

Gaza Metro Network - Route Site Selection

Shafik Jendia¹, Mohammed Skaik²

¹ Professor of Highway Engineering and Infrastructure Planning
sjendia@iugaza.edu.ps

M.Sc. Civil Engineer – Infrastructure and Development, and MBA

Abstract—This paper aims at studying and planning for selecting the best route for a metro network in the Gaza Strip as a strategic trend and solution in order to overcome current and future transportation challenges. Geographic Information Systems (GIS), Multi-Criteria Decision Making methods (MCDM), and Expert Systems (ES) have extensively been used in solving metro components sites selection problems. The planning process in this paper mainly involves identifying the optimal locations for the main components of the system, which are (1) Stations (end and intermediate stations) and (2) the best optimized route. The locations of such components can be classified as the best ones, if they satisfy certain criteria such as engineering, environmental, economic, social, and institutional requirements. The results show that 3 end stations have been chosen to be the origin and destination stations. It also shows that the total proposed metro line length is 51, 759 Km. It covers all the Gaza Strip Governorates. 57 metro stations have been chosen and distributed along the proposed metro route which is branched into two routes starting from Deir Albalah and reaching the two destinations in South Gaza.

Index Terms— Gaza metro, public transportation, urban planning.

1. INTRODUCTION

Growing number of vehicular trips by cars and other means which result in traffic congestion, air pollution and traffic accidents has become a major concern in urban areas. Investments in high capacity rail based mass transit systems are being promoted to arrest this trend (Advani and Tiwari, 2005). Metro has to be understood as, “a tracked, electrically driven local means of transport, which has an integral, continuous track bed of its own (large underground or elevated sections). Metro systems have been introduced in many international cities. Metro systems operate in higher density cities in inner metropolitan areas and rely on interchanges with suburban rail systems to serve commuters from further afield. (Australian Department of Infrastructure, Planning, and Natural Resources, 2004)

2. PROBLEM STATEMENT

According to Palestinian Central Bureau of Statistics (2014), the total Palestinian population counts 4,550,368 capita where 1,760,037 of which are population in the Gaza Strip. Geography of the Gaza Strip is a tiny strip on the Mediterranean Sea with a total area of 565 Km² with a total land boundaries of 62 Km. The boundaries with Egypt has a length of 11 Km while the boundaries with Israel count 51 Km in total. The total coastal line is 40 Km. On the other hand, the natural increase rate of the population is 3.41% in the Gaza Strip.

The problem statement of this paper could be diagnosed in five major features that summarize the current and the future problems in the transportation system and its infrastructure

including the existing and potential road networks in Palestine as a whole and in the Gaza Strip Particularly as follows in Figure (1):

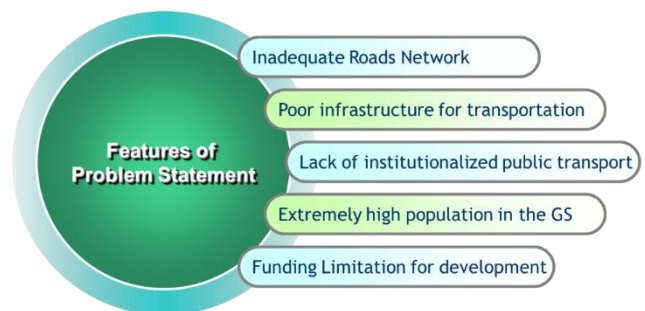


Figure (1): Features of Thesis Problem Statement

3. METHODOLOGY

A diagnostic on the current status of the various transportation sub-sectors has been prepared. An assessment of such diagnostic study results in defining key transportation sectoral and sub-sector issues. Based on such, the sectoral developmental framework can be well defined. A number of general sectoral key issues, as well as some sub-sector issues, are presented here. These include the following: (Abu-Eisheh and Al-Sahili, 2006):

- There have been several restrictions imposed on the movement of passengers and goods within the Palestinian territories and with the outside world.

- There is a considerable damage to the various components of the transportation sector as a result of Israeli military actions, which has to be repaired or replaced.
- There is still no linkage or free passage between the West Bank and the Gaza Strip. The two major Palestinian gates to the outside world and markets, the airport and the seaport that are both located in the Gaza Strip, are not being used due to military operations.
- The inadequate road facilities, which restrict accessibility of a considerable portion of the population and limited accessibility to reliable public transportation services.
- The poor structure and organization of public transportation.
- There are political constraints, which retard the development of a sound and efficient transportation system.
- Development activities in the transportation system have not been following a national transportation master plan.
- Funding is a limiting factor for both the development of the transportation sector and the maintenance of the road network.

