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A feasibility study approach for underground railways - a case study: Line 4 of Athens metro

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ABSTRACT: This article introduces a methodology for conducting feasibility studies for underground railways. The study addresses the factors that determine station location, the attributes that enhance rail use through passenger satisfaction. It incorporates the principles of CBA and financial analysis, presents the social impacts and their requirements for the achievement of the social objectives, and discusses the benefits (social, economic, environmental) that are accrued from the existence of underground railways that render them crucial elements for developing sustainable cities. The case study based on Line 4 of the Athens metro has been used to provide an overall description of the implementation of this methodology by using qualitative and quantitative data. The study reveals that the feasibility of a project is improved by assessing its aspects on a global scale, while the perception of its utility by the target-market is integral in its success.

Keywords: Feasibility study, underground railways

INTRODUCTION

The main interpretation that usually follows the term *feasibility* is one of the following: the case in which an alternative option, a strategy plan, a design or a different location is proved economically preferable; the case in which an alternative option is deemed appropriate in social or environmental terms and the case in which probable construction and operation of a project can be financially viable as well as manageable [1]. A feasibility study is a multidimensional set of actions which aims to analyse and evaluate a project in order to determine if its construction is feasible [2]. Such a study refers to the assessment of results which concern the economic forecast in relation to other important factors, such as socioeconomic efficiency and environmental impact [3]. The defining point of a feasibility study is the necessary information that leads decision-makers to decide if the proposed option or project should be implemented [1][2]. Its necessity in project development is considered significant, as the identification of errors in this stage contributes to better performance of the project [3]. Thus, the success of a project is determined by the assumptions that are set during the feasibility study process [4]. In some cases, a project is not profitable in economic terms; however, its feasibility is attributed to serve another purpose [1].

The present research contributes to the engineering sector and, thus, engineering education by providing a new methodology of feasibility study for underground railway projects, which balances social, environmental and economic aspects. The elements that comprise such a study are identified and analysed separately, while the factors that further improve the quality of a rail project, as well as probable parameters which increase the rail use are examined. The second key part of this article refers to the application of this methodology based on a case study of Line 4 of the Athens underground railway.

PROPOSED METHODOLOGY FOR A FEASIBILITY STUDY FOR UNDERGROUND RAILWAYS

The nature, location and the type of each project are factors leading to the diversification of feasibility studies [5]. Through a recent survey conducted by Shen et al in four different project categories (residential, commercial, public, industrial), the elements that are taken into consideration have been defined [3]. These elements, which are illustrated in Table 1, are categorised in three sections: social, environmental and economic. In this context, a thorough review of guidelines about feasibility studies of appraisal methods for rail projects and of feasibility studies for particular projects, has been carried out in order to lead to the development of a general structure of feasibility study for underground railways. More specifically, the sources used include the following: feasibility study guidelines [6][7]; appraisal guidelines for railway projects and feasibility studies on specific rail projects [8][9]. In the latter case, seven feasibility studies, which have been carried out for specific rail projects world-wide (in Australia, America, Canada, Europe) were reviewed. This led to a better comprehension of the current implementation of feasibility studies applying to real projects [10-16].

Table 1: Elements used for a feasibility study (Source: Shen et al [3]).

Economic Elements	Governmental strategic development policy, market forecast, market competition
	Project function and size, demand and supply analysis, location advantage, technology advantage
	Return on investment, tax policy, life cycle cost, life cycle profit, financing channels, budget estimate
	Investment plan, finance risk assessment
Social Elements	Influence to the local social development, development of new settlement and local communities
	Provision capacity of employment and of public services, cultural and heritage conservation
	Improvement to public health, provision of the infrastructures for other economic activities
	Provision capacity of public infrastructure facilities, safety standards, land consumption
Environmental Elements	Eco-environmental sensitivity of the project location, waste assessment, noise assessment
	Environmentally friendly design, energy consumption performance, air impacts, water impacts

Consequently, by synthesising the information from these diverse sources and by incorporating components that emerged from research on the elements of which a feasibility study consists, a new methodology of feasibility study for underground railways was developed, as illustrated in Figure 1.

