Chapter 6

Application to Transportation Projects in Alexandria, as a Case Study

6.1 Introduction

Developing countries offer a particularly unique local context with regards to urban transport and the integration of modes. In spite of the deteriorating travel conditions, car ownership continues to rise with increasing population growth and improving living standard (Gakenheimer, 1999; McMichael, 2000; Gwilliam, 2003). For instance, the car ownership in Cairo increased in the period between 1996 and 2014; from 94.2 to 164.5 cars/1000 inhabitants, and in Alexandria in the same time from 47.5 to 94.2 cars/1000 inhabitants, almost on unchanged traffic area.

Under these circumstances, infinite transport demands (mainly motorized) continually increase within a finite transport infrastructure. Consequentially the quality of urban life is starting to deteriorate; e.g. traffic congestion, noise, pollution, frequent accidents, and stressed nerves, as well as intensive use of fossil fuels. Actually, the street in metropolitan areas of developing countries has become hostile, and urbanity is in danger.

Public transport faces significant challenges. The government funding is basically directed to construction, expansion and maintenance of roads, while the public transport does not receive the same care. The implementation of public transport projects may be postponed due to budget constraints, and some existing routes may be canceled, on the assumption that public transport hinders the movement of private cars.

Failure of governments to supply organized public transport and the inadequate public transport supply compared to the increase in demand have induced the explosion and the intensive use of privately operated minibuses, microbuses, collective taxis, motorcycle taxis, which are often operated under substandard and unsafe conditions (Kumar and Barrett, 2008). Public transport became unattractive. In the eighties, in Alexandria, for example, the public transport was used for over 53 % of the trips. This is no longer the case nowadays, as it expected that the share of public transport around 25%, in spite of an annual population growth of more than 1.5%, and a daily increase in mobility from 3.82 (in the year 1985) to about 5.0 million trips.

The travel situation in metropolitan areas in developing counties should be improved, and the traffic conflicts should be released. The only way is to promote safe, attractive and effective public transport. In Alexandria, for example, a lot of public transport projects are already available as results of different transportation studies. However, the decision for implementing one or more of these projects has not been taken so far because of conflicting opinions of experts, and the lack of a mechanism for screening the candidate projects and selecting the top priority project, within the framework of limited financial sources.

The subsidized public transport in Alexandria is operated by two state-owned organizations: The "Alexandria Public Transport Authority (APTA)" which as a municipal local transport organization operates buses and trams, and the state railway organization "Egyptian National Railways (ENR)" which operates the Abou Kir regional line. APTA has a Master Plan 2006 to improve the public transport services in Alexandria (APTA, 2006), and ENR submitted in 1998 the project “Alexandria Regional Metro: Abou Qir to El Aamiria” (NAT, 1998) to support the public transport in Alexandria and its extension to the suburb El Aamiria to relieve the high population densities in Alexandria.

The purpose of this Chapter is to apply different techniques for evaluating and rating the transportation projects generated from APTA Mater Plan 2006 prepared by HTM & MENA RAIL and their options, as well as Section 1 of the project “Alexandria Regional Metro: Abou Qir to El Aamiria” which was studied at feasibility study level by SYSTRA, in 1998 in the order of The Transport Ministry/The National Authority of Tunnels (NAT). The following techniques are applied:

- Economic Feasibility
- Multi-Criteria Decision Analysis (MCDA); i.e. both Weighted Sum Model (WSM) and Multifactor Evaluation Process (MFEP)
- Analytical Hierarchy Process (AHP)
- The Proposed Approach CETP

The application is performed with EXCEL PROGRAMMING, to utilize its wide range capability in a decision making process. This capability may be described as follows:

- Excel can deal with large amount of data and information in spreadsheets.
- It works quickly in formatting, formulating, analyzing, and presenting of data.
- It has the ability to create graphical and visual representations of data.
- It can be used for what if analysis for supporting decision making.
- Interactive and immediate results, if any changes occur in the input data; also visual.
- Automatic transfer of data from a spreadsheet to another.
- All Excel spreadsheets can be integrated with each other.

These programs produce the evaluation and ranking of all projects and their options under consideration in a sequence, and the user eliminate after that the projects which have option with higher priority.

The aim of the application is to investigate the practicality and capability of the various techniques used for the sustainable evaluation of large-scale and long-term public transport projects in metropolitan areas of developing countries.

6.2 APTA Master Plan 2006

6.2.1 Background

APTA operates buses, the city tram and the Raml tam. The bus runs approximately on all main roads of the city, and its network includes 110 lines with a total length of almost 2 749 km. Some of the lines continue far into the surrounding area, with line lengths of maximum 65 km. Since 1985, the coverage area of the bus network has increased, but the increase in the number of vehicles is not balanced with the network expansion. The result is deteriorating frequency. Currently there are no specific bus lanes on the roads, the buses are slowed down by traffic jams and waste a significant amount of time during peak hours. APTA owns 336 buses and 132 minibuses, most of them have exceeded the operational lifetime. Only a small fraction of this nominal number is actually operated. The reasons for that are lack of spare parts and insufficient efficiency of the maintenance facilities. Master Plan 2006 does not offer proposals for improving the bus system.

The City tram serves the old city with about 10.0 km/h commercial speed. It has no separated track, and runs with other traffic in the middle of narrow roads in the old city. The total length of the City tram network is about 28 km of double tracks (17 lines). APTA owns 119 tram units; the capacity of each unit is 256 passengers. Due to the location of the city tram tracks in the middle of the roads, the existing road area serves public and private transport. This intermixture leads to disruptions to both transport means. Furthermore, on some locations, the City tram runs in two directions on one-way streets. Most of the City tram trains were manufactured in period 1960–1970 and 15 units in 1986. The rolling stock is outdated with poor operational performances and very low quality of service. The actual operation is random due to the traffic jams and the official headways cannot be reached. Master Plan 2006 does not provide any suggestion for improving the situation of the City tram.

The Raml Tram connects the City Center (Raml Station) to the eastern part of the city (Victoria Station). It runs through dense areas and connects major activity spot points with each other's such as; Alexandria University, Sidi Gaber Rail station, sporting facilities, and business and shopping district at Raml station. The total length of the Raml Tram System is about 10.5 km. it has its own dedicated double track; it is semi-isolated interrupted by 37 road junctions without priority devices. These road junctions are bottlenecks for both tram and general traffic. Some crossings are equipped with traffic lights that are controlled manually by traffic policeman. In total run time, about 15 to 20 minutes are spent on road crossings (total delays of every journey). In general, car traffic has a highest priority and light rail vehicles sometimes wait 5 minutes at one junction for green light.

The track of the Raml Tram is mainly at the same level as the general traffic except around Alexandria University where the tram right of way is lower than the street. On that section, retaining walls run along the tram infrastructure and cars cross above on a bridge. Generally, the track infrastructure is outdated and in poor condition.

APTA owns 42 train sets; each of them consists of three cars. From the owned vehicles, only 34 train sets are technically ready for the service, but only 24 trains are in the actual operation daily. All rolling stock is manufactured by Kinki Sharyo and Toshiba electric equipment. The capacity of one train set (3 cars) is 670 passengers (standing room for 574 with 8 persons/m² and 96 seats), and of the double deck train 800 passengers. The rolling stock is getting outdated with poor operational performances and quality of service. The vehicles were supplied in following order:

- 8 trains in 1976
- 14 trains in 1977
- 14 trains in 1980
- 6 trains in 1994 (with one car in each train with double deck level)

The Raml Tram System has 37 stops and is operated in two routes (Line 1 and Line 2), to connect Victoria with the Raml Station. A third line (Line 3) uses the Raml track from Victoria to Raml Station and continues his trip to Ras El-Teen on the City Tram track (currently not in operation). Table 7 shows the official operation characteristics of the Raml Tram Lines.

Table 7: The Official Operation of Raml Tram Lines

Line	Line Length (km)	Headway (min.)	Round Trip Time (min.)	No. of Trains	Commercial Speed (km/h)
1	10.5	7	119	17	11.6
2	10.2	8	120	15	11.1
3	4.6	30	60	2	11.0

Based on the official data, the capacity of the Raml Tram is 11000 Passengers/hr./direction. The development of the annual number of passengers on the Raml Tram (in millions) from the official APTA statistics can be described as in Figure 8. The continuing decrease in ridership is a direct result of the poor quality of service, large delays, and the longer trip time compared to alternative transportation systems.

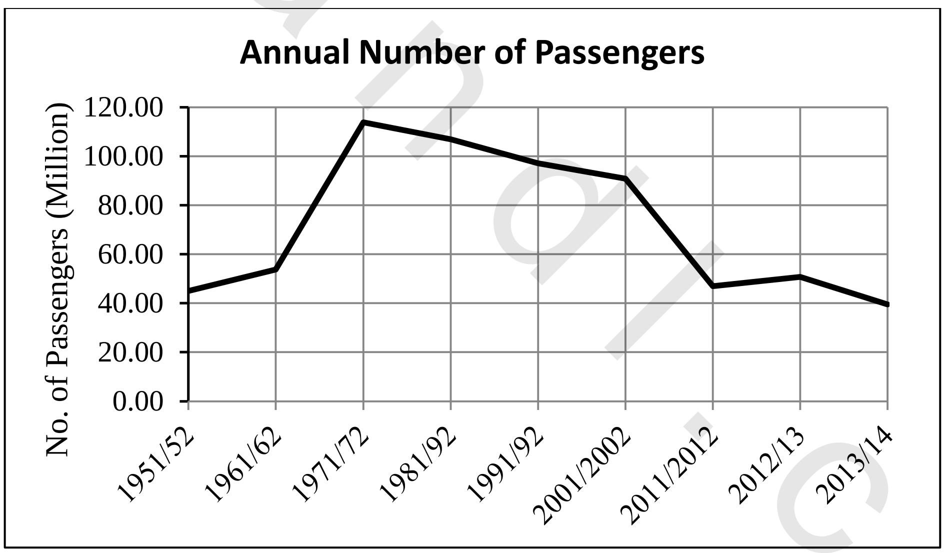

Figure 8: Historic Development of Raml Tram Ridership

6.2.2 Master Plan Projects

The APTA Master Plan 2006 includes 6 public transport projects: the Rehabilitation of the Raml Tram and the creation of five Light Rail Transit (LRT) projects in high population density areas which do not have sufficient public transport supply (Figure 9). The Purpose is to relieve the acute urban transportation problems. These projects are:

Projec1: Rehabilitation of the Raml Tram
Project 2: Montazah – Victoria
Project 3: Victoria – Awaid
Project 4: Awaid - Canal Station (Mina El-Basal)
Project 5: Sidi Gaber (15 of May) - El Nozha
Project 6: Canal Station (Mina El-Bassal) - KP 21

Table 8 contains a general description of these projects and Table 9 presents the main technical characteristics of the Light rail system.

