*Impact Assessment and Project Appraisal,* volume 18, number 4, December 2000, pages 323–333, Beech Tree Publishing, 10 Watford Close, Guildford, Surrey GU1 2EP, UK.

# Railway electrification

## Cost–benefit analysis of railway electrification: case study for Cairo–Alexandria railway line

**Fathy El-Sayed Al-Tony and Abdelkader Lashine**

***Egypt National Railway trains (passenger and freight) are currently operated with diesel traction, except for two electrified Metro lines in Cairo of about 55 km in length. An electrified rail system could have a number of operational and environmental benefits. This paper examines the economic and financial viability of a proposed electrification scheme for the Cairo–Alexandria railway line. The framework of appraisal developed identifies the potential direct and indirect benefits of the scheme, and its costs. The evaluation of different types of costs and benefits included a sequence of analytical steps. The results showed that the scheme achieves only about 9% internal rate of return. However, applying a broader cost–benefit analysis to include all sources of benefits shows that it is highly desirable on an economic basis. Despite the extreme difficulty of obtaining the required data and information, plausible and coherent results were achieved, which are also seen to be consistent with other results of electrification schemes in Europe.***

Keywords: cost–benefit analysis; railway electrification; Egypt

Dr Fathy El-Sayed Al-Tony is Assistant Professor, Transport Economics Department, Egyptian National Institute for Transportation, PO Box 34, Abbasia, Naser Road, Naser City, Cairo, Egypt; Tel: +20 2 2604903, Fax: +20 2 2604121; E-mail: enit@intouch.com. Dr Abdelkader Lashine is Previous Chairman of the Transport Planning Authority.

FOR A COUNTRY with the population size and diversified economic structure of Egypt, transport plays a vital role. It must provide efficient and reliable services, and, given the scarcity of financial resources in the economy, it must accomplish these objectives at a minimum cost. It is of paramount importance, therefore, to ensure that the vital production activities of the economy are not hindered by lack of transportation.

Railways can play a critical role in domestic transport. All economies which produce or consume large amounts of bulk commodities, need an efficient rail service. Railways can also be important in passenger service: India Railways and China Railways are the world's second and third largest transport carriers, each carries about 50% more passenger traffic than all of the West European and North American railways combined.

Many developing mega-cities such as Buenos Aires and Bombay are heavily dependent on rail for urban transport as well (Thompson, 1992). Railways also play a critical role in a nation's competitiveness. World trade is increasingly governed by total logistics costs with heavy emphasis on speed, reliability, flexibility, and real-time information. The cheapest mode can be disadvantageous if it is slow and unreliable. Then those countries with poor rail systems cede a logistical advantage to countries whose railways perform better.

Railway investment projects can also help in meeting environmental targets. Rail schemes can have impacts on localised water, soil quality and can change the local ecology through induced economic development. Additionally, railways can handle heavy passenger flows efficiently and with minimal air and noise pollution.


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**Table 1. Percentage of electrified track and percentage of traffic using it in Europe and Japan**

| Country | Britain | France | Germany | Japan | Italy | Holland | Sweden | Switzerland |
|---|---|---|---|---|---|---|---|---|
| % electrified track | 30 | 39 | 45 | 58 | 60 | 70 | 65 | 100 |
| % of traffic | 55 | 88 | 90 | 93 | 93 | 90 | 95 | 100 |

*Source*: Toshik Saito (1993)

The railway network of the Egyptian National Railway (ENR) is approximately 4430 km long and consists of about 43 lines. These lines are classified into three classes depending on train speed and/or passing tonnage. In the first class are 6 lines of 1402 km. In the second class are 11 lines 800 km, and the third class has 26 lines of 2224 km.

ENR plays a vital role in transporting both passengers and freight in Egypt. It draws its importance from being one of the earliest railways in the world. ENR is the governmental authority, affiliated to the Ministry of Transport, in charge of operation, maintenance and upgrading the railway network and railway services. Although ENR has a significant role in passenger transportation (carrying about 50% of total passenger traffic) it has a minor share of freight transport (only about 5%).

