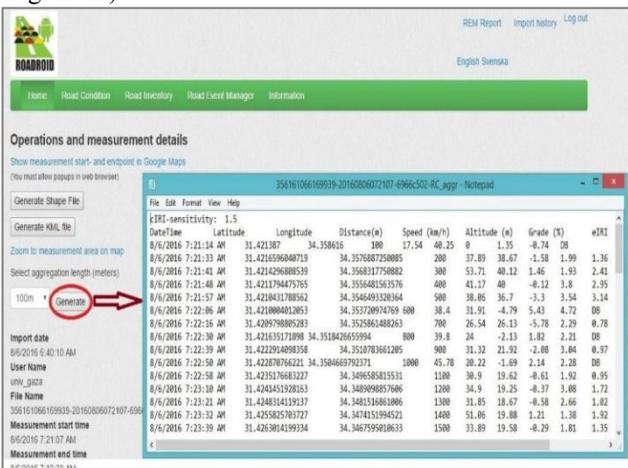


Figure 12: Download aggregated files

E Make charts from aggregated files

Importing data from the Roadroid Website is a text file format. The data is copied and pasted in Excel file to make charts of results (See Figure 13).

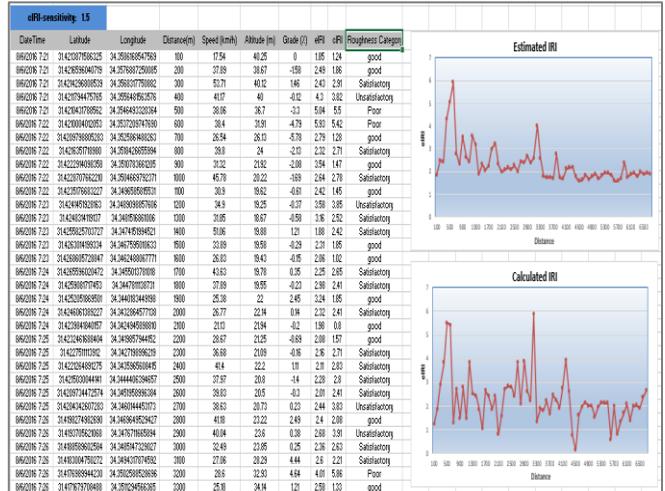
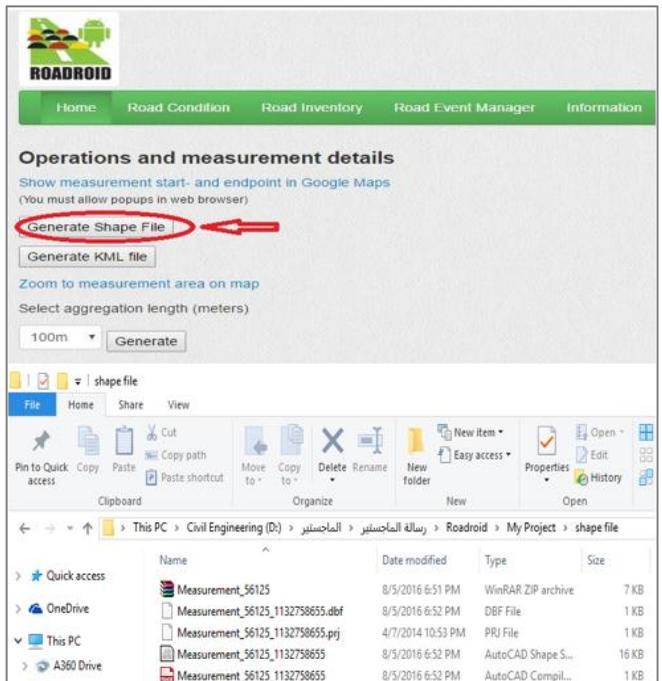


Figure 13: Make charts in Excel from aggregated files

F Export 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 14). The shapefile exported from Roadroid web service represents the route 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 14 Generate Shape File Format to be used in GIS



III GEOGRAPHIC INFORMATION SYSTEM (GIS)

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 [4]. 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) [5].

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 [6]. 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 and anywhere [7].

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 [6].

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[6].

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 [6].

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

A Add shape file that is resulted from Roadroid application, which represents the path of the road in case study. This task is illustrated in Figure (15).