4. RELEVANT EFFORT

The Road network in the Gaza Strip is considered as the main foundation of infrastructure. It is the only way for people, light and heavy goods carriers. Roads network should be developed, improved and continuously maintained to provide safe and secure driving environment for the rapid increase of driving population. (Lubbad, 2013). Few studies tried to investigate the possible solution of such a crisis. (El-Turkmani et al, 2003) suggested that a railway track in the Gaza Strip would be a possible solution. (Lubbad, 2013) Sat the road networks of the Gaza Strip as a case study, Divided the road networks into groups, Collected the roads representative Data, Surveyed the road information such as: Road widths, number of lanes and counting location for the representative roads were collected, Surveyed information on vehicles such as: number of vehicles, number of axles and weight of axle were collected. That will be very useful as a database for this research. A preliminary study was undertaken for a possible track for a metro project in the Gaza Strip by (Jendia and Hussein, 2011).

Al-Yazori (2013), the majority of the Gaza Strip residents use taxi in their movement. Relying completely on taxi and neglecting the availability of public transport could lead to more traffic congestion and negative impacts on the environment in the future. Al-Yazori, in his thesis for proposing a "Metro" route as a public transportation mode in Gaza City, examines the approval of the community of a metro network as a public transportation through a questionnaire. Random sample was selected and 96 questionnaire papers were distributed among the potential users of a metro facility in Gaza. The result was a full satisfaction by the community

to use a "Metro" route as a public transportation mode in Gaza City. Al-Yazori recommends to extend the metro network to include other areas in the Gaza Strip to solve traffic congestions in the future.

5. METRO SYSTEMS CHARACTERISTICS

Metro systems have been introduced in many international cities worldwide. These systems have limited seating and several doors on each side of the carriage. This design allows a high capacity with a larger number of standing passengers and faster times for passengers to move in and out of the carriages, reducing station dwell times. These metro systems operate in higher density cities in inner metropolitan areas and rely on interchanges with suburban rail systems to serve commuters from further afield. (Australian Department of Infrastructure, Planning, and Natural Resources, 2004).

A metro system generally has the following characteristics:

- capacity to transport up to 20,000 people per hour;
- typical average operating speeds between 35 and 65 kilometers per hour depending on geometry and other design parameters
- exclusive rights of way and protected at-grade crossings with grade-separation preferred;
- a corridor width of 12 meters for track sections and 18 meters at stations;
- stations spaced at between 1 to 2 kilometers apart, the adjacent residential density or the location of employment and commercial and use; and
- a minimum radius of 50 meters with a maximum gradient of 6 to 8 percent.

6. STRATEGIES FOR CORRIDOR PLANNING

Planning process for a metro network includes three parameters: short term parameters, long term parameters, and the service efficiency level. These parameters are shown in the following Figure:

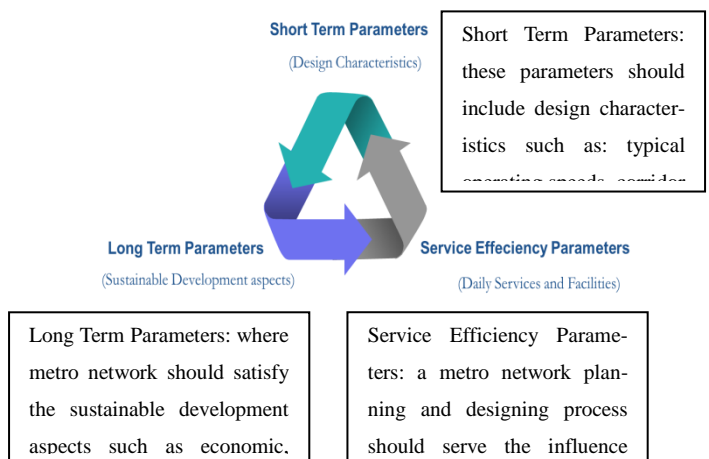


Figure (2): Metro Network Planning Parameters

7. ROUTE SITE SELECTION OF METRO NETWORKS

Building a new urban transportation facility is a major long-term investment for owners and investors. Route/site selection of such a capital project (e.g. a corridor rapid transit project like a metro-rail system) is considered a crucial action made by owners/investors that significantly affects their profit and loss. Decisions related to the locations of the facilities (e.g. metro-rail routes, stations, depots, etc.) influence economies of the metropolitan area. Routes/sites that satisfy the screening criteria are subjected to detailed evaluation. Geographic Information Systems (GIS), Multi-Criteria Decision Making methods (MCDM), and Expert Systems (ES) have extensively been used in solving site selection problems. However, each of these techniques has its own limitations in addressing spatial data, which is indispensable when one is dealing with spatial decision problems such as a route or a site selection problem. An ES is used to assist the decision makers in determine values for the screening criteria of the site screening phase, building the decision model and assigning weights to the attributes used as evaluation criteria for the site evaluation phase (Farkas, 2009).