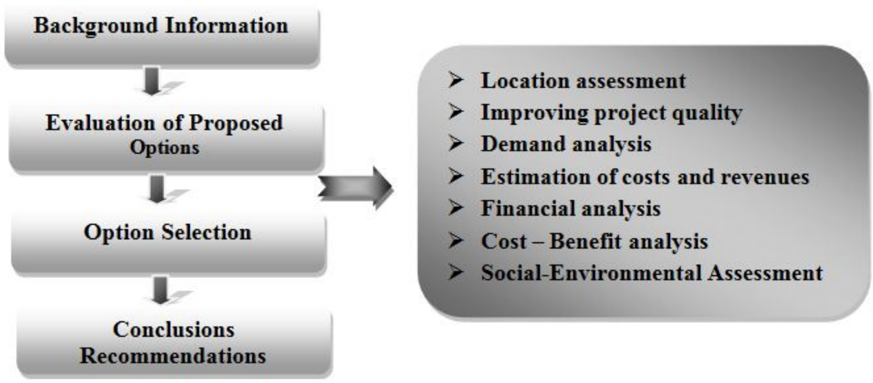

Figure 1: Methodology for conducting feasibility studies for underground railways.

Location Assessment

The design of a railway line includes the examination of factors such as topological configuration, quantity of stations and lines, frequency of lines and pricing [17]. The density of lines, the demanding period of parking time around the station, as well as pedestrians' accessibility to the station, are differential variables regarding whether a probable traveller will be attracted to use the metro or not ([17-19]). Locations that enable access to health, education, entertainment services and provide connection to other railway stations should be probably planned to operate as stations before the design of the line, while the location of other stations should preferably be chosen with criteria to attract or serve a larger number of passengers [18].

Improving Project Quality

The basic criterion through which a transportation project is evaluated as qualitative is to meet user needs [20]. The term *quality* is defined by the transfer that travellers experience while it is synthesised by elements, which are related to the design and the operation of the railway line [21]. Access and egress time, service intervals, in-vehicle time, transfers between modes, reliability information provision, system efficiency are some of these elements, while accessibility is considered to be a key factor in determination of the use of rail as an alternative solution [22][23]. Reliability has been found in various surveys to be a prominent element, which identifies transportation quality and influences passengers' choice [24]. Following a survey carried out by Brons, the factors that contribute to passengers' satisfaction in order to choose rail are travel comfort, reliability, station organisation and information, service schedule, dynamic information, price/quality ratio, accessibility and ticket service [25].

Demand Analysis

Demand forecasting is an important step in a feasibility study as it assesses the necessity of the project [26]. The broad coverage of areas, advanced connectivity and the placement of stations are factors that increase the demand for the use of public transportation [27]. The outcomes of the demand forecasts are necessary as they contribute to the determination of elements such as the roadway capacity and the length of station platforms [28][29]. This stresses the importance of the precision in forecasting demand [28]. However according to recent statistical surveys conducted by Flyvbjerg [28], and Flyvbjerg et al [30] related to the accuracy in demand forecasts in transportation projects, an average of overestimation of 106% in rail projects was observed. In the same vein, Van Vee [31], and Flyvbjerg et al [32] mention that the overestimation of demand is a common phenomenon while Holz et al support the view that the quality of forecasts needs to be improved [33].

Costs of Underground Railways

The construction cost of a railway line varies even within the same city, as it depends on the technical characteristics (subsoil, housing situations) of each project, which are linked to local conditions [32]. Further factors that determine the cost of a railway are the length, planning and design parameters, the construction works and station equipment [34]. Large projects are characterised by wider variation in a scale from 40% to 200% [35][36], while the systematic underestimation and final overrun of costs which has been noted depends, strictly and incrementally on delays and extensive duration of the implementation phase [32][37]. Furthermore, regarding data presented by Flyvbjerg et al, underground railways are four to six times more costly than at-grade ones [37].

With reference to the operational costs, these are increased by the existence of characteristics, such as ventilation, lighting, air conditioning or platform screen doors, but simultaneously these factors increase the satisfaction of customers by providing them comfort, reliability and quality of services [38]. Maintenance costs are usually estimated by using historical expenditure figures [39].

Cost-Benefit Analysis

The economic appraisal of transportation projects is interlinked with cost - benefit analysis (CBA), as it is a main index regarding the value of investment [33]. Through a comparison between costs and benefits by using the benefit cost ratio (BCR), the economic net present value (ENPV) and the economic rate of return (ERR), the social value of the project can be produced. The value of travel time savings is considered to be a key characteristic for transport studies as it occupies 50-70% of the total benefit [29][40]. Vehicle operating costs (VOCS) are accrued by multiplying the default operating cost per vehicle kilometre by the number of vehicle kilometres saved by the project [41]. The methods, which are intended to evaluate the non-user benefits related to the prevention of accidents are referred to as the average danger levels according to transport mode, while the environmental externalities generally depend upon the travel distances and exposure to polluting emissions [6].