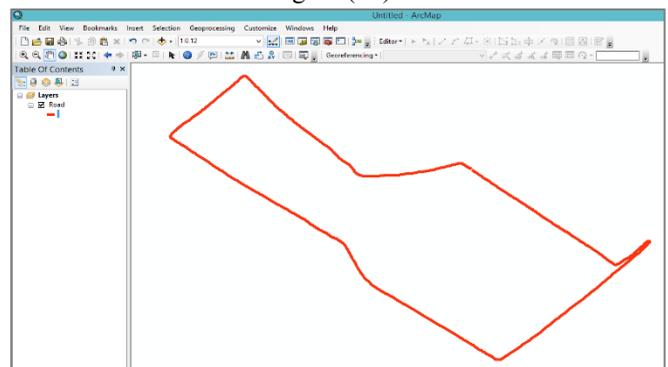


Figure 15: Add shape file that result from Roadroid application.

B Defining the local coordinate system of Palestine in the GIS for the Road shapefile, "Palestine 1923 Palestine Grid". This task is illustrated in Figure (16).

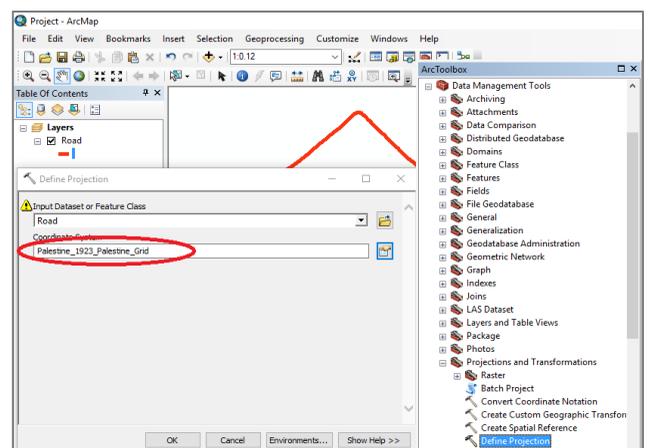


Figure 16: Gaza Coordinate System Definitions

C Adding Deir al-Balah aerial photo which is obtained from the municipality of Deir al-Balah. This task is illustrated in Figure (17).

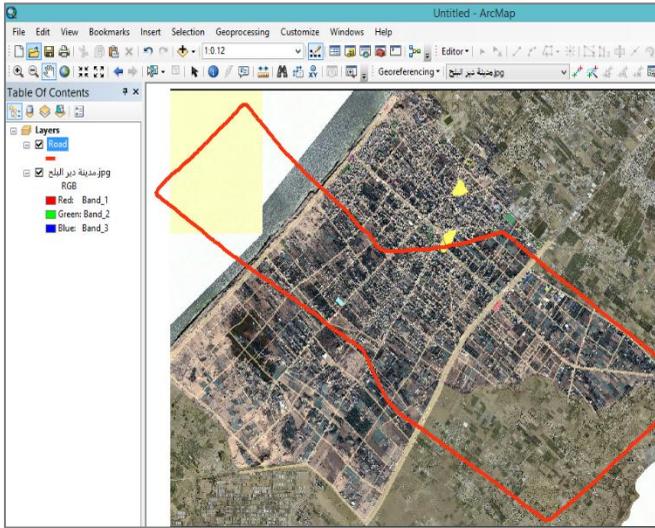


Figure 17: Adding Deir Al-Balah Aerial photo.

D It is 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 (18).

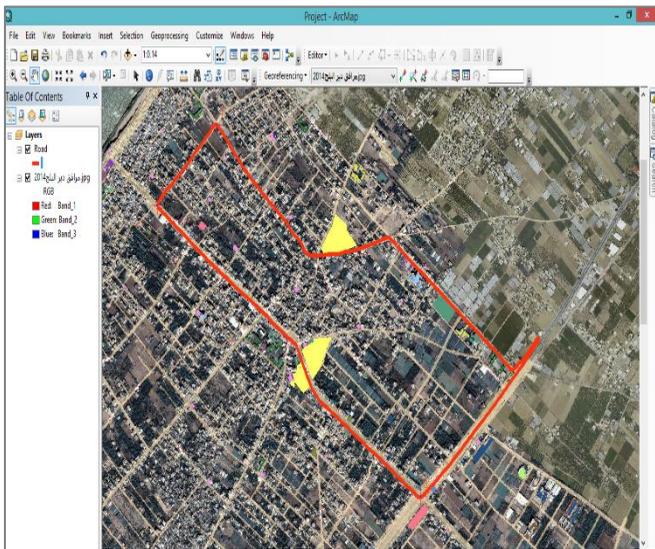


Figure 18: Georeferencing Raster data with Vector data.