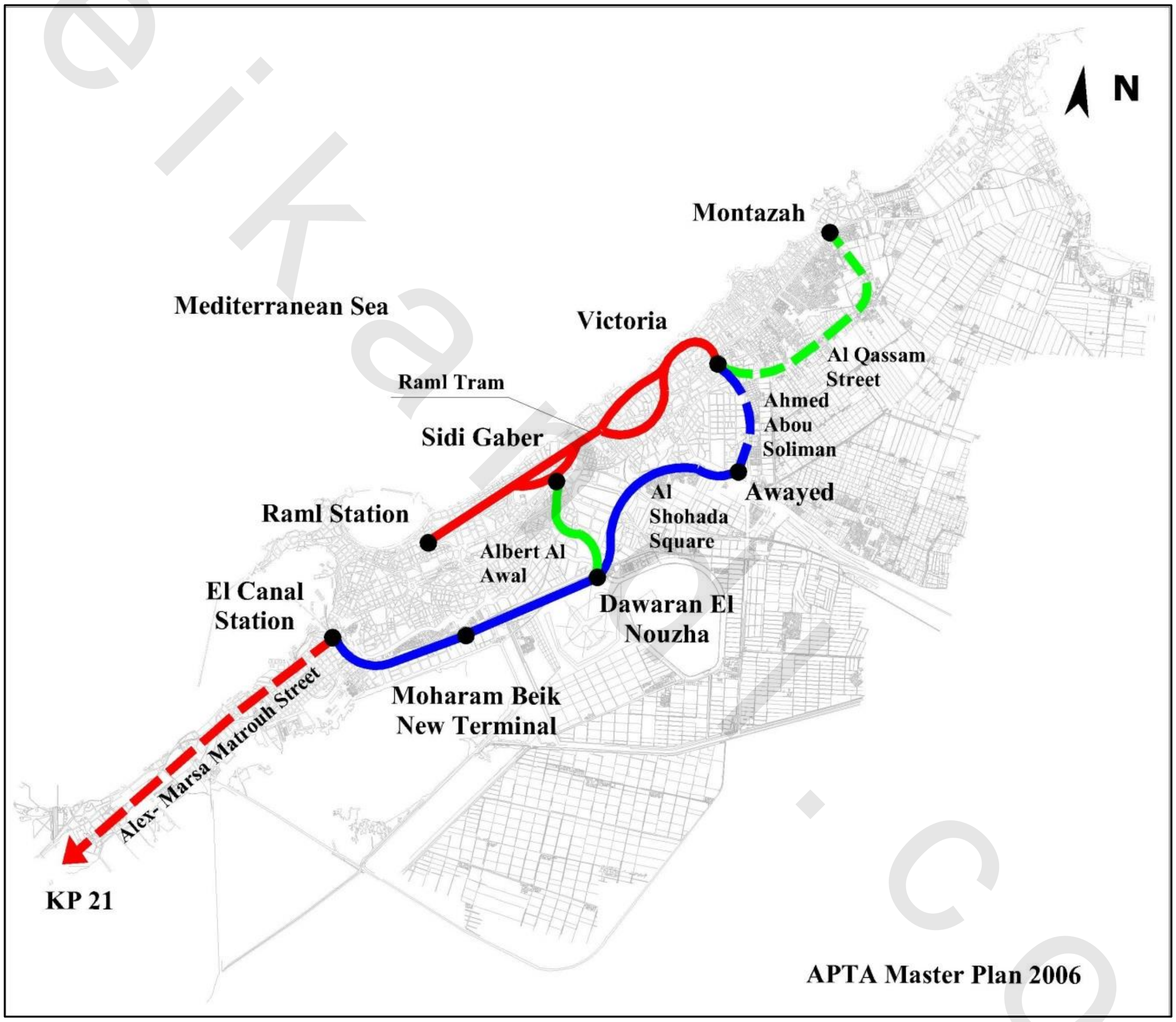

Figure 9: APTA Master Plan 2006

Table 8: The General Description of APTA Projects

Project Elements	Units	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6
Construction Period	Years	2	2	1	3	1	3
Line Length	Km	11.50	8.40	4.15	14.60	3.40	19.50
Tunnel Length	Km	0	0.06*	0.06*	0	0	0
Bridge Length	Km	0	0	0	0	0	19.50
No. of Stations	Station	37	14	6	18	4	25
No. of Crossings	Crossings	30	12	4	18	4	0
No. of Vehicles/Train	Vehicle	3	2	2	2	2	2
Commercial Speed	Km/h	22.50	22.50	22.50	22.50	22.50	30.00
Headway	Min.	3.00	5.00	5.00	5.00	5.00	5.00
Trip Time	Min.	31	22	11	39	9	39
Annul Line Capacity	Pass. (Million)	140	55	55	55	55	55

* 60 m. long Tunnel to cross the Horia Road and Abou Kir Rail Railway at Victoria Station

Table 9: The Main Technical Characteristics of APTA Projects

System Elements	Description
Track Infrastructure	Rail S49 ballast track (including 2 loops), Switches, type 1:8, at each stop
Crossings	Concrete plates for road crossing, assuming an average road width 20.00 m, Traffic light system at every junction controlled by approaching trams, Fencing at pedestrian crossing
Stations	Platforms of 90.00 m x 2.00 m, Installing info panel at every platform for real time travel information
Communication	Operation Control Room equipped with phone-lines, video-walls, computers, emergency equipment, etc., GSM-R (Global System for Mobile Communication-Radio), For communication and data exchange between vehicles, stations, info panels, traffic-lights, and the Operational Control room, Glass fiber network Alongside the tracks
Power Supply	Power Station, Power cable (400 V – AC) for double track

For investigating more project options, it is suggested in this thesis to add to APTA Master Plan 2006 the operation of 5 corridors with bus rapid transit system (BRT), as project options. These options are related to the projects from 2 to 6. Thus, the evaluation compares the operation on these corridors with bus transit as well as with light rail (the master plan original projects).The main Features of the suggested BRT system are new modern air-conditioned, partially separated lanes, traffic signals, interactive passenger information, and operation control center.

6.3 "Alexandria Regional Metro: Abou Qir to El Aamiria" Project

6.3.1 Background

The Abou Kir Railway line (21.5 km long) is a double track regional system on the whole line. It starts from Alexandria central station (Misr station) connecting the central area with Abu Kir, as well as the dense low-income zones along the line.
There are 16 stations along the line with an average distance of 1.5 km between them. The infrastructure is made of double track. The rails used in the Abou Kir line are non-welded, VIGNOL 52 rails. The sleepers used are wooden sleepers. The ballast section seems generally to be in a bad condition.

Signaling control system used in Abou Kir line is electro-mechanical system, automatic block section, lighted signals and mechanical switches. Switches along the line are not currently used for shunting operations for Abou Kir trains, except at Misr station and Abu Kir station.

Each train set running on the Abou Kir line consists of a diesel-electric locomotive at the head of the train, and six carriages. The carriages were constructed in 1979, they have the following characteristics:

- Maximum speed 100 km/h.
- Capacity: 2nd class 84 seats and 156 standing: 3rd class 108 seats and 172 standing.
- Each train has a capacity of about 1 500 passengers.
- The total fleet on the line is 12 sets of trains, from which 11 in service and one as stand-by at Abou Kir.

The Abu Kir line is also used each day by 5 military trains and 4 freight trains. Intercity trains from Alexandria main station towards Rosetta also run on it and leave it at Mamoura Station. Freight trains also use the Abu Kir Railway on their run between Kabbary station on the Matrouh line and Mamoura station where they leave towards Rosetta. The freight trains do not affect the operation of the regional passenger trains of the Abu Kir line, as the freight trains often run at night.

According to the official timetable, the trains cover the total line in 52 minutes, with a theoretical 25 km/h commercial speed. This figure can be considered as rather optimistic and achieved only at off-peak hour. The current theoretical headway is 20 minutes at peak hour. With 20 minutes headways and 1500 passengers per train, the nominal capacity of the line is 4500 passengers per hours per direction.

The official statistics of the Abou Kir line shows that its productivity is decreased from 48.1 Million passengers in 2002/2003 to 25.0 Million passengers in 2012/2013. These values reflect a significant reduction in ridership in the last 10 years (-48%). This trend can be due to poor quality of service and longer journey time.

6.3.2 The Project: Alexandria Regional Metro

The original subject of this study was the construction of a Regional Rapid Transit System (RRT) from Abou Qir to Amria (El Aamiria). The purpose of this system is to create a modern, safe, rapid and reliable transit system between Abou Qir in the extreme East of the city and El Aamiria in the extreme West, making use of the existing Abou Qir railway line and the right of way of the Matrouh railway line.

The implementation of the Regional Line has been divided into 3 sections as follows (Figure 10):

- First Section: From Abou Qir to Misr Station over a length of about 21.5 km,
- Second Section: From Misr Station to El Max to cross the centre of the town, over a length of about 7.5 km,
- Third Section: Section 3 (From El Max Station) was proposed at the beginning to follow the right of way of Matrouh Rail Line till El Aamiria (18.5 Km). However, according to NAT request, an alternative serving El Dekheila then the coastal area till Agami and KP 21 of Matrouh Road (17.00 Km) was selected and approved.

The total length of the Line was about 46 km.

Section 1: From Abou Qir Station, the eastern terminal of the present Abou Qir railway line, the new regional metro will run over almost its whole length using the existing Abou Qir railway line up to Misr Station (21.50 Km). Section 1 is further divided into three sub-sections A, B and C designated as follows:

- Sub-Section (1A), from Abou Qir to Victoria: At grade (9.50 Km).
- Sub-Section (1B), from Victoria to El Zahiria: Elevated (6.00 Km).
- Sub-Section (1C): from El Zahiria to Misr Station: At grade (6.00 Km).

The construction time of the implementation of section 1 is three years.

Section 2: It is completely a new section of the Metro Line running through the city centre starting from Misr Station to El Max (7.50 Km). Section 2 is further divided into two sub-sections A and B designated as follows:

- Sub-Section (2A), Starting from Misr Station to El Canal Station at the entrance of El Aman street, passing through Sheriff Street, then Osman Abaza Street: Underground deep tunnel crossing the city centre.
- Sub-Section (2B), from El Canal Station to El Max: Underground deep tunnel from El Canal Station up to the crossing of El Noubareyah Canal, and then the Line elevates up to El Max area.

The construction time of the implementation of section 2, including the building of Misr Station in tunnel, is five years.

Section 3: It starts from El Max Station; the alignment of the Metro Line shall follow the northern coast road up to K.P. 21 of Matrouh road: elevated on bridge. The construction time of the implementation of this section is five years.

Misr Metro station would be built at grade as a temporary terminal station located at the level of the existing ENR Misr (Alexandria) station, and no ENR freight trains would run on the Metro line after the opening.

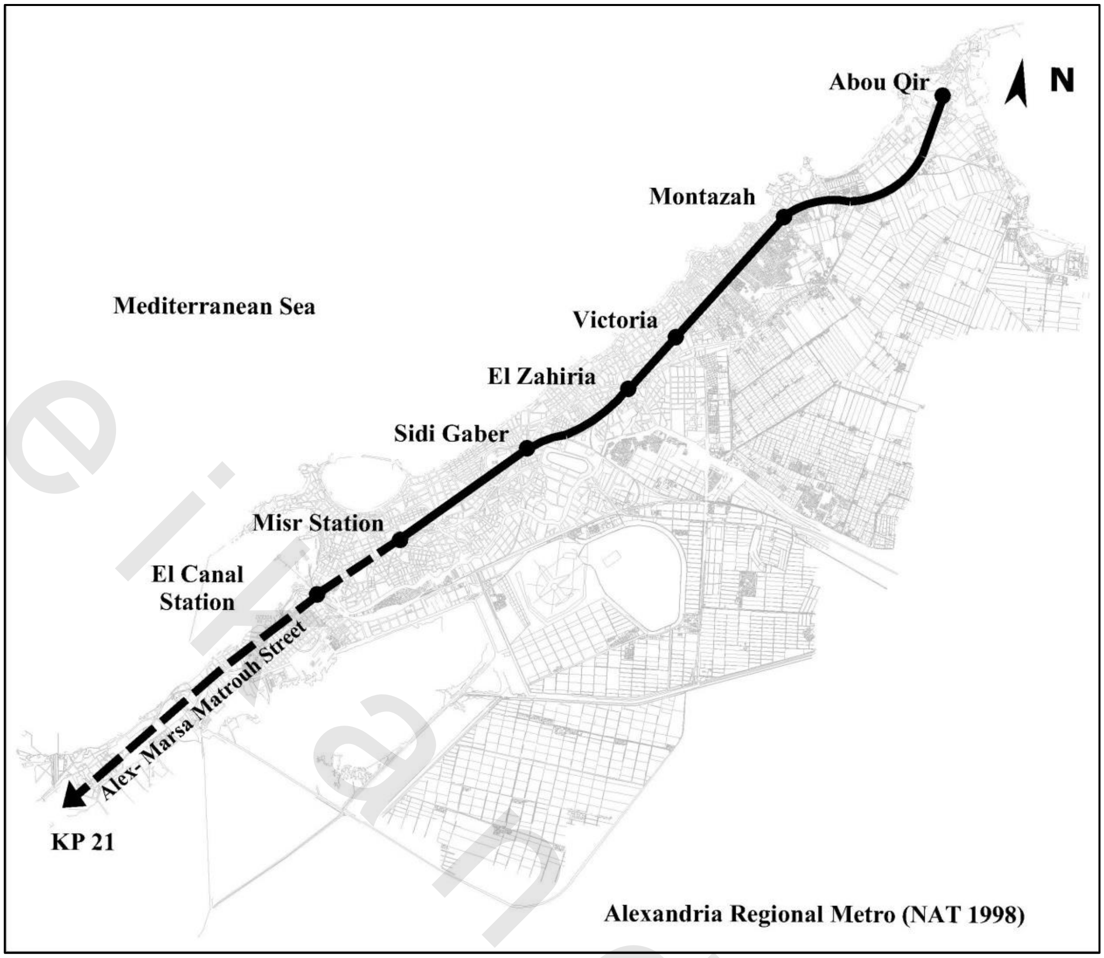

Figure 10: Alexandria Regional Metro

The operation of the Metro line would be as in Table 10, and Table 11 presents the cost estimations (Value January 1997).