The 1996/97 number of rail passengers excluding the Metro was about 771 million representing 52,929 million passenger kilometres, with an average travel distance about 71 km. The annual average growth ratio during the 90s of the number of rail passengers and passenger kilometres was 4.1% and 5.8% respectively. The average travel distance showed a stable increase during the same decade. As for the share ratio by ticket type, normal tickets are about 63% of the total, season tickets 14–15%, kilometre tickets (travel cards issued for 1,000, 2,000… kilometres of rail travel) merely 0.1%, and conductor tickets (issued on the train by the conductor) about 22–24%.

The total rail freight transport volume and total tonne kilometres were 12 million and 3,969 million in 1996/97. The major commodities in terms of share ratio of tonnage to the total tonnage during the 90s are iron ore 20–23%, wheat 10–15%, coal and coke 9–13%, petroleum products 10–17%, phosphate 5–8% and ENR commodities 17–18%. These commodities amount to about 80% in both tonnage and tonne kilometre of ENR. The average transport distance is estimated to be about 330 km.

ENR has been suffering from a deficit since 1975 (JICA, 1996). The cost-recovery ratio (defined as revenue divided by expenses) went down to 33–34% in the middle of the 1980s. However, the current deficit excluding depreciation has been improved gradually in the 1990s. Consequently, the cost-recovery ratio went up to 107% in 1994/95. On the other hand, including depreciation in 1994/95, the cost-recovery ratio was still below 100%. In addition, ENR has not been paying interest cost since 1992/93. If this were included on the income statement in 1993/94, for example, the cost-recovery ratio would be down to 43%. So ENR is still facing financial deficit, especially a large burden of capital cost (JICA, 1996).

ENR trains (passenger and freight) are being operated with diesel traction, except two electrified Metro lines in Cairo of about 55 km in length. An electrified rail system can have a number of operational and environmental benefits. In terms of operational aspects, it facilitates the use of high-speed, high-powered, high-acceleration and lower-noise traction motors in comparison with diesel engines. These factors contribute to a better level of customer service and help to improve competitiveness with other modes of transport. The most successful passenger railway services in the world (including high-speed and urban rail systems) are electrified. Table 1 illustrates the ratio of electrified rail track and the amount of traffic using this track in Europe and Japan.

As shown in Table 1, in most countries, the percentage of traffic using the electrified track is much more than the percentage of electrified track. This indicates that electric traction in railways facilitates moving heavy traffic effectively. In addition, it shows that electrified rail routes usually have a high level of traffic density.

Electrification schemes necessitate costly, fixed installations for power supply (sub-stations) and power transmission (contact wire system) as well as cabling of telecommunication lines alongside the railway line and reconstruction of some existing buildings. The capital requirements of electrification are thus high. It follows that routes to be electrified must have a traffic density high enough to justify the initial costs of the scheme. Electrification is often not profitable on lines with low traffic, and the development of appropriate infrastructure may result in significant short-term landscape disruption, as well as increased visual disruption from overhead power lines. All these issues should be examined when making the decision to electrify rail tracks.

In most countries, a minimum level of traffic is required to start examining the feasibility of railway electrification schemes. Japan Railways identify a minimum "turnout point" of 40 trains per day (JICA, 1979). The World Bank studies of electrification identify a minimum level of traffic before proceeding with appraisal (World Bank, 1984). In Europe, most railway electrification proposals have to go through both financial and economic evaluation, and have to yield sufficient direct and indirect benefits to justify the initial capital investment of the proposed schemes (DTp, 1984). This can only happen if railway lines have a high level of traffic demand.