Financial Analysis

The financial analysis consists of the financial net present value, financial return on investment cost (FNPV(C) and FRR (C)), sources of financing, financial sustainability, the financial net present value and financial return on the national capital (FNPV(K) and FRR(K)) [6]. The FNPV is defined as the sum that results when the expected investment and operating costs of the project are deducted from the discounted value of the expected revenues as per Equation (1):

$$FNPV = \sum_{t=0} atSt = \frac{S_0}{(1+i)^0} + \ldots + \frac{S_n}{(1+i)^n} \quad (1)$$

where $at = \frac{1}{(1+i)} t$ and t = time horizon.

The FRR is defined as the discount rate that produces a zero FNPV as per Equation (2):

$$FNPV = \sum \left[\frac{St}{(1+FRR)} t \right] = 0 \quad (2)$$

Financial sustainability is one of the most important features in a feasibility study [1]. The term *financial sustainability* includes the possibility of a project not running the risk of a cash shortfall in any phase of its implementation for the considered period of time [6].

Social and Environmental Assessment

One of the most important aims for the improvement of public sector projects according to Shen et al is to fulfil the social objectives, which should be addressed in all public projects [3]. The potential social impacts, which are expected from the existence and the operation of a railway project could be divided into three categories, namely socioeconomic efficiency (passenger time savings, reduction of traffic congestion, cost saving to society), development plan of the city (increase of productivity, efficiently function of urban areas, urban development) and social improvements (access for all people, land acquisition) [38]. The large-scale tendency is that underground railways contribute to minimising the negative effects of environmental pollution [41]. Noise pollution is minimised in underground transport infrastructure compared with elevated and surface ones, while the saving of energy is of high importance. In addition, the construction of an underground railway is associated with environmental preservation and elimination of crossings with non-physical obstacles [38].

CASE STUDY - LINE 4 OF THE ATHENS UNDERGROUND RAILWAY

The second key part of this article refers to the implementation of the developed methodology in a case study, which is Line 4 of the Athens Metro. The new Line 4 is U-shaped, is 33 km long and includes the construction of 29 new stations [42].

Data and Procedure

The case study analysis of Line 4 of the Athens underground railway relied on qualitative and quantitative information gathered through contact with Attiko Metro SA, by extracting data from AMEL SA, the Municipalities of Athens that Line 4 will cross, relevant research papers, the European Commission and from field research. This information was necessary to document elements for the location of Line 4, passengers' satisfaction, expected ridership, estimated project costs and revenues, benefits and financial attributes. Specifically, elements of the wider area (health-educational services, important places, connection with other lines) of the probable station location were derived from field research. The demographic data were gathered from the Municipalities of Athens that Line 4 will cross. Corresponding data for passengers' satisfaction were derived from a survey that Attiko Metro SA conducted in 2005. The data about the expected demand and the estimated construction cost of Line 4 came from Attiko Metro SA.

The assumptions were built up by analysing estimated and actual data before and after the operation of the existing metro lines. This information was derived by extracting elements from the Metro Development Study for Athens and published data from Attiko Metro SA's annual economic report for 2007. Respective data about the operating and maintenance costs emerged from published AMEL data. In addition, data about the reliability of metro services, the capacity of rolling stock, necessary features for disable people that are incorporated in the design of the existing underground service and the technical characteristics that enhance the safety of passengers derived from Attiko Metro SA. Respective data about the recommended period of project appraisal, the discount rates, design life of an underground railway project, probable funding from EU, and the conversion factors for monetary values were derived from the European Commission.

Results and Analysis

Line 4 is expected to serve densely populated areas and the main avenues of Athens, as well as providing access to health, education and to other important places. The priorities for services were set according to a relevant study conducted by the Attiko Metro SA, in relation to the attributes that enhance passengers' satisfaction. These are: reliability, reasonably fast, personal safety, ticket service, travel comfort. The expected demand for Line 4 is about 500,000 passengers daily [42]. Regarding the demand estimation for Lines 2 and 3 (450.000 passengers), the first two years the overestimation was around 83.67% and 63.64%, respectively. According to published data from AMEL SA [43], the annual boarding for the year 2010 was approximately 170 million passengers. On the basis of the latter elements, it was appropriate to assume that it would take three years to reach the predicted levels, with 50% of the full expected demand to have being reached in the first year and 75% in the second year.