Table 10: The Operation Elements of the propose Regional Metro

The Metro Sections	1	2	3
Operational Headway	4 Minutes	3 Minutes 20 sec.	2 Minutes 30 sec.
Total No. of needed Trains	22	33	60
Trip Time	1980 s	2630 s	3755 s
Commercial Speed	38.77 km/h	39.61 km/h	40.77 km/h

Table 11: Cost Estimations of the proposed Regional Metro (Value January 1997)

The Metro Sections	Overall Cost Estimations Misr Station built with Section 2	% of Rolling Stock from Overall Costs
Section 1	800 M.US$	417 M.US$ (52%)
Section 2	943 M.US$	134 M.US$ (14%)
Section 3	634 M.US$	433 M.US$ (68%)
TOTAL	2377 M.US$	984 M.US$ (40%)

Only Section 1 of the Regional Metro is subjected to investigation in the framework of this thesis; i.e. rehabilitation of existing Abou Kir system. The remaining sections of the project have not taken into account, as the aim of the study is not find the optimal solution, but only to test the effectiveness of the methods used. It should also be noted, that the implementation of these sections needs huge funds, and long time period (about 10 years).

6.4 Defining the Projects Options

Table 12 and Figure 13 present the different projects and options that will be evaluated and prioritized in the framework of this application.

Table 12: The Project Options

Projects	Corridors	Options	Transit Type	Construction Period (Years)
Project 1	Raml Tram Rehabilitation	Option 1	LRT	2
Project 2	Montazah - Victoria	Option 2-1	LRT	2
		Option 2-2	BRT	1
Project 3	Victoria - Awaid	Option 3-1	LRT	1
		Option 3-2	BRT	1
Project 4	Awaid - Mina El-Basal	Option 4-1	LRT	3
		Option 4-2	BRT	1
Project 5	Sidi Gaber - El Nozha	Option 5-1	LRT	1
		Option 5-2	BRT	1
Project 6	Mina El-Bassal - KP 21	Option 6-1	LRT	3
		Option 6-2	BRT	1
Project 7	Abou Kir Rehabilitation	Option 7	RRT	3

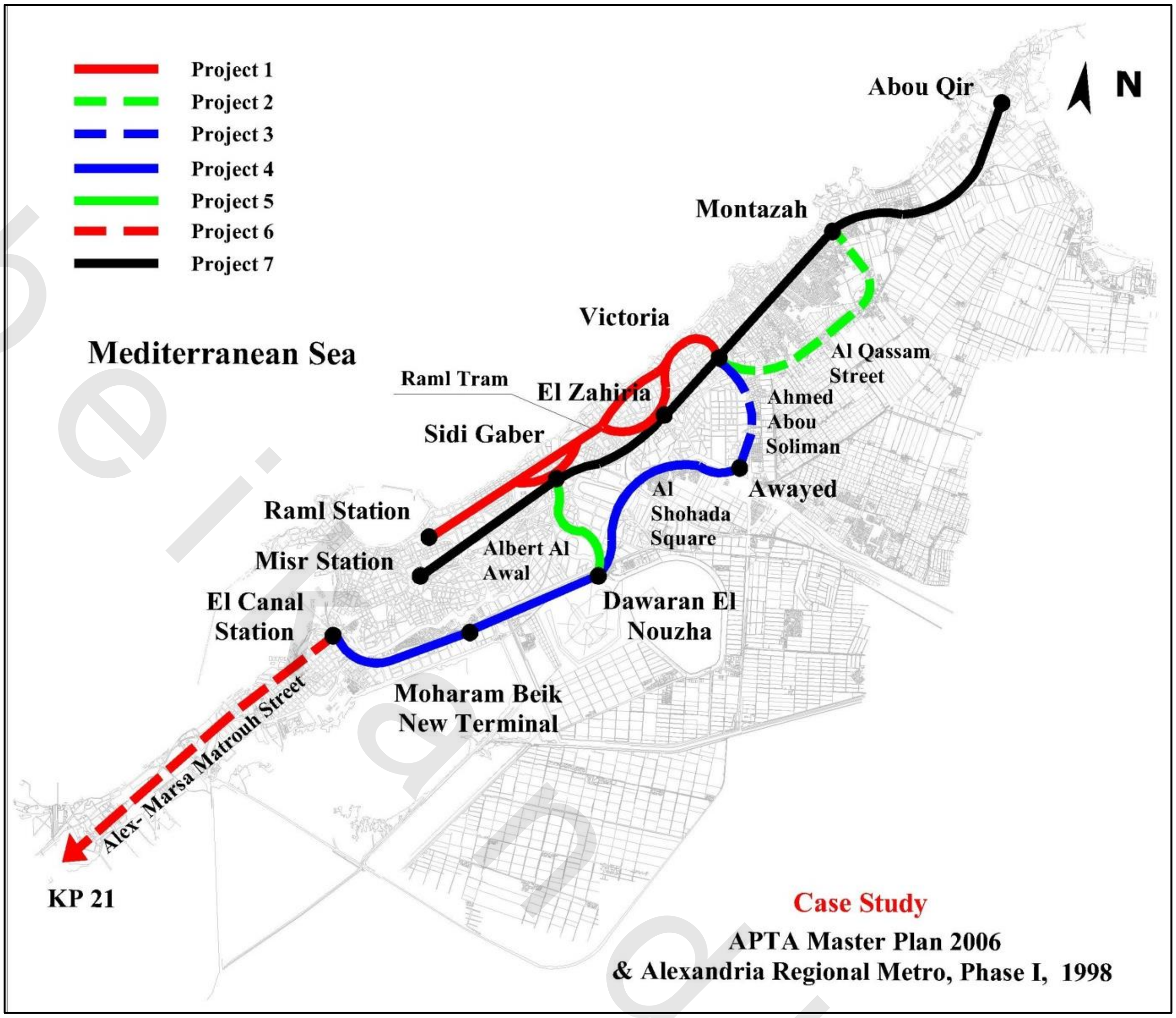

Figure 11: Projects Options for Evaluation and Prioritization

6.5 Feasibility Analysis

For comparing and rating the different projects options described above in Item 4, a feasibility analysis is carried out taking into account economical, technical, and environmental criteria. The analysis is established on the techniques defined in Chapter II. All the criteria used in the analysis are qualified; either in monetary terms or preference values.

Two facts are considered by the feasibility analysis: (1) large scale public transport projects are nonprofit and depend mainly on public funds, (2) the transport tariff is not economic, but social and subsidized. Therefore, the application of some economic evaluation tools, such as cost/effectiveness, benefit/cost ratio, and return on interest, may be unsuccessful. Thus, the economic analysis is based on the concept that the costs should equal the revenue without profit or taxes.

Therefore, from given operating elements (such as commercial speed, headway, vehicle capacity, and investment and ongoing costs), the annual recovery costs of initial investments and the cost of passenger-km are calculated as economic indicators. The calculations are based on given inflation and discount rates over the operating lifetime (Life Cycle Cost Analysis).

In the framework of this analysis, the total subsidies are calculated based on the actual ticket cost an assumed social flat tariff. The total subsidies are not an indicator for evaluating projects, but only show how high the subsidies are.

The feasibility analysis is also applied to determine the technical indicators for prioritizing the projects; i.e. trip time, commercial speed, annual train-km, annual passengers-km, and annual reduction in current traffic volumes by modal shift to the project under analysis.

The feasibility analysis is, furthermore, used to predict some environmental impacts of the project alternatives, such as energy consumption, energy consumption rate (TJ/Pass-Km), the greenhouse gas emissions (GHG) "carbon dioxide (CO_2), Methane (CH_4), Nitrogen Dioxide (NO_2)", as well as energy and emissions saving by modal shift to the project under consideration.

Four different programs are developed in the framework of the thesis for the feasibility analysis of the 7 options. Three programs are shaped for analyzing LRT, BRT, and RRT, individually, based on life cycle cost analysis. Each of which includes 4 spreadsheets; Introduction, Input/output, Investments, and graphical representation. The LRT and RRT programs enable the calculations for projects with one, two, or three construction periods.

Annex I (from I-1 to I-7) contains the feasibility analysis of the various options, as pictures of the EXCEL spreadsheets. For each project option, the following economic analyses are performed over the lifetime of the project:

- Cost Cash Flow (Present Value)
- Benefits
- Cumulative Net Present Value
- Net Benefits

In addition the following economic elements are calculated:

1. Benefit/Cost Ratio
2. Net Benefit (PV)
3. Return on Interest
4. Payback Period
5. Cost of Passenger-Km

Figure 12 illustrates the virtual results of the economic analysis of Project 1 (LRT); i.e. Raml Tram Raml Tram Rehabilitation, as an example.

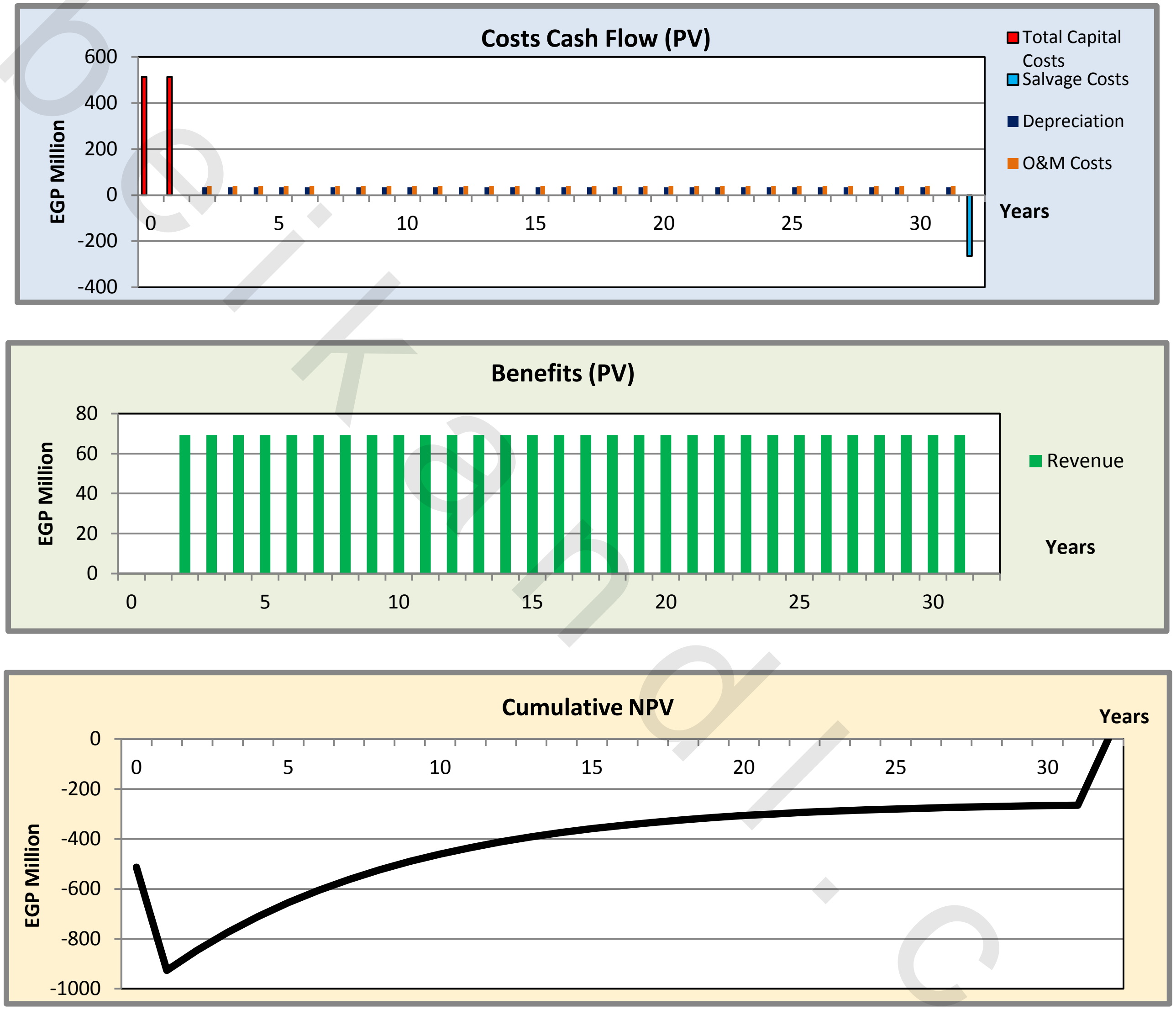

Figure 12: The Economic Analysis of Project 1 (LRT)