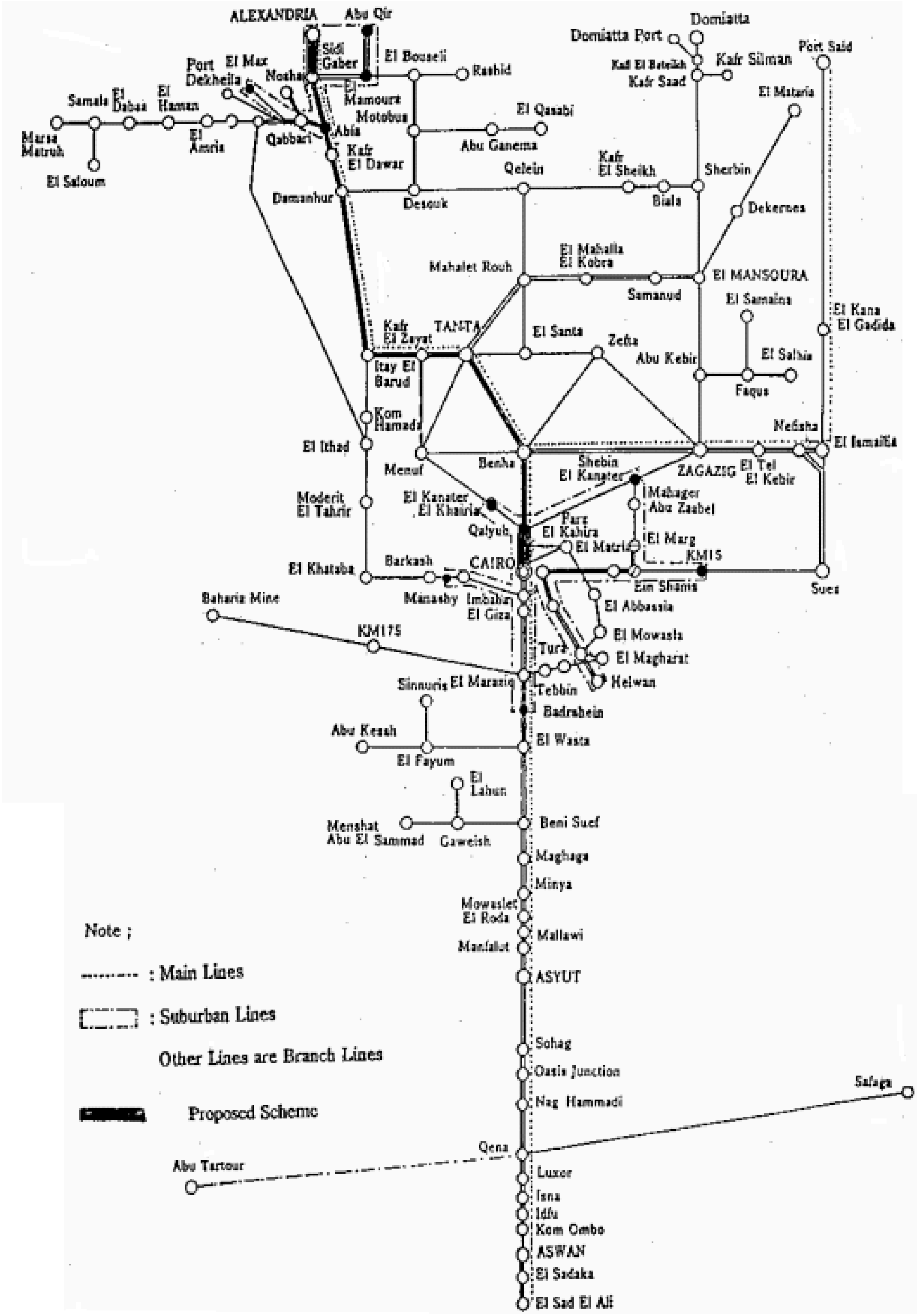


**Figure 1. Railway network of Egypt National Railways**

## Proposed scheme

The Cairo–Alexandria railway line, 208 km long, is one of the main lines of ENR. It carries about 30% of ENR passengers. The Master Plan study of the railway (JICA, 1996) identified the daily capacity for the line at 176 passenger trains and 65 freight trains with allowable speed up to 120km/h. The line has the highest passenger density (214 thousands passenger km/km) of all the ENR lines. Most of the line is flat, gradients are rare and do not exceed 0.5%. The track gauge is about 1435mm.

The daily number of passenger trains operating on the line is 65 in each direction. Some of these (32) are express trains (air-conditioned trains, mixed trains, and those that are not air-conditioned) that operate on the whole distance between Cairo and Alexandria. Others (33) are local trains that operate between one point and another on the line. Figure 1 shows a map of Egypt's rail network and the proposed line for electrification. A previous study (JICA, 1979) recommended that the electrification of this line would have enough benefits to justify the investment.