E Adding IRI data that results from Roadroid application and saved as Excel format and setting local coordinate system of Palestine "Palestine 1923 Palestine Grid S". Then converting IRI from text file to Shapefile. By GIS, geographic data of various levels can be Viewed, Analyzed and Visualized. This task is illustrated in Figure (19).

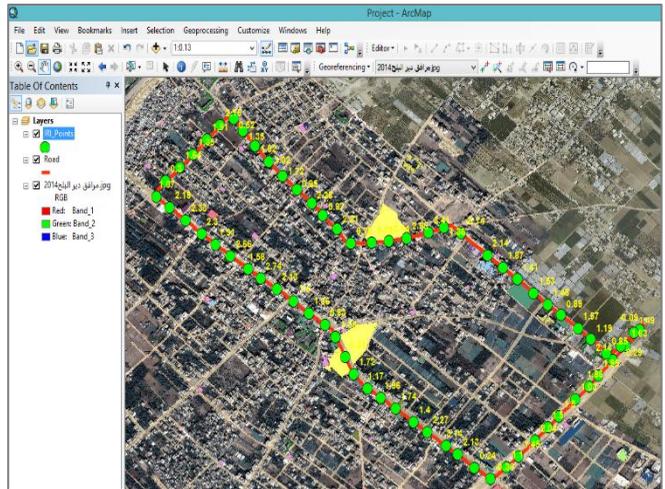


Figure 19: Viewing, analysis and visualization of Geographic Data by GIS

F IRI can be classified according to roughness category which has been clarified in Table (1) through "Sympology". This task is illustrated in Figure (20).

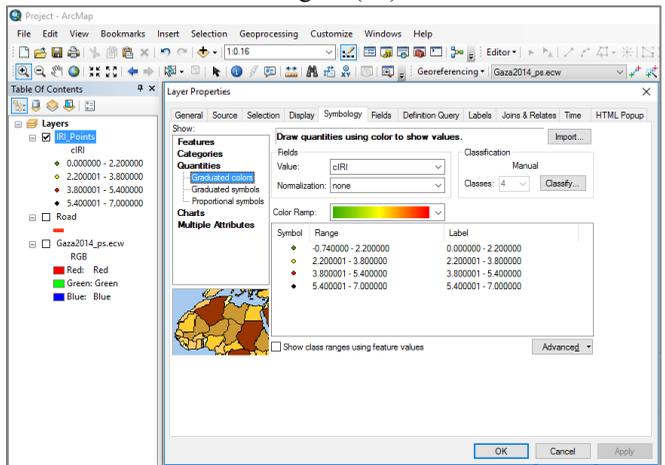


Figure 20: IRI Sympology in ArcMap

G Roughness Categories can be summarized in separate table to be used in drawing diagram. This task is illustrated in Figure (21) & Figure (22).

OID	Roughness	Count_Roughness	Sum_Distance_m
0	good	49	4900
1	Poor	2	200
2	Satisfactory	14	1400
3	Unsatisfactory	2	200

Figure 21: Summarize Roughness Categories

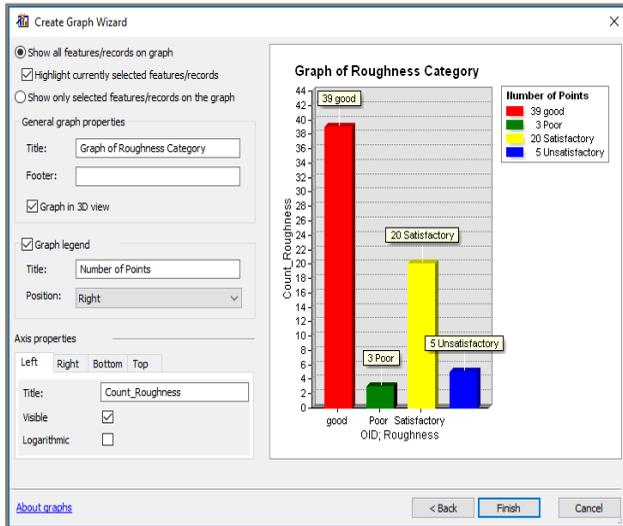


Figure 22: Roughness Categories diagram in ArcMap

IV 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 [8]. There are several steps to reach to the best alternative by AHP, as shown in a flow chart illustrated in Figure (23) which explain the methodology of AHP followed in this research.