8. SPATIAL MULTI-CRITERIA EVALUATION (SMCE)

Spatial Multi- Criteria Decision Analysis (SMCA) is a process that combines and transforms geographical data (the input) into a decision (the output). This process consists of procedures that involve the utilization of geographical data, the decision maker's preferences and the manipulation of data. In the context of route/site selection of urban transportation facilities the value-focused approach has many advantages over the other (Sharifi and Retsios, 2004).

According to Eldrandaly, Eldin, and Sui (2003), the screening criteria include multiple measures, such as engineering, economic, institutional, social, and environmental factors. The goal in a route/site selection project is to find the best location with desired conditions that satisfy predetermined selection criteria. The various elements of this criteria structure are briefly described as follows:

Goal and Objectives: The goal of this framework is to identify an effective public mass transportation system for a metropolitan area integrated with an efficient land use so that it meets the present and long-term socio-economic and environmental requirements of the residents of the marked territory.

9. PLANNING AND DESIGNING A METRO NETWORK FOR THE GAZA STRIP

The Route Site selection process mainly involves identifying the optimal locations for the main components of the system. The locations of such components should satisfy certain criteria such as engineering, environmental, and economical requirements. In other words, the location that reduces costs, has less impact on the environment, and can be used without any construction or engineering constraints is the favourable one.

The researchers would suggest the potential metro line that links the north of the Gaza Strip with its south. This configuration is not randomly selected, but based on the analysis of future travel demand. For example, the eastern part is characterized by the agricultural and industrial regions which could be a source for attraction of many workers and employees currently and in the future. The western part is well known for tourist attraction. In addition, the operation of sea port of Gaza would attract more and more people. The designing process went through following steps:

1. At the first step, it is crucial to state the problem precisely. The problem can be formulated as determining the best locations for the proposed metro lines and their stations. This step also involves breaking the main problem down into sub-problems so that it would be easier for handling it.
2. At the second step, the data needed for solving the problem is identified and collected from different sources. The data is identified based on the criteria defining the optimal sites.
3. The third step constitutes the core of this work because here the data is geo-processed and spatially analysed for making decisions regarding the best locations for metro lines. This step involves a series of geo-processes expressed as cartographic model. The Model Builder tool in ArcGIS is used for this purpose.
4. The fourth step includes the evaluation process of the results. If the results are not satisfactory, then the proposed methodology should be revised.

10.1 STATING THE PROBLEM AND OBJECTIVE

The main problem is finding the best location for metro system components. That means we need to identify the optimal sites for stations and routes. That can be achieved by considering the criteria that satisfy the engineering, environmental, and economical requirements.

From one hand, the optimal site for a station should satisfy the following criteria:

1. It should be in Close proximity to the highly dense populated areas
2. Near the vital places, such as universities, schools, shopping centres, etc. those places plays important role in trip generation and attractiveness.
3. It should be in close proximity to the existing important intersections. The most important intersection is that one with the following characteristics:
 - a. It has a high number of available parkings
 - b. It has a large space.
 - c. It has high traffic volume.
4. The distance between stations should be 1 km apart
5. The walking distance travelled by pedestrians to any proposed station should not exceed 0.5 km.
6. The station should be in a suitable land.
7. For construction and environmental considerations, the site should be selected where the water table level is deep.

- 8. The corridor width at the station should be at least 18m.

The aforementioned criteria is specified for intermediate stations, for end stations extra criteria is need such as: being in a large area/space for parking and maintenance works, and being far away from the borders for security purposes.

On the other hand, the optimal site for a route is the one that keeps the cost at its least value. Therefore, it should satisfy the following criteria:

- Its intersection with existing buildings should be avoided as much as possible.
- The route should be far from the water table.
- The soil type is preferably to be sandy
- The slope should be as minimal as possible. The maximum gradient should be 6 to 8%
- The corridor width should be 12 meters for track sections.

10.2 DATA COLLECTION AND PRE-PROCESSING

The data is one of the main components of any problem solving process. Therefore, the required data should be first identified and collected from relevant sources. The data could be easily identified from the criteria mentioned in the previous section. When the data has a spatial context, they will be referred to as layers. The data needed is listed in Table 1.