This research paper is concerned with examining the financial and economic viability of electrification of the Cairo–Alexandria railway line. The paper develops a framework of appraisal that identifies the direct and indirect potential sources of benefits of the proposed scheme and uses that framework to estimate these benefits over the project life. The appraisal framework and procedures consider passenger operation only, leaving aside freight operations.[1]

## Financial and economic appraisal

At the most general level, the techniques for assessing investment in the transport sector are financial appraisal (FA), economic appraisal (EA), and multi-criteria decision-making techniques. This section describes the first two techniques and highlights how they vary in assessing investment schemes.

### *Financial appraisal*

Financial appraisal (FA) is a method by which the effects of an investment on a particular industry, firm or private investor can be measured. The primary facet of FA is that it considers only the direct impacts of the project on the entrepreneur (railway operator) on a cash basis. Any direct or indirect impacts on other parties are not included.

The second facet is that it accepts actual prices in the market (at the time of evaluation). The rate of return on the investment is estimated by market conditions, whether competitive or imperfect. The external impacts of the project on the rest of the community or direct impacts on the consumers of the service provided and resource cost adjustments (shadow pricing) are all irrelevant in the FA technique.

In the transport sector, many investment projects, such as railway electrification, have impacts other than on the entrepreneur (railway operator), such as benefits to users (improvements in service quality) and benefits or costs to society (reduction in external costs of road transport such as congestion relief and accident reduction). These impacts are not included in the FA framework.

### *Economic appraisal*

Cost–benefit analysis (CBA) is the most popular technique for carrying out economic appraisal for transport investment projects. It is defined as:

> "a particular way of assessing the desirability of projects, where it is important to take a long view (in the sense of looking at repercussions in the further as well as the nearer future) and a wide view (in the sense of allowing for side effects of many kinds on many persons, industries, regions etc.), that is, it implies the enumeration and evaluation of all the relevant costs and benefits." (Prest and Turvey, 1965)

CBA is the usual method for testing the 'soundness' of proposed schemes. It involves an estimation of the value of the resources to be employed — 'the costs' — which is compared with the value of the goods or services to be produced — 'the benefits'. In contrast with financial appraisal, CBA measures the effects of an investment to society as a whole.

Thus, CBA is a comprehensive technique measuring the expected real impacts of a transport investment scheme on a society. These impacts could be direct (revenue or profit to the operator) or indirect (benefits to users of the transport facility or to the community such as improvements in service quality, reduction in road congestion time delays, road accident costs, air and noise pollution), tangible (measurable) or intangible.

## Appraisal framework and procedures

Since the Cairo–Alexandria railway line is currently being operated by diesel traction, the method used for appraisal of the electrification scheme is based on comparing the 'with electrification' situation to the 'without' (that is continuing operations by diesel traction).

Figure 2 illustrates the appraisal framework developed for identifying and estimating different types of cost and benefit of the electrification scheme.

The following sections explain the procedures for measuring different types of benefit and cost.

### *Benefit algorithm*

The appraisal framework of the electrification proposal in this study identifies four potential sources of benefit from the scheme that would be included in the appraisal process. These are:

railway financial benefits (producer surplus);
railway user benefits (consumer surplus);
road user and environmental benefits;
community benefits.

**Cost–benefit analysis is a comprehensive technique measuring the expected real impacts, both direct (revenue or profit to operator) and indirect (improvements in service quality, reduction in road congestion), of a transport investment scheme**