The estimated construction cost for Lines 2 and 3 was approximately €830 million in 1991, while in 1994 the construction cost was redefined at about €952 million. However, according to the official data from the annual internal economic report of Attiko Metro SA in 2007, a cost of €2.758 billion was presented, shaping the cost per route kilometre at around €156 million. The latter indicates a cost overrun of 289.8%. The estimated construction cost of Line 4 is €3.3 billion, which means that the construction cost, per kilometre, is €100 million [42]. For the purposes of evaluation, it has been assumed in one case that the cost would equal to €3.3 billion and in a second case, in which a cost overrun of 40% was added, the cost reached €4.620 billion. With respect to the annual operational expenses, by proportionally calculating them for Line 4, these would be approximately €118 million (personnel expenses: €72,712,000, maintenance and repair costs: €4,810,000, other expenses: €39,712,000). The revenues were calculated assuming a growth rate of 2.2% for a fifteen year period and an average price of 70% of the full price (€1.40) including multi-use tickets.

Through the cost-benefit analysis (Table 5), where the distribution of costs was assumed to be linear (five-year period of construction), it was revealed that the main contributors to the present value of benefits are the travel time savings, as they contribute to the 43% of the total benefits in the first year of the operation of Line 4, while in the last year of the appraisal period, they contribute to the 48% of the total benefits. The benefits were categorised into user benefits (travel time savings), non-user benefits (accident benefits, environmental externalities), fare revenue from new users and residual value of rail assets.

Table 5: Cost-benefit analysis of Line 4 (€ billion).

Present value of benefits	5.216
Present value of operating costs	1.011
Present value of capital costs	2.452
Discount rate	5,50 %
ENPV	1.752
ERR	9.50 %
B/C ratio	1.71

The positive ENPV indicates that the option will be economically feasible and it will, therefore, provide good value for money. The B/C ratio identifies the relationship between benefits and costs, showing that the costs equal 1.71 of the total benefits. In the case in which the benefits have been compared with an additional cost overrun, the project is economically feasible, giving a positive ENPV (933€ million). For the programming period 2007-2013, the European Commission recommends that a 5% real rate should be considered [6]. The reference time horizon recommended for the same period, regarding railways, is 30 years, while underground railways have a design life of 100 years. Through the financial analysis (Table 6), it has been demonstrated that the project is not financially feasible, as the indicator FRR (1.5%) is lower than the applied discount rate (5%), while FNPV is negative (€-1,433 billion). For the project as a whole, the revenue from passengers cover about 49% of the total costs, giving a financial BCR of about 0.49.

Table 6: Financial analysis of Line 4 (billion €).

Present value of revenues	2,183	Including the EU grant	
Present value of residual value	534		
Present value of operating costs	1,303		
Present value of capital costs	2,857	Present value of capital costs	2,347
Discount rate	5.00 %	Discount rate	5.00 %
FNPV (C)	-1,443	FNPV (K)	-932
FRR(C)	1.50 %	FRR(K)	2.40 %
Financial BCR	0.49	Financial BCR	0.6

The funding gap would amount to approximately €1.4 billion, while the funding from the European Union was estimated to be €589 million. The period of amortisation of Line 4 is expected to be 35 years, as the revenue from the project breaks even with its cost after 35 years of its operation.

The social performance of a construction project is assessed through the evaluation of social performance elements. These elements, which are transformed into criteria accrued through the determination of the social objectives that are expected from the existence of a railway project and are: reliability, capacity enhancement, community links and networks, accessibility, reduced mobility - mobility for special users, affordability, geographic and personal safety. The outcomes showed that an investment in an underground railway line is very valuable, since it provides the opportunity for people with no means of private transportation to travel, it contributes to the upgrading of the areas around the metro stations, as well as propelling the improvement of the quality of people's life.

In relation to the environmental improvements, a study conducted before and after the operation of the metro revealed a decrease in the levels of air pollution from 8% to 4% due to the reduction of private vehicles (reduced by 70,000) [42]. It is estimated that the new metro Line 4 will contribute to the decrease of the use of private vehicles by people who bring up to 81,000 cars into Athens. This will lead to the reduction in air pollution, in greenhouse gas emissions and in noise pollution. However, the amount of benefit depends on the regional vehicle emissions.

CONCLUSIONS

This article introduced a new methodology for conducting feasibility studies for underground railways, through which diverse factors that could positively influence the education of engineers and the engineering culture overall were examined. It has been framed from economic, environmental and social attributes, while the factors which stimulate the rail use, through the passengers' satisfaction, were incorporated into this methodology.

Analysis of the factors that determine station location revealed that locations that enable access to health, education services and important places, as well as points within densely populated areas should be considered as possible locations for metro stations. In relation to the quality of the project services, ten elements that contribute to passengers' satisfaction were determined, while reliability is considered to be one of the most prominent. The study further shows cost overruns that occur in projects with a long implementation phase vary between 40% - 200%, while the average overestimation in demand forecasts in rail projects is about 106%. As far as the environmental benefits are concerned, the large-scale tendency is that underground railways contribute to minimising the negative effects of environmental pollution.