TABLE 1

Data Required for Spatial Analysis

Criteria	Data required	Data model
1.Close to the highly dense areas	• Population density	• Table
2.Near the vital places	• Vital places (e.g. universities, Public facilities...).	• Vector layer: points
3.Close to the existing important intersections	• Important intersections and Parking places	• Vector layer: points • Vector layer: points
4.Walking distance not to exceed 0.5 km	• Existing road network	• Vector layer: polylines
5.station should be in a suitable land	• Land use	• Raster layer
6.water table level should be deep	• Water table level	• Raster layer
7.The intersection of routes with existing buildings should be avoided.	• Existing buildings	• Vector layer: polygons
8.soil type is preferably to be sandy	• Soil types	• Raster
9.slope should be as minimal as possible	• Digital Elevation Model	• Raster

Once the data was collected, the data was inspected and pre-processed to bring it into a suitable format for the next step,

which is the analysis. The pre-processing includes converting all the data into suitable GIS formats. For example, some data has been collected as CAD files (e.g. Buildings) and Excel files (e.g. water table elevations). CAD and Excel files were converted into Environmental Systems Research Institute (ESRI) Geodatabase Feature Classes. Furthermore, all layers should have the same coordinate system, which is the Palestine 1923 Palestine Grid. The following sections describes samples of the collected data in more details.

The required data were collected from local sources such as municipalities, relevant ministries, and GIS professionals. The collection process was one of the difficult tasks in this work. That was because of the lack of consistent and accurate data. Even if it was available, it would be difficult to get it due to the legal constraints. The data collected are as follows:

More information and detailed description and analysis for these data are described in Appendix (1).

10.3 SPATIAL ANALYSIS

After data collection and pre-processing, the data is to be analyzed spatially and non-spatially to come to the final solution of the problem. The data was analyzed using the spatial analysis techniques provided by ArcGIS Desktop 10.1. The analysis that is concerned with selecting best sites for facilities is known as suitability analysis. Such analysis has been used extensively for selecting the optimal regions for metro stations. The procedure followed for identifying the optimal sites can be summarized in the following three steps:

1. Select the optimal sites for end stations (master origin and master destination).
2. Select the least cost path between the master origin and master destination.
3. Distribute the intermediate stations along that path according to the criteria specified previously.

The idea that would be used here is to rank the regions of the Gaza Strip according to the criteria mentioned previously in this chapter. The scale 1-10 will be used for such purpose. If a location is ranked 10, it would be the most suitable location for metro station. That also means 100% of the criteria has been satisfied.

On the other hand, if a location is ranked 1, then it is the least suitable location for a metro station. That can also be interpreted as 10% or less of the criteria has been satisfied. In addition, number 0 in the scale means that this component is restricted and forbidden.

10.3.1 SITE SECTION OF END STATIONS

The optimal sites for end stations should satisfy the following criteria:

1. The station should be on a suitable land.
2. The station should be far away from borders including the coastal lines.
3. The station should be located in Rafah or Northern Governorates since these are the border gover-

norates while the Gaza Strip is a narrow, 40-km long slice of land between the Mediterranean to the west and the Negev desert to the east.

4. The area should be large enough so that the station works as a parking area for trains and for maintenance.

After the data is collected and preprocessed, a sequence of geo-processes are performed to answer the basic question, which is where the optimal sites for end stations should be located. Please refer to the cartographic model in appendix 2.

10.3.2 SITE SELECTION OF THE LEAST COST ROUTE

After the selection of optimal sites for end stations, the major routes of the metro system can be constructed by searching for the least cost paths. The cost could be in terms of environmental, economic, construction costs. The least cost path should satisfy the following criteria:

1. Intersection with existing buildings should be avoided.
2. Route should be far from the water table.
3. Soil type is preferably to be sandy.
4. maximum gradient should be 6 to 8%
5. The corridor width should be 12 meters for track sections.
6. Close to vital regions (universities, parks, main stations, ...)
7. Close to dense populated areas

In order to solve the problem of finding the least cost path for metro lines, some of geo-processing tools, which are provided by ArcGIS, are used extensively to make the final decision. The steps can be summarized as follows:

1. The above criteria are combined and weighted using the Simple Linear Combination method as explained previously in this chapter. The output was a raster layer called Cost Raster Surface with values from 1 to 10.
2. The Cost Distance tool is employed to compute the least cumulative cost distance for each pixel from the origin to destination.
3. The output of the Cost Distance is inputted to Cost Path tool which computes the least cost path from the origin to destination.