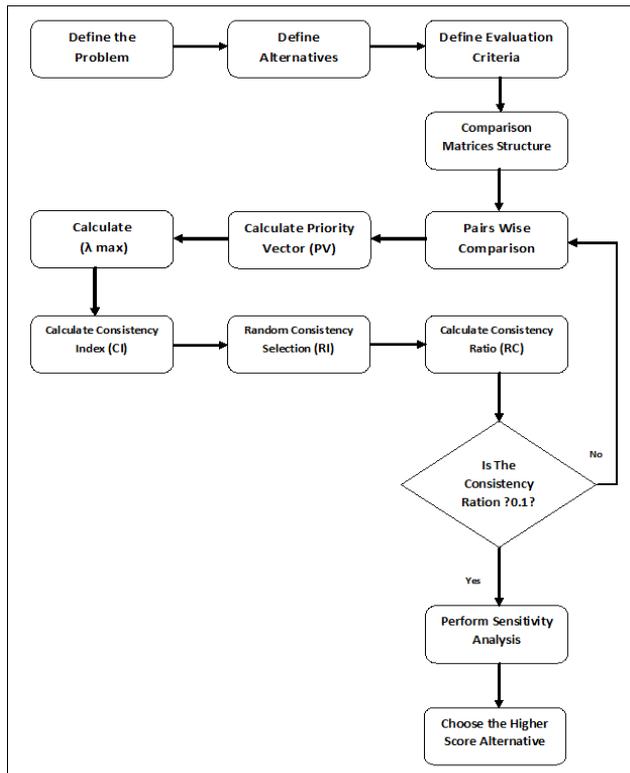


Figure 23 AHP Methodology

A 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 (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).

TABLE 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 smartphones 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
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.

B 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 (24). 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 consists of three levels; the first level is the main goal of this research. It is "Selection Appropriate Road Network Inventory method", the second level is 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 is the alternatives "visual inspection survey, Smartphone application, aerial/Satellite images" as shown in Figure (24).

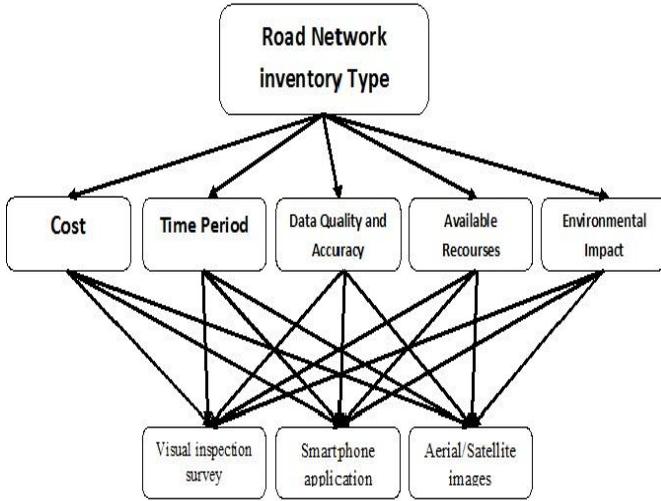


Figure 24: Hierarchy of the research problem

C 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 $nX(n - 1)/2$.

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 4) [8]. In this research the questionnaire is filled by an interview with 10 specialists in road field from various ministries, municipalities and non-governmental organizations (NGO's).

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 4).

TABLE 4
Scale of Relative Importance [8]

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 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 4). The values of the pairwise comparisons in the AHP are determined according to the scale introduced by Saaty (1980) [8]. 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 5).

In this Research: The tables of the pairwise comparison matrices are developed with its differentiation values mobilized from the survey (data collected by an interviews) for the criteria with each other like the Table (5) in additional for the

alternatives with respect to each criterion separately.