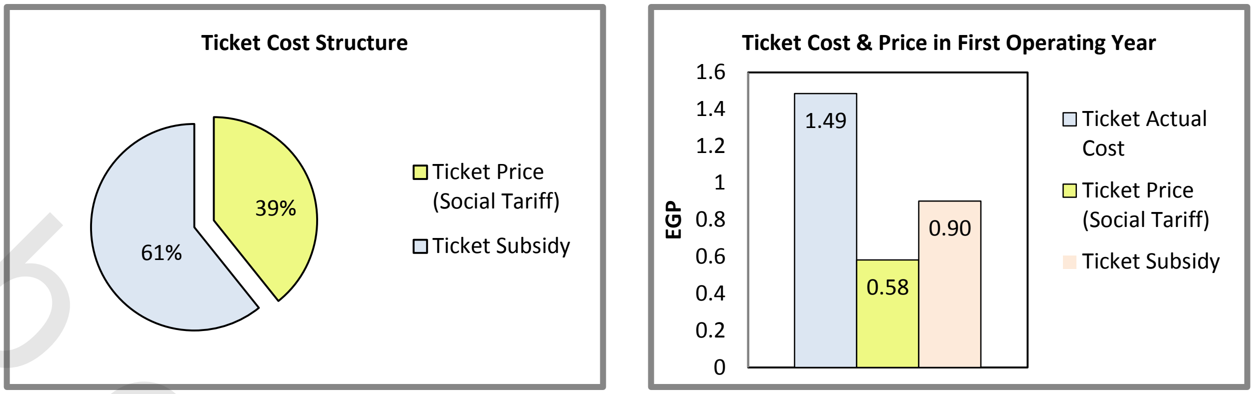

Figure 13: Tariff Structure

The programs are formulated in the manner; that the inputs and the outputs are presented beside each other's, so that the user can predict immediately the influences of changing any item of the input (Figure 13). Otherwise, the options are nonprofit projects; the programs allow the user to insert certain percentages of profit and taxes, if necessary.

The last program in the feasibility analysis (Options Comparison) is designed to compare the options (Annex 1-8). It composes ten spreadsheets; from which seven include the inputs/outputs of the feasibility analysis of the projects options, an options comparison, input, and graphical representation spreadsheets. The first seven datasheets are integrated with the programs. They transfer automatically the inputs and outputs of each option. The input spreadsheet includes assumptions regarding average trip length, average vehicle occupancy, and the specific energy consumption. The user can modify at any time one or more of these assumptions, and the new values are automatically transferred to all related spreadsheets. The spreadsheet "comparison" collects all related information and compares the options from economical, technical, and environmental points of views. It is also equipped with interactive calculator to determine energy and emissions saving by a modal shift to the project in concern. The calculation is based on the productivity of the specific project, i.e. total passengers.-km.

The program "Options Comparison" allows the decision maker to investigate the results visually from the graphical representation spreadsheet. Thus, the program can support the decision by changing any input data at any phase of the feasibility analysis, if needed. Figure 14 illustrates the visual results of the feasibility analysis of the candidate projects, based on the given input data. The analysis indicates the following aspects:

- One or more indicators are not enough to evaluate and rate non-profit projects options, for example project 7 (RRT) has the highest initial investments, but at the same time the lowest cost per passengers-km, from economical point of view.
- Although, the Initial investments of all BRT projects are low, they reach the high rates by costs per passengers-km.
- Maximum transportation capacity can be achieved through project 7 (RRT) and Project (6-1), because of their relative high commercial speeds.
- Project 7 (RRT) is absolutely the best one in reduction in traffic volumes and in saving energy due to its high capability to make changes in modal shift. Meanwhile, it is a serious source of environmental pollutions and great consumer of energy.

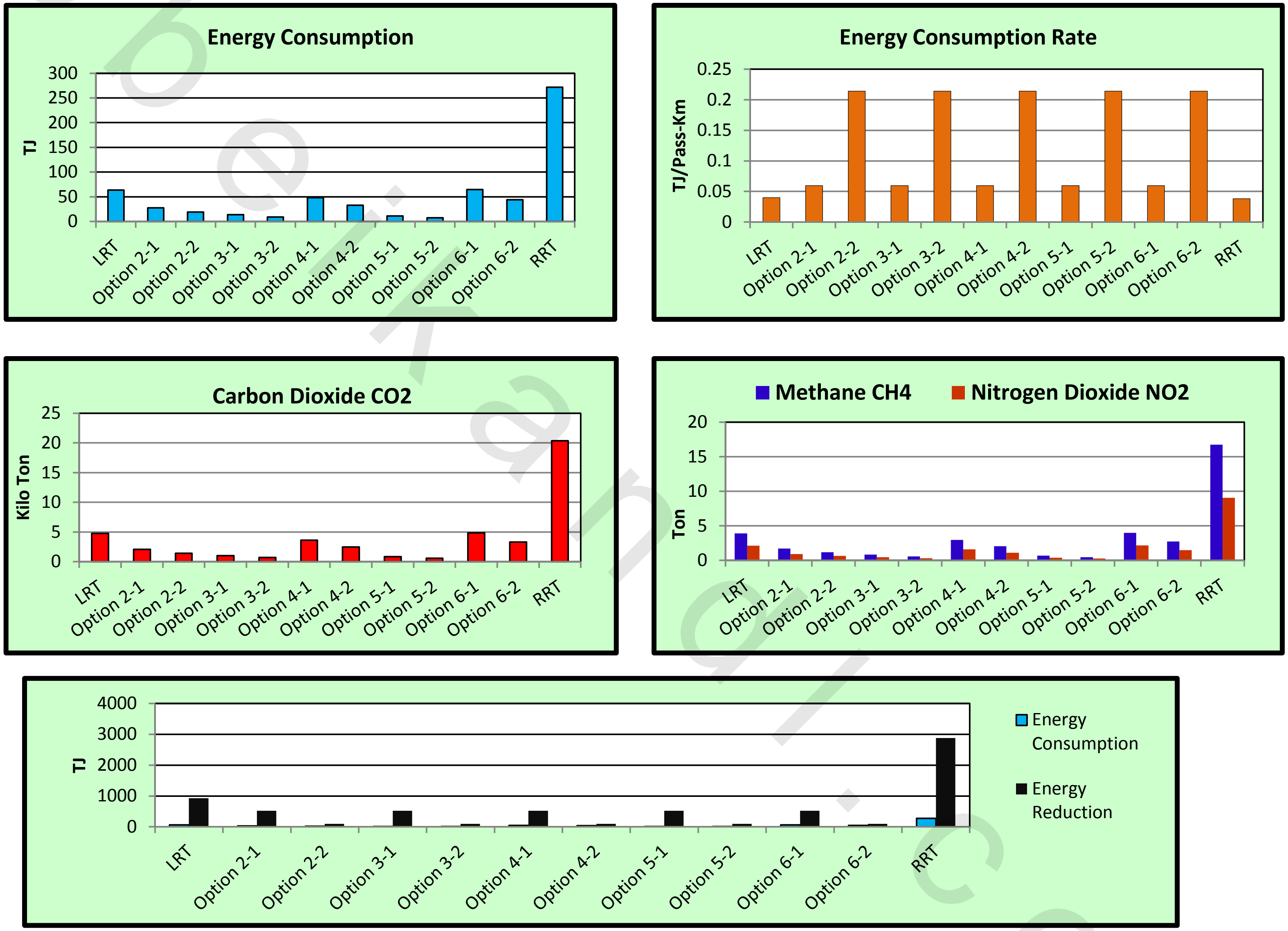

Figure 14: The Visual Results of the Feasibility Analysis

6.6 Multi-Criteria Decision Analysis (MCDA)

A program (MCDA) is developed in the framework of the thesis for the application of the Multi-Criteria Decision Analysis. It includes four spreadsheets, "Introduction" that contains the application theory, "WSM" for performing the Weighted Sum Model, "MFEP" for applying the Multifactor Evaluation Process, and Graphics for visual presentation of results.

The projects options and the ten decision criteria used in the feasibility analysis are subjected to MCDA. The relative weight of importance to each criterion is assigned, from an individual point of view. Table 13 shows the criteria and their relative weights.

Table 13: The Criteria and their Relative Weights

Criteria			Relative Weights
CR 1	Initial Investments	EGP (Million)	5
CR 2	Initial Investments per one Km Long	EGP (Million)	5
CR 3	Cost of Passenger-Km	EGP	8
CR 4	Commercial Speed	Km/h	10
CR 5	Annual Passengers-Km	Million	10
CR 6	Annual Line Capacity	Pass. (Million)	10
CR 7	Annual Reduction in Traffic Volumes	PCU (Million)	10
CR 8	Energy Consumption Rate	TJ/Pass-Km	8
CR 9	Carbon Dioxide CO_2	Kilo-Ton	5
CR 10	Energy Reduction	TJ	6

The two MCDA techniques; i.e. the weighted sum model (WSM) and the Multifactor Evaluation Process (MFEP) are applied. Annex II presents pictures of the four EXCEL spreadsheets which are used for the application of the MCDA techniques.

6.6.1 Weighted Sum Model (WSM)

Regarding the consequences described in Item 3.4.3.1 of this thesis, the criteria and option matrixes are constructed, and then the scaling matrix is formulated after the regulation of the values of both "Less is Better" and "More is Better" criteria. The weighted sum score for each option is calculated, and the options are rated according to their score.

Figure 15 presents the weighted score of each criterion regarding the projects options to be prioritized, based on the given weights. Option 7 (RRT) is the best solution concerning all criterion, except criteria 1 and 2, i.e. initial investments and investments per km. Meanwhile, all BRT projects do not earn any weighted score for criterion CR 4, CR 5, CR 6, CR 7, CR 8, and CR 10; i.e. commercial speed, annual passengers-km, annual line capacity, annual reduction in traffic volumes, energy consumption rate, and energy reduction. Figure 16 illustrates the rating of the candidate options.