10.3.3 SITE SELECTION OF INTERMEDIATE METRO STATIONS

Criteria 1: Population Density

The final output of this step is a raster composed of cells. Each cell represents a region of size 30x30 m² that could be a core of a station. Each cell has a value representing how much it is suitable for a metro station. The regions with highest population density receives a rank of 10, and those with lowest density receives a rank of 1.0. The population data is obtained for each municipality in the Gaza Strip. The

processes that are performed to get the raster suitability map is summarized as follows:

1. The population density was estimated for each region in the Gaza Strip. ArcGIS Spatial Analyst provides tools for such purpose. The Kernel Density tool is used in this work.
2. The output of the Kernel Density tool is a raster composed of cells. Each cell has a value representing population density.
3. The density raster is reclassified to new values that ranges from one to ten (1-10). The Reclassify tool is employed for that purpose. The cells with highest density values get the new value 10, and those with lowest density values get the new value 1.0.

The output raster of this step will be overlaid with raster layers from other criteria, and averaged to get final suitability map.

Criteria 2: Near Vital Places

The final output of this step is a raster composed of cells. Each cell represents a region of size 30x30m². Each cell has a value representing how much it is suitable for a metro station. The regions that are the closest to vital places receives a rank of 10, and those that are furthest receives a rank of 1.0. The processes that are performed to get the raster suitability map of this criterion are as follows:

1. For each region in the Gaza Strip, the distance to the nearest vital place is computed. The Euclidean Distance tool is used. The output is a raster composed of cells. Each cell has a value representing the distance to nearest vital place.
2. The distances obtained in the previous step are reclassified. The cells with the highest values get a new value of 1.0 and those of lowest values get 10.

The output raster of this step will be overlaid with raster layers from other criteria, and averaged to get final suitability map.

Criteria 3: Close to the Existing Important Intersections

A procedure for reclassifying the intersections according to their importance is adopted. Before we introduce the procedure, we need to know the specifications of important intersection. The intersection can be classified as important if:

- It is located on regional and primary roads, and
- It is located in a vital, active and dense area.

1. The procedure adopted for identifying the important intersections is summarized as follows:
2. All intersections are ranked according to their position on roads. The regional roads get highest score and the local roads get the lowest.
3. All intersections are also ranked according to their proximity to the vital places.
4. The ranks are combined using the weighted linear combination assuming equal influence for both ranks.
5. The intersection which gets the highest rank

10. THE RESULTS OF GAZA METRO NETWORK PLANNING PROCESS

The Results shown in Figure (3) highlights that 3 end stations have been chosen to be the origin and destination stations. It also shows that the total proposed metro line length is 51,759 km. It covers all the Gaza Strip Governorates and serves the most vital places. Intermediate stations are 57 stations distributed along the proposed metro route. It also serves the most important intersections and vital places in the Gaza Strip Governorates.

The proposed metro facilities seem to be a promising public transportation mode in the Gaza Strip. It will facilitate the movement of goods and passengers for different usages across the Gaza Strip Governorates. In addition, it will facilitate the potential regional connection of the Gaza Strip beside the physical connection of the Gaza Strip with the West Bank reaching to a national frame work of developing and improving the Palestinian public transportation infrastructure and facilities. Figure (3) also shows the best possible route and intermediate stations of the Metro network. It shows that the best origin metro station is located in Um-El Naser Area with coordinates (34o 32' E, 31 o 43' N) while two destination stations have been chosen in the East of Khan Yunis Governorate with coordinates (34o 20' E, 31 o 17' N) and in Rafah Governorate with coordinates (34o 15' E, 31 o 19' N). This is clear where the main two borders of the Gaza Strip are Rafat Crossing Border and Beit Hanoon (Erez) Crossing could be served by these origin and end destinations. The other crossing borders of the Gaza Strip could also be served by the intermediate stations assuming that Goods movement will be served by the metro.

The least cost route runs throughout the Gaza Strip Governorates as shown in Figure (3) with a total length of 51,759 m. The route is integrated with the main vital places and roads of the Gaza Strip as approached in the methodology adopted where further and deep investigation of another structural design components should be carried out. The corridor minimizes the intervention on the existing facilities and infrastructure as much as possible through taking into consideration all the criteria mentioned the previous chapters. Figure (3) also shows that the metro network is divided into two branches starting from Deir Albalah Governorate with coordinates (34o 21' E, 31 o 22' N) for the splitting point reaching the final destinations in Khan Yunis and Rafat Governorates.

The Intermediate Stations are located along the route where it is spaced at 500 m inside the governorates or where there are vital place that should be served by these stations. On the other hand, the intermediate stations are spaced at 1.0 Km between the Gaza Strip Governorates where there is a light duty on the metro stations. The total number of the intermediate stations is 57 stations where each station locates on a suitable place based on the criteria mentioned previously.