TABLE 5
Criteria pairwise comparison.

Criteria	Cost	Time Period	Data Quality and Accuracy	Available Re-courses	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

D Check Consistency of Matrices

AHP provides 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 research, the CR is calculated for each pairwise 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 (6). Then Calculating the priority vector.

TABLE 6
Pairwise comparison with cost

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

Table (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 (7) is obtained by dividing 1 (from Table 3.6) by 3.94 , the sum of the column items in Table (6) (1 + 2.7+0.23).

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

TABLE 7
Synthesized matrix for cost.

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

The priority vector in Table (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 (8) is 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 8
Priority vector

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

b) Calculating λ max

To calculate the λmax, it is required to calculate the weighted sum matrices, and that was by adding the multiplying of the priority vector in Table (8) with each column in of the pair wise comparison matrix in Table (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 calculating the weighted sum matrix, each element of the weighted sum matrix is 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) is selected from Table (9) depending on the matrix size (value of n=3).

$$RCI = 0.58$$

TABLE 9
RCI values for different values of n [6]

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 is calculated by dividing CI by RCI 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.

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

E Perform Sensitivity Analysis

Sensitivity analysis allow 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.

F Select the Best Alternative

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

Over all priority weight for road network inventory shown in figure (25). 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.

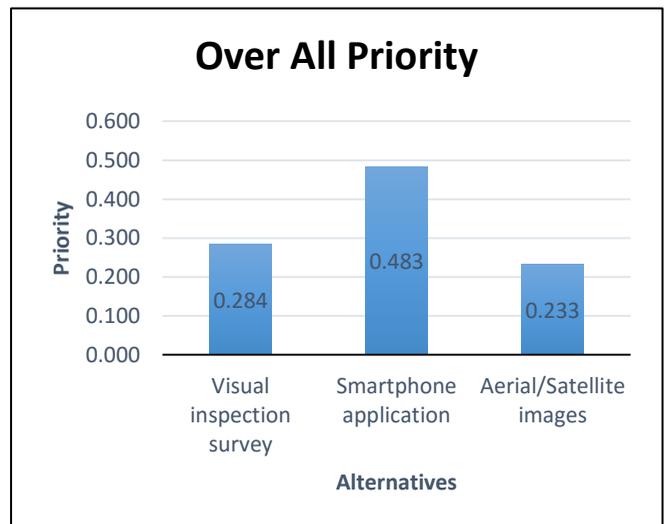


Figure 25: Road network inventories priority comparison with overall criteria.

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.

G Select the Best Alternative

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 (26).

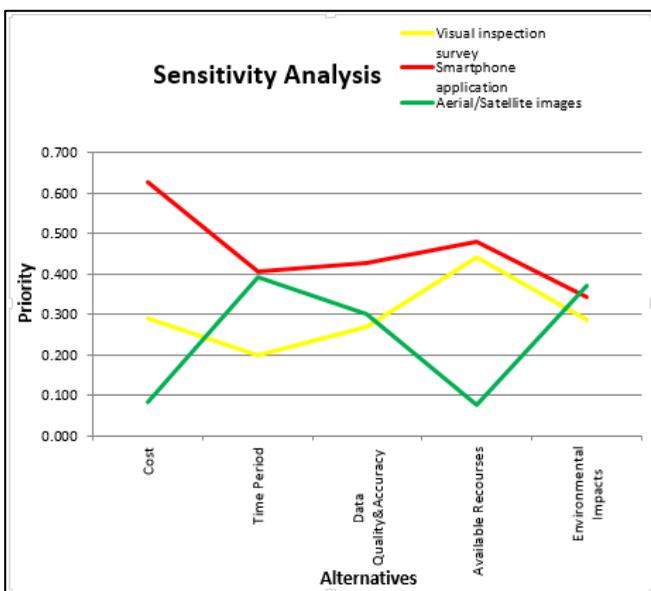


Figure 26: Result of sensitivity Analysis.

Figure (26) 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.

V CONCLUSION

At the end of this study, it is turned out that 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 illustrates this with the use of android software "Roadroid". 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 months. 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. 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.

VI RECOMINDATION

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

- 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.
- 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.

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