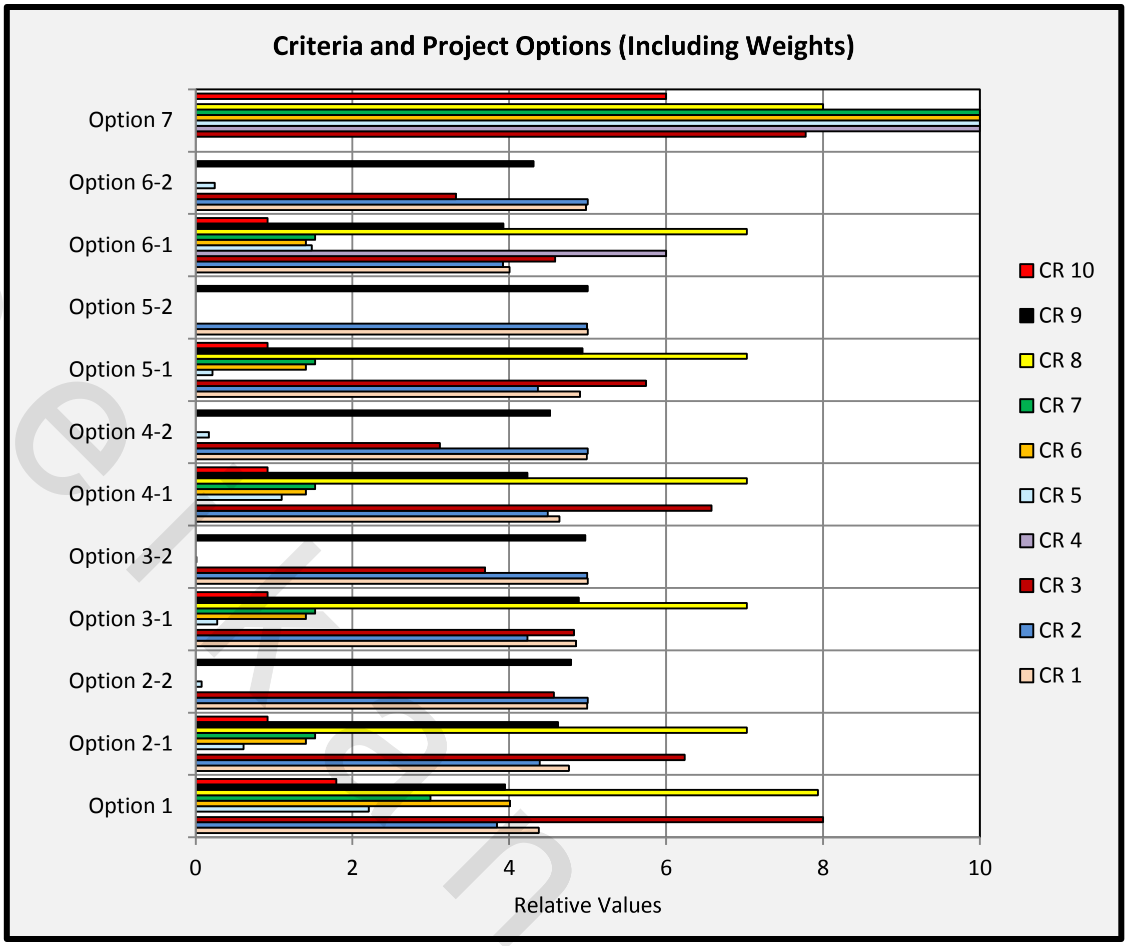

Figure 15: Weighted Score of each Criterion and the Projects Options

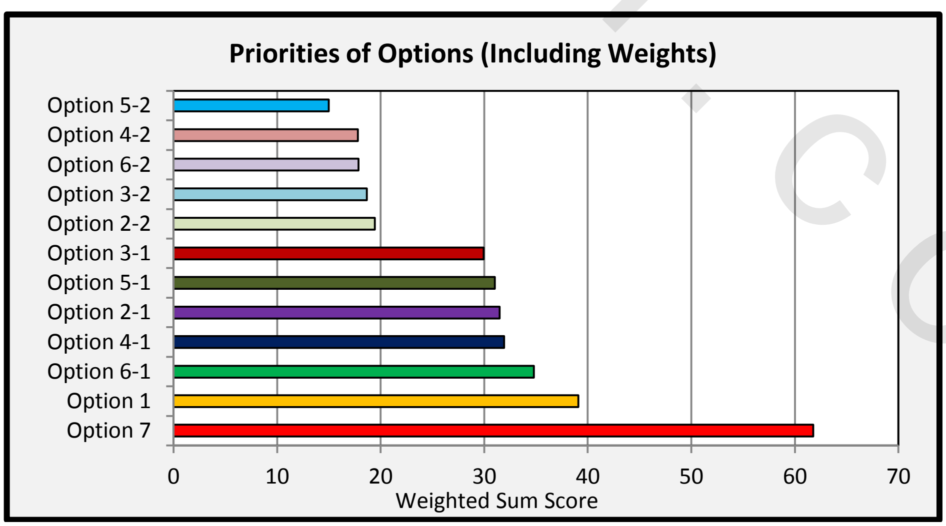

Figure 16: Rating of the Candidate Projects Options (WSM)

A limited sensitivity analysis is performed to test result variations when the weights are changed. For the application purpose, 8 scenarios are proposed; each contains a different set of weights for each criterion (Table 14). The WSM procedure is repeated for each scenario, and accordingly the projects options are rearranged and prioritized. Table 14 shows the ranking of the various project options for each scenario.

The sensitivity analysis explains that there are no significant variations in the ranking of the projects. The two projects (Option 7 & Option 1) are still at the forefront without change in ranking in all scenarios, but there are slight alterations among the other projects. Reporting the results with a description of the advantages and the disadvantages or each project is, therefore, essential for a proper decision. In Table 15, a value in red between brackets indicates a change in the ranking of the project option under this scenario

Table 14: Criteria Weights Scenarios

Criteria	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
CR 1	6	7	6	8	6	10	12	10
CR 2	6	7	6	8	6	10	10	13
CR 3	10	12	9	13	9	10	10	13
CR 4	13	14	12	16	12	10	6	10
CR 5	13	12	14	11	14	10	12	10
CR 6	13	12	14	11	14	10	12	8
CR 7	13	12	14	11	14	10	10	10
CR 8	10	9	11	9	11	10	7	13
CR 9	6	7	6	8	6	10	10	8
CR 10	8	7	8	6	8	10	10	6

Table 15: Rank of the Candidate Projects according to the Weights Scenarios

Options	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Option 1	2	2	2	2	2	2	2	2
Option 2-1	5	5	5	5	5	5	(4)	5
Option 2-2	8	8	8	8	8	8	8	8
Option 3-1	7	7	7	7	7	7	7	7
Option 3-2	9	9	9	9	9	9	9	9
Option 4-1	4	4	4	4	4	4	(3)	4
Option 4-2	11	11	11	11	11	(10)	(10)	11
Option 5-1	6	6	6	6	6	6	(5)	6
Option 5-2	12	12	12	12	12	12	12	12
Option 6-1	3	3	3	3	3	3	(6)	3
Option 6-2	10	10	10	10	10	(11)	(11)	10
Option 7	1	1	1	1	1	1	1	1

6.6.2 Multifactor Evaluation Process (MFEP)

The candidate projects options are subjected to the Multifactor Evaluation Process (MFEP) using the same ten decision criteria employed in the WSM evaluation with their relative weights of importance. As expected, there are major variations in the ranking of the projects, except the three projects with the highest scores that keep the same order in both WSM and MEEP (compare Figure 17 with Figure 16).

One of the most interesting findings of this analysis shows that short distance BRT systems can be recommended, such as LRS. From the visual analysis of the results, Project Option 5-2 is to be compared with Option 5-1 (Sidi Gaber – El-Nozha; 3.4 km). It is also the same case of option 3-2 and option 3-1 (Victoria – Awaid; 4.15 km).

A sensitivity analysis is also carried out with the same weights scenarios in Table 13. The results shows that the two projects with the highest scores (Option 7 & Option 1) are still at the forefront without any change in the ranking in all scenarios, but there are still slight alterations among the other projects.

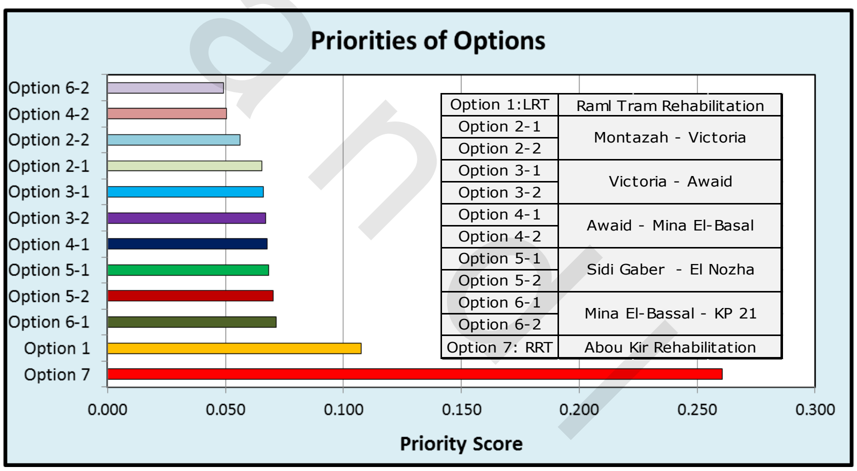

Figure 17: Rating of the Candidate Projects Options (MFEP)

6.7 Analytical Hierarchy Process (AHP)

The program (AHP) is developed for the application of the Analytical Hierarchy Process. It includes three spreadsheets, "Introduction" that composes the application theory, "Calculations", and Graphics for visual presentation of results.

The different projects options are subjected to the Analytical Hierarchy Process for evaluating and rating in consistent with ten decision criteria, two of which are qualitative criteria (Table 16). Annex III presents pictures of the three EXCEL spreadsheets which are used for the application.

Table 16: Decision Criteria for AHP

CR 1	Initial Investments
CR 2	Cost of Passenger-Km
CR 3	Annual Passengers-Km
CR 4	Commercial Speed
CR 5	Energy Consumption
CR 6	Carbon Dioxide Emissions CO_2
CR 7	Demand Intensity (Crossing high Density Areas)
CR 8	Accessibility to Central Areas, Work and Education Places
CR 9	Reduction in Traffic Volumes
CR 10	Energy Reduction

The application of the Analytical Hierarchy Process is carried out in the following steps, according to the rules described in Item 4.2 in this thesis:

- Determining the beneficial direction of each criterion; “More is Better” and “Less is Better”.
- For each criterion, a pairwise comparison between candidate options is being performed, using the AHP preceding scale. The preference values are arranged in a pairwise comparison matrix.
- After normalizing the performance values in this matrix, a normalized matrix is formulated. The average of each row in the normalized matrix presents the priority vector of this option regarding this criterion.
- The consistency of the performance values should be tested.
- After completing the pairwise comparison between the options concerning all criteria, the local priority vector (LP) of each alternative is calculated, regarding the beneficial direction of each criterion; “More is Better” and “Less is Better”.
- Pairwise comparison between each two criterion is determined to determine the weighted vector for each criterion. A consistency of the performance values should also be tested at this step.
- The last step is to combine the local priorities across all criteria in order to determine the global priority for rating of the different options.

Figure 18 presents the local priority of each criterion regarding the projects options to be prioritized, before weighting. Option 7 (RRT) has the best preference values concerning four criterion (CR3, CR4, CR9, and CR19), i.e. Annual Passengers-Km, Commercial Speed, Reduction in Traffic Volumes, and Energy Reduction. In the second rate, Option 1 (Rehabilitation o Raml Tram) has reliable preferences values to four criteria (CR 2, CR 6, CR 7, and CR 8), i.e. cost of passenger-km, carbon dioxide emissions, demand intensity, and accessibility to central areas, work and education places. Figure 19 illustrates the rating of the candidate projects after weighting.