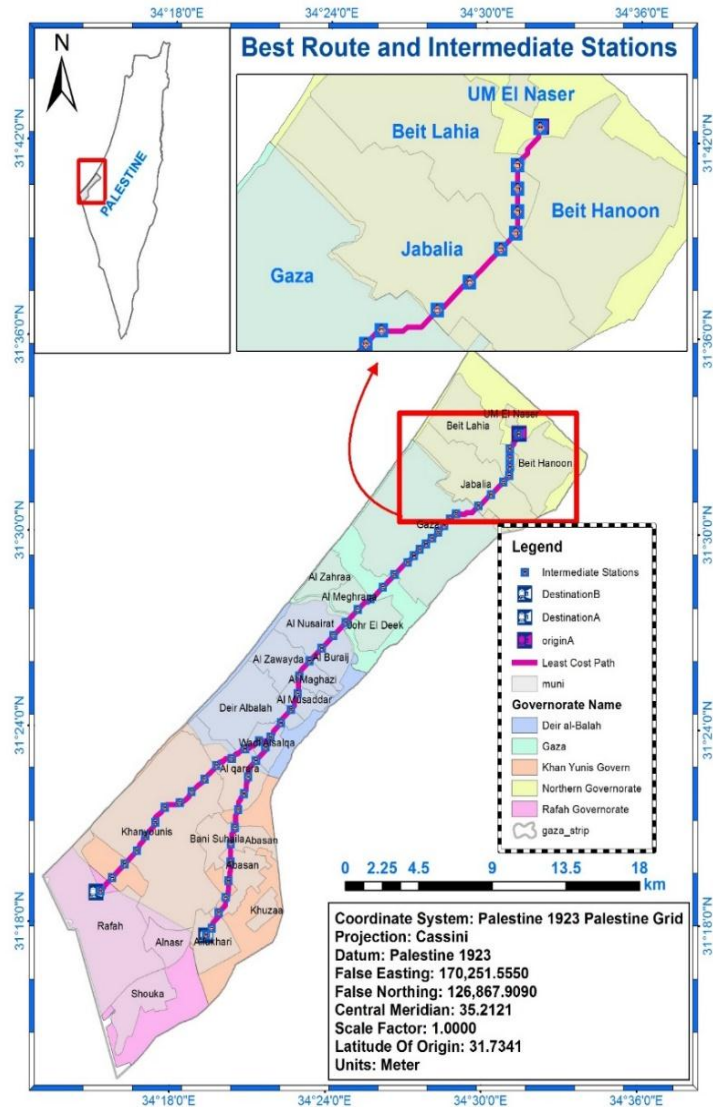


Figure (3): Gaza Metro Network Components

11. RECOMMENDATIONS

- The authors recommend adopting the proposed Metro Network for the Gaza Strip as a feasible solution for current and future challenges.
- The study recommends institutionalizing public transportation systems in order to provide better services for passengers in the Gaza Strip.
- Environmental impacts should be investigated to minimize the ecological consequences of such a strategic infrastructure project.
- Economic factors should be studied to highlight economic impacts of the establishing and running the metro network in the Gaza Strip.
- A customer profile should be developed for the metro facility that helps in improving the service and the best practice for running the facilities taking into consideration: Flexibility, Convenience to reach stop/station, and Speed.

- National strategies and actions are needed to ensure that the corridor can meet the long term performance envisioned by corridor partners. These strategies include developing capital projects that will address significant capacity deficiencies and/or bottlenecks, other less-costly improvements that address specific safety and/or operational issues and policy-type directives that proactively promote development of the corridor vision through local ordinances and access guidelines. In short a transportation long-range funding solutions that are realistic, innovation, and focused.

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APPENDIX

1. Data Acquired for Spatial Analysis

Figure (A) population density across the Gaza Strip.