With respect to the second part of this study, the new methodology was applied to the case study of Line 4 of the Athens underground railway. By comparing the economic performance of the project in relation to the benefits on a social, environmental and economic perspective, as well as through the analysis of social criteria (affordability, accessibility, safety) the feasibility of the Line 4 was evaluated. The study reveals that the feasibility of a project is improved by assessing the project aspects on a global level.

It is recommended that the attributes that synthesise the quality of an underground railway project, as well as the identification of factors that increase railway usage should be an integral part of a feasibility study, since the success of a project is determined by the degree of its utility to those for whom it is constructed. The new methodology is based on three main directions and their components, which support sustainability. It is of great importance to promote and incorporate into the process of any feasibility study, elements that come along with the principles of sustainable development. In this respect, professional practice will be able to meet future demands, and the quality of life can be improved.

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BIOGRAPHIES

Kassiani Tsimplokoukou graduated with a Bachelor of Engineering degree from the Technological Education Institute of Piraeus as a civil engineer. During her studies she was employed in two laboratories in the Civil Engineering Department of the Technological Education Institute of Piraeus. She worked on standard test methods for quality control of construction materials, laboratory testing of concrete mix design and statistical analysis of results in the Quality Control and Materials Technology Laboratory. She has also been teaching as an assistant in the Computer-Aided Design Laboratory. Upon the completion of her studies she enrolled in the Master's course, Management in Construction at Kingston University (UK), School of Engineering, in cooperation with the Technological Education Institute of Piraeus, Department of Civil Engineering, which she has recently completed. In parallel she has worked in the fields of construction and management of commercial projects in Athens. Additionally, she has gained experience in the supervision of public infrastructure projects, particularly in road construction and installation of gas pipelines. Her experience has influenced her research interests. Specifically, her interests concern the optimal management and development of infrastructure projects over their life cycle along with the principles of sustainability. Future projects will include but are not limited to the principles of quality and environmental management.

Eleni Sfakianaki graduated from the University of Patras, Greece, as a civil engineer (five year course). She then completed a Masters course in Construction Management at the University of Sheffield, Civil Engineering Department, UK. She was awarded a full scholarship from the University of Sheffield to complete a PhD in Environmental Management with the use of GIS, which she successfully defended in 2000. Once she completed her PhD, she was appointed a Lecturer at Kingston University's School of Engineering, UK. She worked as a lecturer for three years full-time. She then started working as a consultant in sectors such as construction management, environmental assessment and tourism. She has gathered considerable experience in project management and co-ordination. She has worked in some of the largest investment projects in Greece. After she left Kingston University, she continued her academic career in Greece on a part-time basis. She taught at both undergraduate and postgraduate levels and continued research at the same time. Since last year she has been an assistant professor at the Hellenic Open University, School of Social Sciences, Business

Administration Department. She has attended a large number of conferences and has published in referred journals. Her main interests include engineering, education, total quality management, environment and economics. She also has an interest in sustainability and the quality of life.

George Metaxas graduated from the National Technological University of Athens (NTUA), Greece as a civil engineer. He then work as assistant lecturer in NTUA in postgraduate level giving lectures on reinforced concrete, advanced fluid engineering, applied hydraulics and methods of applied mathematics in hydraulics. Afterwards, he worked as a lecturer in the Agricultural University of Athens (AUA) in the Hydraulics Department. He was later appointed Professor at the Technological Education Institute of Piraeus (TEI) in Civil Engineering Department. He was elected four times to be Head of the Department of Civil Engineering and twice as Dean of the Faculty of Engineering. He established the postgraduate courses in TEIs in collaboration with foreign institutes, and since 2000, he has been the Field Leader of the postgraduate course of the Civil Engineering Department in collaboration with Kingston University (UK). During 2004 he completed his PhD from AUA. During his academic career he has been awarded with UNESCO International Centre for Engineering Education (UICEE) Silver Badge of Honour for distinguished contributions to engineering education, outstanding achievements in the globalisation of engineering education through the activities of the Centre, and, in particular, for remarkable service to the UICEE. He has also been awarded an honorary Doctor of Engineering by Kingston University, UK. He is a member in various scientific organisations such as the World Institute of Engineering and Technological Education. As a civil engineer he has worked as consultant engineer with large consulting firms in Greece and has designed and supervised large projects in Athens, Greece.