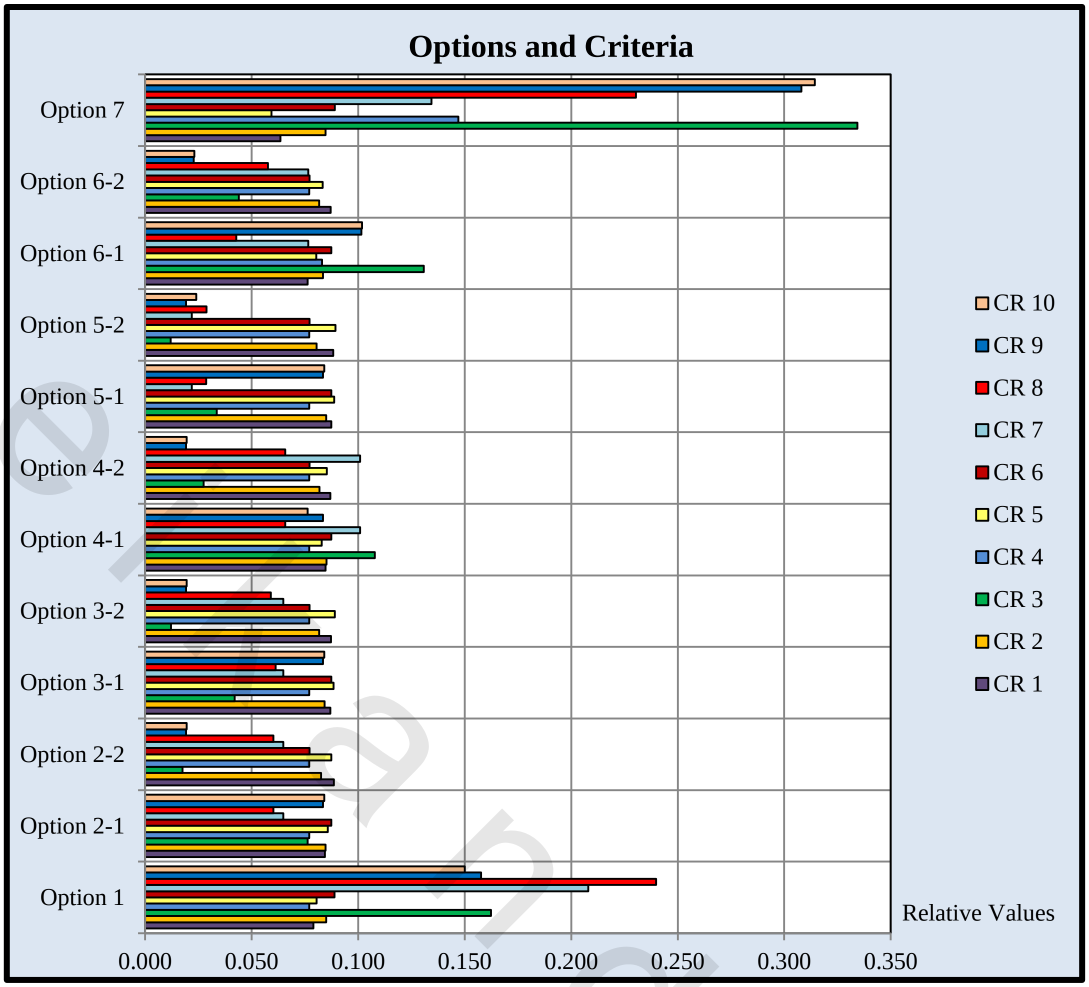

Figure 18: Local Priority of each Criterion before weighting and the Options

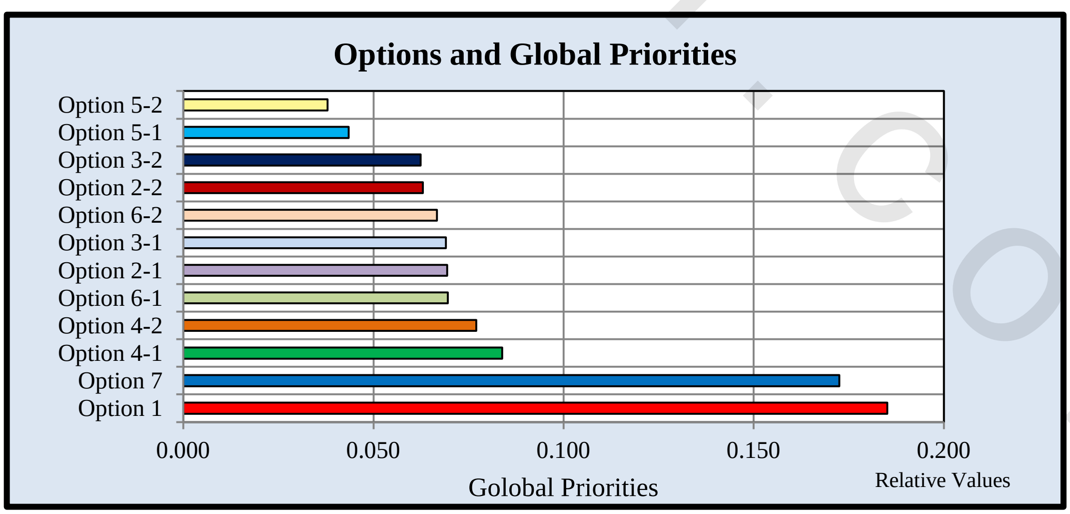

Figure 19: Rating of the Candidate Projects Options (AHP)

The sensitivity analysis is carried out visual in an interactive graphical interface, due to the immense number of weights embedded in the AHP procedure. The analysis is performed in four levels; changes in weighted vectors of the economic criteria (CR 1 & CR 2), transport efficiency criteria (CR 4 & CR 9), social criteria (CR 7 & CR 8), and in the environmental criteria (CR5, CR 6, CR & CR 10). The goal of the changes is to observe the percentage of a change that causes an alteration in the order of the projects. The results are as follows: No changes occurred till ± 20% by economic criteria, ± 35% by transport efficiency, ± 30% by social criteria, and ± 40% by environmental criteria.

6.8 The Proposed Approach CETP

The program (CETP) is developed for the comprehensive analysis of transportation project options and arranging them regarding their importance to sustainable criteria. It is based on integration between Multi-Criteria Decision Analysis (MCDA) and the Analytical Hierarchy Process (AHP). The CETP is an interactive program that includes eight spreadsheets, Introduction, Criteria, Indicators, Economic, Social, Environment, Transport, and Graphics.

CETP is designed in the form of a hierarchy structure. Therefore, the purpose of the different spreadsheets are: the "Introduction" is to present the application theory, "Criteria" to investigate the importance of the four sustainable criteria among each other's, "Indicators" to identify the indictors of each criterion and expecting their relative importance. The aim of the four following Worksheets is to analyse, evaluate, and rate the candidate projects options from economic, social, environmental, and transportation efficiency viewpoints. The "Graphics" spreadsheet includes the visual presentation of the results. Annex IV presents pictures of the eight EXCEL spreadsheets which are used in the application.

The candidate projects options described above are subjected to CETP application. The sustainable criteria are economic, social, environment, and transport efficiency. Table 17 illustrates the selected indicators. CETP accepts quantitative and qualitative indicators.

The application of the CETP is carried out in the following steps, according to the rules described in Item 4.3.1 in this thesis:

- Relative Importance of the Sustainable Criteria
    a. Carry out a pairwise comparison between the four sustainable criteria based on the weights of stockholders. Participants are politicians, experts, and system providers.
    b. Constructing a pairwise comparison matrix.
    c. Generate a normalized matrix.
    d. Calculate the average of each row, which presents the priority vector of the criteria.
    e. Perform the consistency test to insure that an acceptable consistency between the weights is achieved.

Table 17: Selected Indicators for CETP Application

Economic Indicators		
EC1	Initial Investments	Quantitative Indicators
EC2	Initial Investments/Km	
EC3	Cost of Passenger-Km	
EC6	Economic Progress	Qualitative Indicators
Social Indicators		
SO6	Accessibility*	Qualitative Indicators
SO7	Affordability**	
Environmental Indicators		
EN1	Energy Consumption	Quantitative Indicators
EN2	CO_2 Emissions	
EN3	Energy Reduction	
EN6	Noise pollution	Qualitative Indicators
EN7	Aesthetic Approval	
Transport Efficiency Indicators		
TR1	Commercial Speed	Quantitative Indicators
TR2	Annual Passengers-Km	
TR3	Annual Line Capacity	
TR4	Reduction in Traffic Volumes	
TR6	Crossing high Density Areas	Qualitative Indicators

*Accessibility to Central Areas, Work and Education Places
**Capability to pay the costs of the service

- Relative Importance of the Indicators
  a. For each of the four sustainable criteria, identify the sub-criteria, and relative weights from the viewpoint of the stockholders.
  b. Carry out a pairwise comparison between the indicators of each sustainable criterion based on the weights of specific stockholders. Participants are experts, transport system providers.
  c. For each sustainable criterion:
     - Constructing a pairwise comparison matrix.
     - Generate a normalized matrix (sum the elements of each column j and divide each value by its column sum).
     - Calculate the average of each row.
     - Compute the priority vector of the indictors by multiplying the average by the specific criteria priority.
     - Perform the consistency test to insure that an acceptable consistency between the weights is reached
- Priority of Projects Options regarding the Indicators
  For Quantitative Criteria: Rating of projects options is achieved using the Multi-Criteria Decision Analysis (MCDA), as follows:

a. Construct a matrix that contains the performance values of each criterion for all alternatives, as well as the relative stockholders weights of the different criterion.
b. Determine the minimum and the maximum performance value of each criterion, and calculate the deference between them.
c. Create a scaling matrix for "more is better" criterion and "less is better" criterion:
   - In case of criteria with more is better, set 0 for the minimum value and 1 for the maximum value for each criterion, and the other values of this criterion in a linear scale between 0 and 1; and
   - In case of criteria with less is better, set 1 for the minimum value and 0 for the maximum value for each criterion, and the other values of this criterion in a linear scale between 0 and 1.
   - The scaled matrix contains, then, the relative importance of each criterion for each project option in a scale between 0 and 1.
   - Calculate the weighted sum Score for each project regarding each criterion by multiplying the normalized value by the specific indicator weight.

For Qualitative Criteria: Rating of project alternatives is reached using the Analytical Hierarchy Process (AHP), as follows:

a. Constructing pairwise comparison matrices based on the weights of stockholders.
b. Sum the elements of each column
c. Divide each value by its column sum to generate normalized matrices. The sum of each column will be 1
d. Calculate the average of each row, which presents the priority vector of the row
e. Calculate the local priority vector of each alternative:
   - In case of a "more is better" criterion, the priority vector of the alternative presents the local priority vector of a particular criterion
   - In case of a "less is better" criterion, the priority vector of the alternative regarding this criterion should be regulated to calculate the local priority vector
f. Pairwise comparison between each two criterion to determine the weighted vector for each criterion.
g. Construct a matrix that includes local priority of all alternatives against all criteria, as well as the weighted vector for each criterion.
h. Calculate the global priority of the alternatives to combine the local priorities across all criteria. the global Priority is the sum of the local priorities multiplied by weighted vector

- Priorities Aggregation
  a. Calculate the sum of local priority of each option to determine its Composite Index.
  b. Prioritize the options according to their indexes.
- Visual Composite Sustainability Level
  a. Calculate the area of the trapezium reflects the relative sustainability global priorities of each option.
  b. Determine the percentage of the trapezium area of an option to the maximum achievable sustainability to predict its visual composite sustainability index.

Annex 4 includes the application of the CETP in detail. The results can be presented as follows:

- Relative Importance of the Sustainable Criteria

Based on the following pairwise comparison between the four sustainable criteria, Figure 20 drives the relative importance of the four sustainable criteria:

Pairwise Comparison

Criteria	Input	Criteria
Economic Sustainability	2.0	Social Sustainability
Economic Sustainability	0.5	Environmental Sustainability
Economic Sustainability	1.0	Transport System Efficiency
Social Sustainability	1.0	Environmental Sustainability
Social Sustainability	0.5	Transport System Efficiency
Environmental Sustainability	0.5	Transport System Efficiency

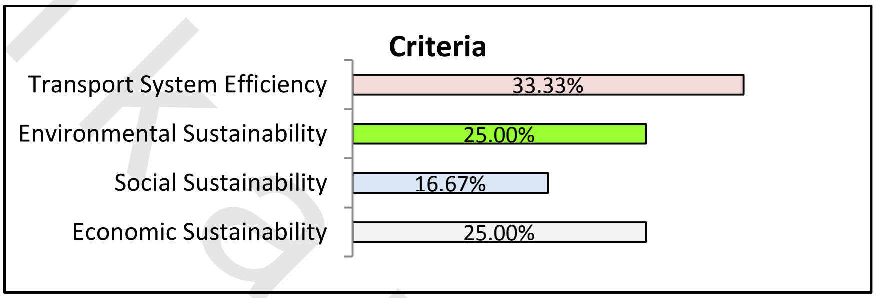

Figure 20: Relative Importance of the Sustainable Criteria

- Relative Importance of the Indicators

Figure 21 presents the relative importance of the different indicators for the four sustainable criteria (10 quantitative indicators and 6 qualitative indicators), based on the weights given for pairwise comparison in Annex 4.

- Priority of the Projects Options

Figure 22 shows the rating of the various projects options regarding the four sustainable criteria. Projects priorities vary according to the nature of the indicator used, for example, the project 1 has high priority with the economic and social evaluation, while project 7 is the best project regarding transport efficiency, and option 4-1 is in the front from the environment point of view. The analysis of this example indicates the following reasons (Figure 23):

- Regarding the indicator EC 1 (Initial Investments), and the Indicator EC 2 (Initial Investments/Km): All projects become more weighted sum vectors than Project 7, and Project 1 has got higher value than Project 7. In addition, Project 1 is absolutely the best project for TR 6 (Accessibility).
- Project 4-1 gains mathematically high values, but based on the visual analysis, all the projects are nearly at the same level.