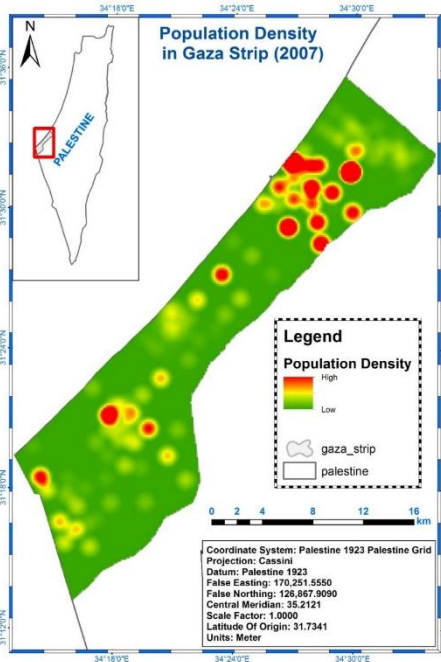


Figure (B) Vital Places in the Gaza Strip

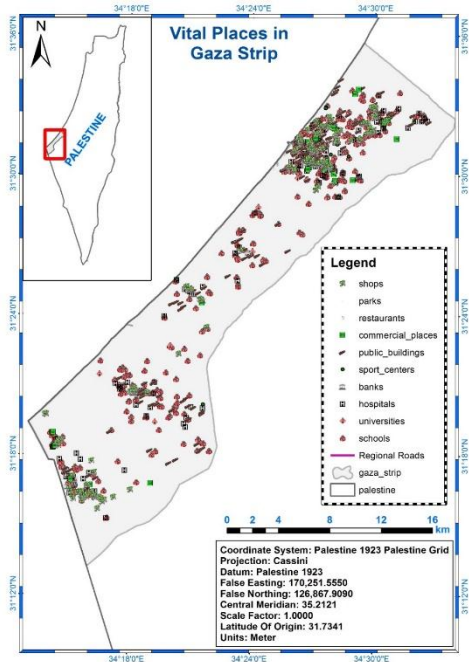


Figure (C) Existing Road Network in the Gaza Strip

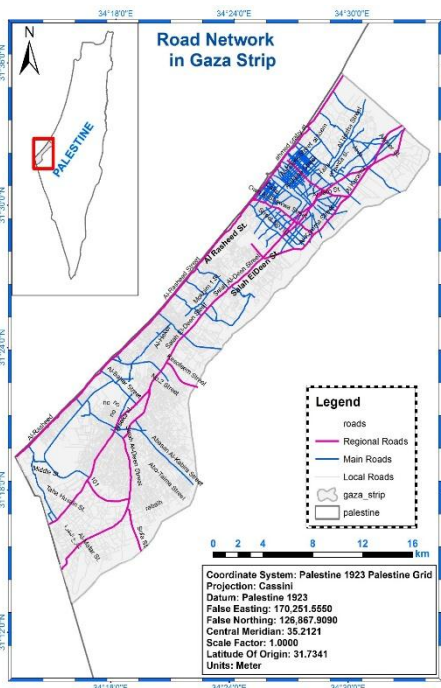
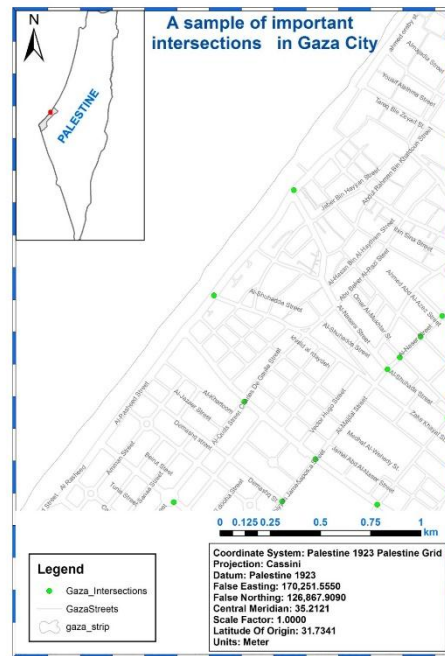


Figure (D) Important Intersections in Gaza



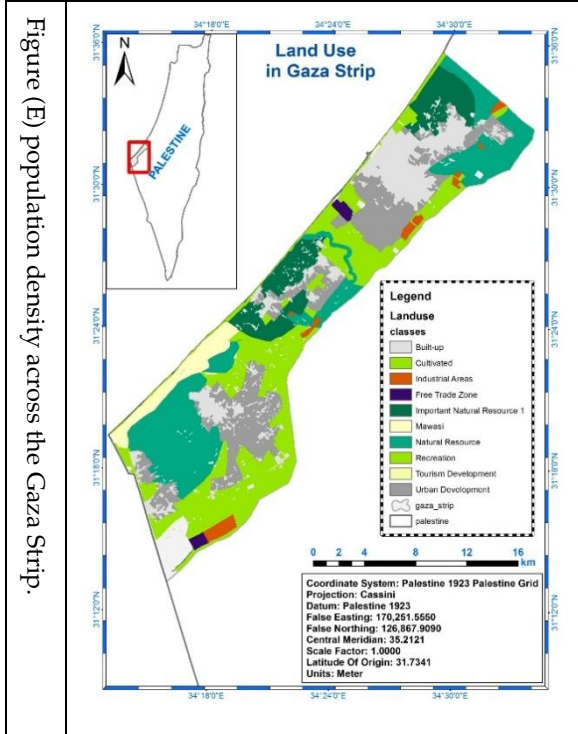


Figure (E) population density across the Gaza Strip.