- Project 7 succeeds in achieves the highest values for four transport efficiency indicators (Commercial Speed, Annual Passengers-Km, Annual Line Capacity, and Reduction in Traffic Volumes).

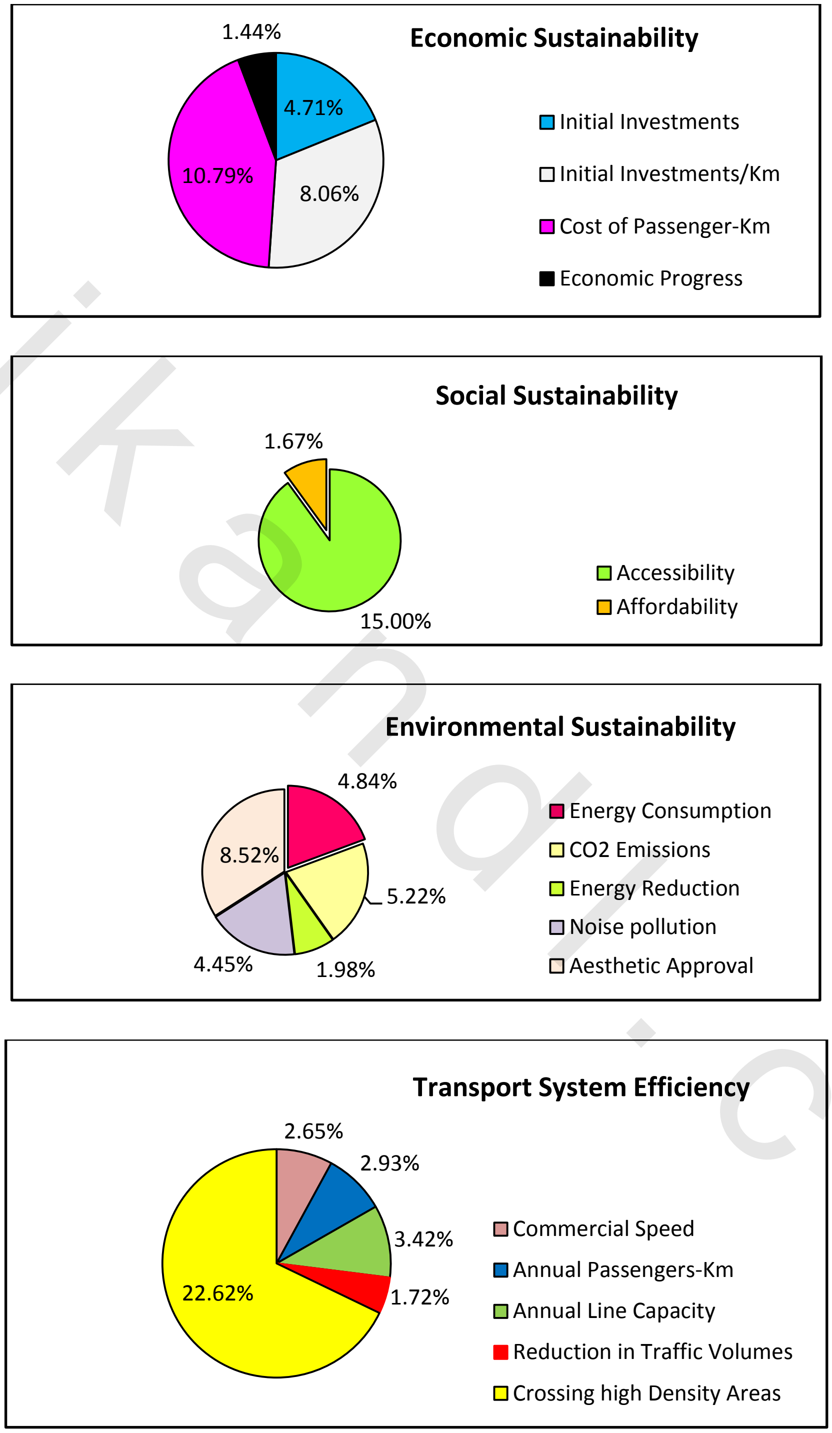

Figure 21: Relative Importance of the Indicators

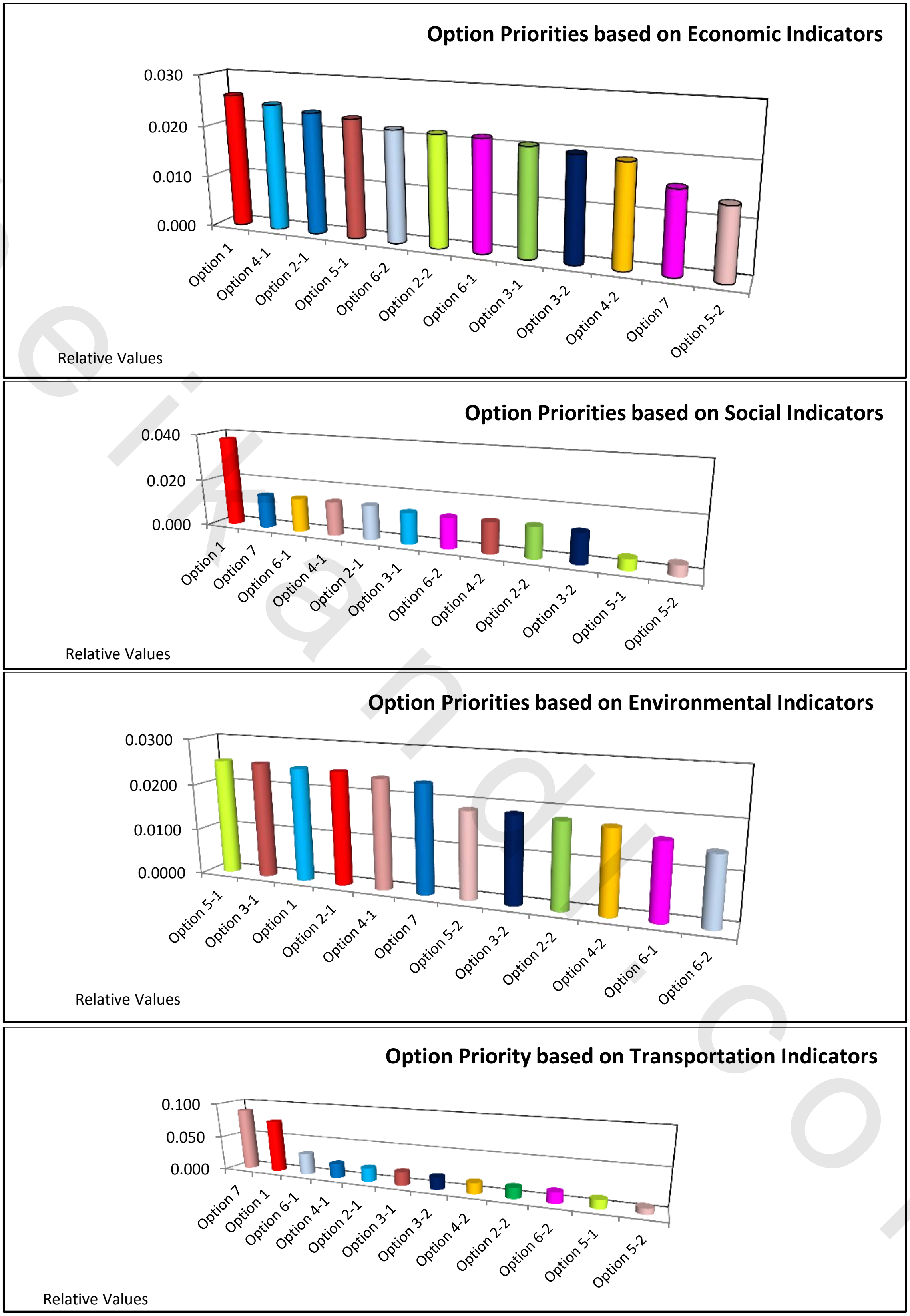

Figure 22: Global Priorities of the Projects Options

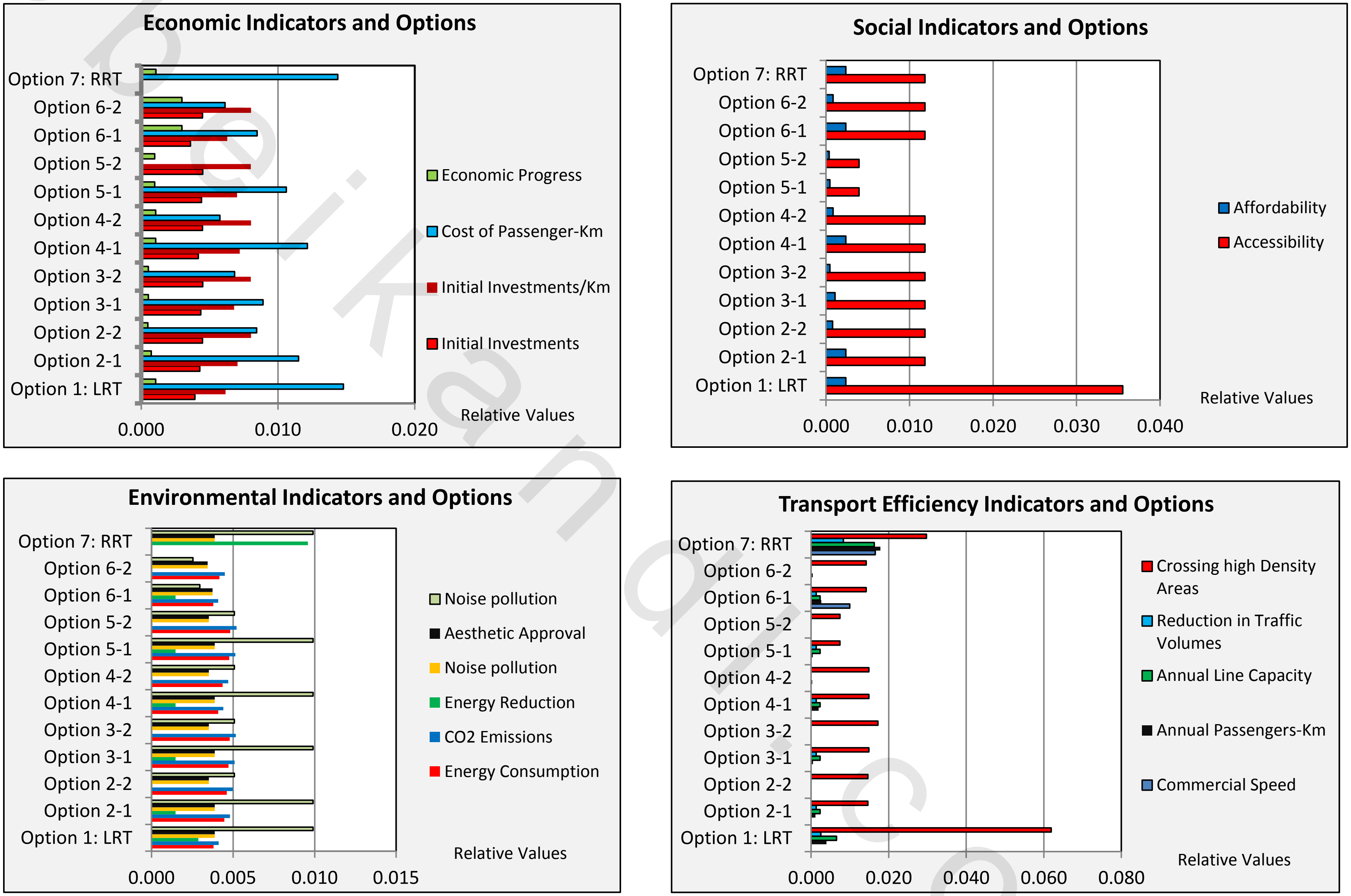

Figure 23: Indicators and Options according to weighted Vectors

- Priorities Aggregation

The sum of local priority of each option is calculated to determine its Composite Index, and then the different options are prioritized according to their indexes Table 18 shows composite index of each option, and Figure 24 presents the different options arranged according to their composite indexes. Thus, the ranking of the projects is as follows: Project 1, Project 7, Project 4-1, Project 6-1, Project 2-1, Project 3-1, and Project 5-1; respectively. In this context, the presence of the BRT systems does not appear.