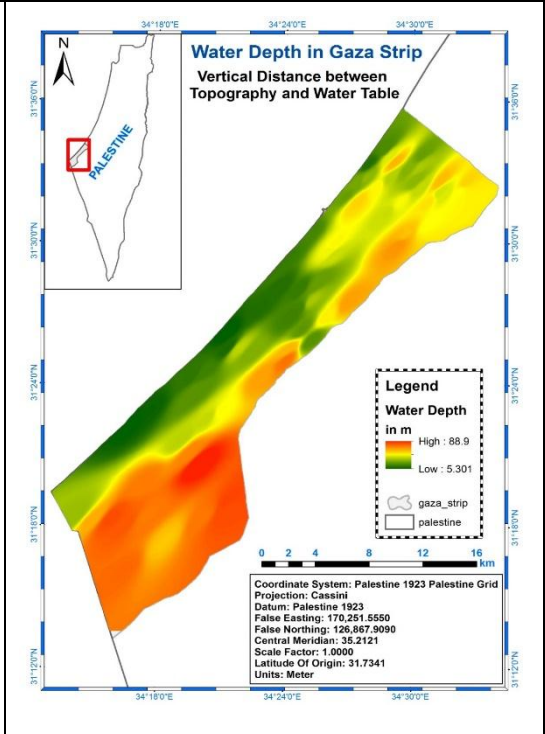


Figure (F) Water Table Depth in the Gaza Strip

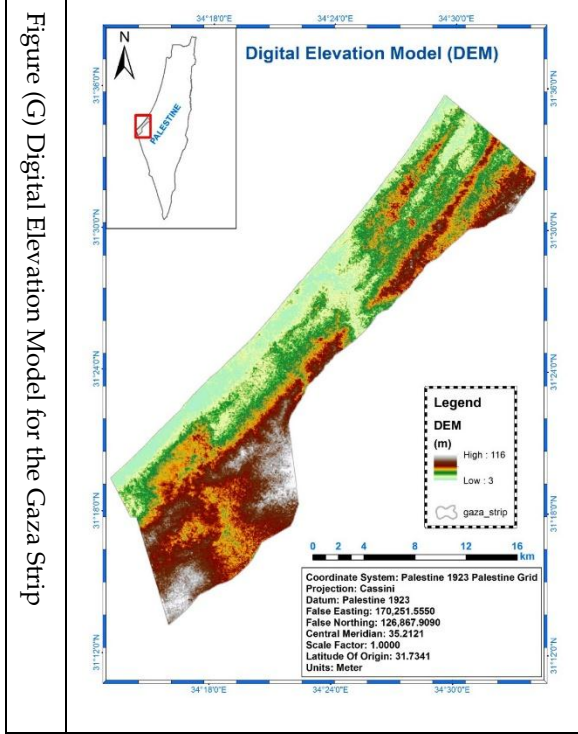


Figure (G) Digital Elevation Model for the Gaza Strip

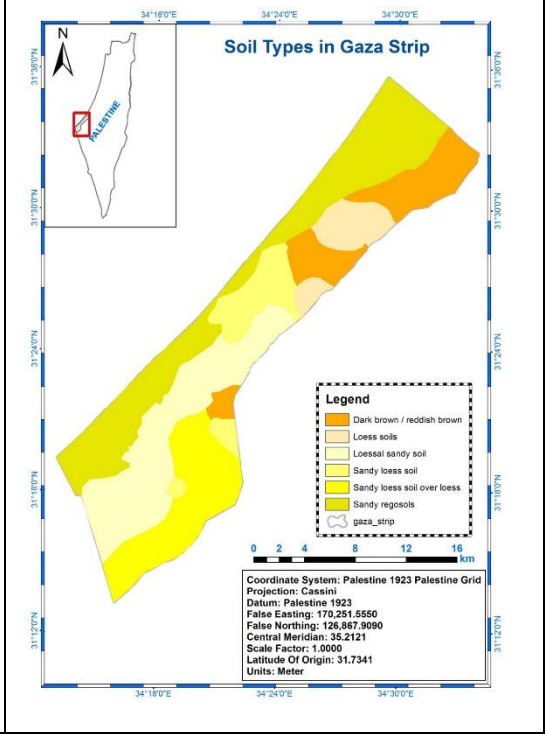


Figure (H) Soil Types Distribution in the Gaza Strip

2. Cartographic Model of End Stations Selection