Table 18: Composite Indexes

Options	Global Priorities				Composite Priority Index	Composite Sustainable Area	Relative Sustainable level	Rating
	Economic	Social	Environmental	Transport Efficiency				
Option 1: LRT	0.026	0.038	0.025	0.075	0.163	0.0026	88.0%	1
Option 7: RRT	0.015	0.014	0.023	0.089	0.142	0.0008	61.8%	2
Option 4-1	0.025	0.014	0.024	0.020	0.083	0.0005	25.8%	3
Option 6-1	0.021	0.014	0.016	0.030	0.082	0.0007	25.7%	4
Option 2-1	0.024	0.014	0.025	0.019	0.082	0.0006	24.9%	5
Option 3-1	0.021	0.013	0.025	0.019	0.077	0.0008	22.5%	6
Option 3-2	0.020	0.012	0.019	0.017	0.068	0.0005	17.5%	7
Option 2-2	0.021	0.013	0.018	0.015	0.067	0.0004	16.8%	8
Option 4-2	0.019	0.013	0.018	0.015	0.065	0.0002	15.9%	9
Option 5-1	0.023	0.004	0.025	0.011	0.064	0.0008	11.7%	10
Option 6-2	0.022	0.013	0.015	0.015	0.064	0.0008	15.3%	11
Option 5-2	0.013	0.004	0.019	0.007	0.044	0.002	5.8%	12
Maximum Achievable Sustainability	0.026	0.038	0.025	0.089	0.177	0.0032	100.0%	

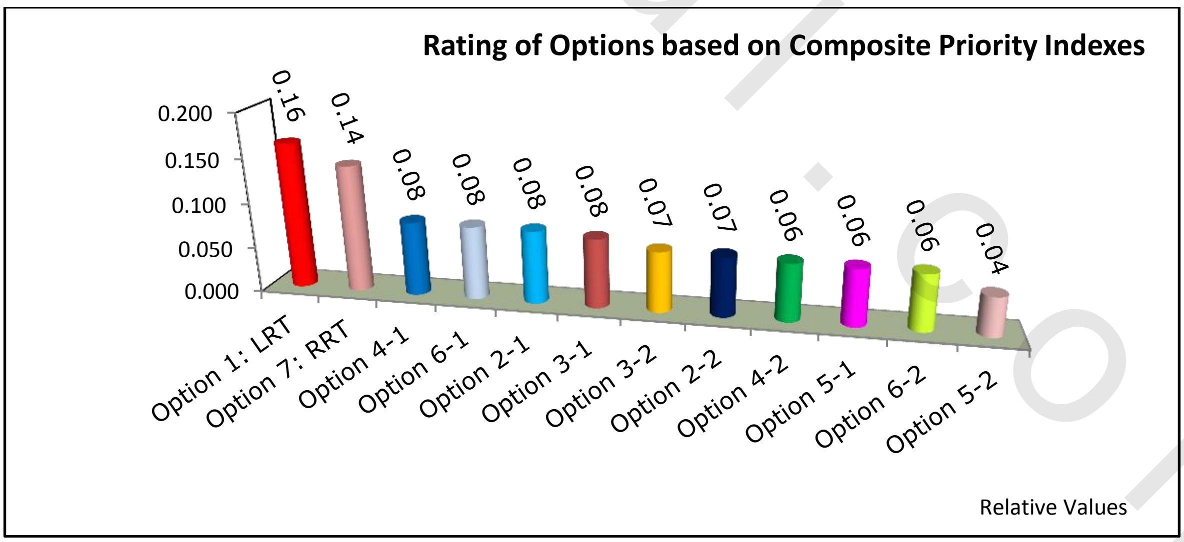

Figure 24: Arranging of Options according to their Composite Indexes

- Visual Composite Sustainability Level

The area of the trapezium that reflects the relative sustainability global priorities of each option is calculated. The maximum achievable sustainability values of all options on the four axis shape the maximum achievable sustainability trapezium. The percentage of the trapezium area of an option to the maximum achievable sustainability is the visual composite sustainability level of this option. Table 17 includes also the relative composite levels of all options, as well as the maximum achievable sustainability level.

Figure 25 illustrates the visual composite sustainability levels of the four high priority options, as an example. The trapezium covered with a red line presents the sustainability level of Option 1; the trapezium with green outline represents the sustainability of Option 7. The blue outline covers the sustainability of the project 6-1, and the shape with brown outline represents Option 4-1. Clearly, Option 1 appears to be the "best" of the four projects, since its results in the maximum achievable sustainability level: 88%. The visual composite levels of the other options in a successive order are included in Annex 4.

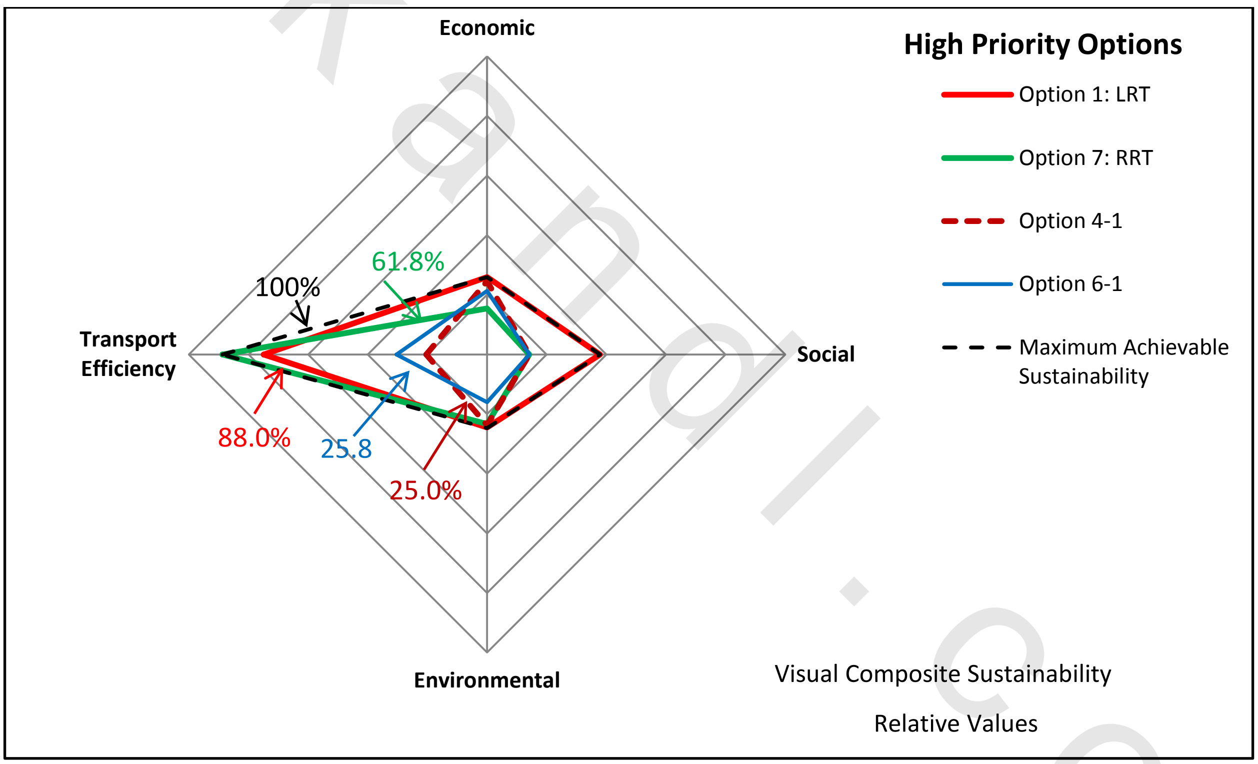

Figure 25: The Visual Composite Sustainability Levels of the Four High Priority Options

- Visual Sensitivity Analysis

In case of non-identical, but comparable options, such Option 4-1and Option 6-1, the dimensional values show that while the two options seem to be alike from the social perspective, the main differences are to be found in their economic, environmental and transport efficiency. The investigation of these multiple dimensional levels using the visualizing tool enables the decision maker to discover the trade-offs between the differences. While Project 6-1 has some advantages in the transport efficiency, Project 4-1 is better regarding economic and environmental sustainability. This type of tradeoffs can be valuable for understanding the impacts of decision making on the urban ability to achieve its current priorities (Jeon, Amekudzi, & Guensler, 2013).

In cases where the overall sustainability levels is slight variance between two or more options, but there are definite differences in the scores of the four different sustainability dimensions, understanding the impacts of selecting one option over another would require understanding the tradeoffs that are being made from option to option.

Therefore, the dimensional sustainability indexes as well as the composite index can function as decision criteria to identify superior options for predetermined objectives and priorities. These priorities, determined from subjective weights, are critical for deciding the relative emphasis to be placed on each dimension of sustainability. (Jeon, 2010) suggests that decision makers should not just rely on a resulting index but must also examine the relevance of (1) weights and (2) evaluating process relative to the vision, goals, and priorities for their respective regions.

The evaluation above is based on all consistently distributed weights for each performance measure and sustainability dimension indicating that equal levels of importance are placed on all measures and dimensions. As a standard, such a ‘‘neutral’’ weighting scenario enables decision makers to readily track the changes in the results by applying different weights. However, the importance of weights for the various criteria should be in a farther study recognized.

6.9 Comparison between the different Techniques

A. Economic Feasibility Analysis

Advantages

The feasibility analysis is essential for highlighting the differences between alternatives.

Disadvantages

- Overlooking indirect impacts.
- Uncertainty in estimating costs and benefits regarding variations in inflation, foreign exchange, and interest rates over project lifespan.
- Ignoring sustainable indicators that reflect community needs for its long term development.
- It uses only a single element, such as Cost-Benefit ratio for the evaluation.
- It is insufficient for a comprehensive evaluation.

B. Multi-Criteria Decision Analysis (MCDA)

Advantages

- MCDA is used for developing guidance to decision makers in dealing with multiple criteria instead of utilizing a common single attribute.
- MCDA corporates sustainability into transport planning processes.

Disadvantages

- MCDA may lead to doubt the results, due to its complexity nature of the methodology and the large amounts of data that must be “stored and operated”.
- Charging weights without testing the consistency of allocated weights may lead to subjective and non-transparent results.
- MCDA depends mainly on scientific analysis. Local knowledge is restricted only to setting the criteria weights.

C. Analytical Hierarchy Process (AHP)

Advantages

- The process is carried out in successive steps, so that data management is not complicated.
- AHP is based on pairwise comparison and stakeholders participate at each step.
- It is supported with a mechanism to insure the consistency of the weights at each step.
- The judgment preference relative linear scale is practically attractive, user-friendly.

Disadvantages

- If a large number of evaluation criteria and project options exist in an evaluation process, AHP will suffer hard debates during allocation of weights for pairwise comparison.
- AHP-Structure (also MCDM) may lead to doubt results, due to allocation of all weights for all criteria at one step (non-precise understanding of fine differences).

D. The Proposed Approach “Comprehensive Evaluation of Transport Projects” (CETP)

Advantages

- CETP Investigating the role of each project in achieving city sustainability.
- It considers the four essential sustainable criteria (economic, social, environmental, and transport efficiency.
- It can deal with quantitative criteria (in monetary unites or performance values) and qualitative criteria, and either with “less is better” or “more is better” criteria.
- It takes also direct and indirect impacts into consideration.
- It brings a process that highlights efficient decision making through a systematic, step-by-step procedure to facilitate data management and testing the consistency of allocated weights by stakeholders.
- CEPT integrates scientific analysis with local knowledge by setting weights at the different steps of the process.
- It allows group decision making by setting of weights.

- CEPT produces a global priority index which is used for rating the project options, and a composite sustainability level, which presents the percentage of the achieved sustainability of each option to the maximum achievable sustainability.
- The evaluation facilitates the decision making by introducing a visual presentation of the interrelationships between indicators and results.
- The visual presentation allows preforming a sensitivity test in situations where uncertainties exist in the definition of criteria weights.
- The procedure allows a trade-offs analysis between advantages and disadvantages of each project option.