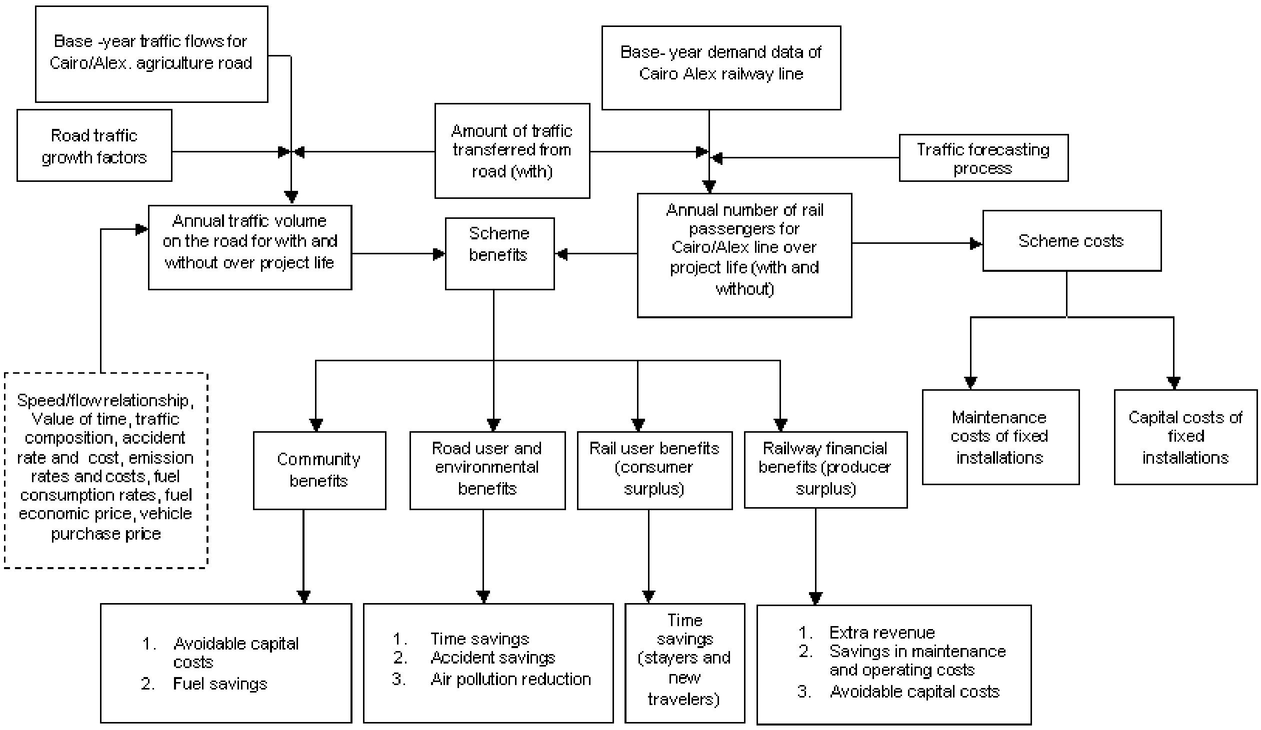


**Figure 2. Structure of appraisal**

This section, with the help of Figures 3 and 4, illustrates how these benefits are incorporated in the benefit algorithm.

*Railway financial benefits* refer to the net profit (sometimes called producer surplus) that the railway authority gains as a result of the electrification scheme. As shown in Figure 3, when rail investment shifts the marginal cost curve uniformly downward, the area $GC_2BM_2$–$GC_1AM_1$ will represent the operator's profit. Equation (1) represents this type of benefit in mathematical form.

$$RFB = (TR_{with} - TOC_{with}) - (TR_{without} - TOC_{without}) \quad (1)$$

where

$RFB$ = rail financial benefit (net profit) which is gained from the electrification scheme over the project life

$TR_{with}$, $TR_{without}$ = total revenue with and without the electrification scheme

$TOC_{with}$, $TOC_{without}$ = total operating and maintenance costs with and without the electrification scheme.

*Railway user benefits* are gained by railway users in terms of improvements to the quality of services as a result of the project. In Figure 3, $GC_2$ and $GC_1$ are the generalised cost of travelling by rail with and without the scheme. $Q_2$ and $Q_1$ are the number of trips with and without the scheme. The area $GC_1ABGC_2$ represents the consumer surplus gained by rail users (stayers and new travellers transferring from road). Equation (2) illustrates this in mathematical form:

$$RUB = ½ (GC_{without} - GC_{with})(Q_{without} + Q_{with}) \quad (2)$$

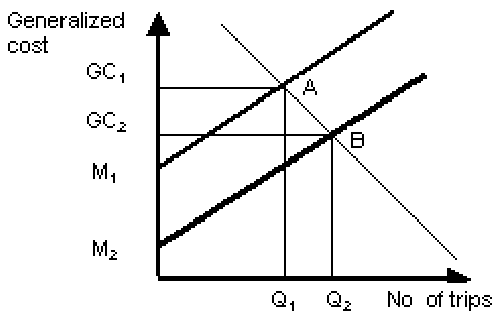


**Figure 3. Improvements in quality of rail service**

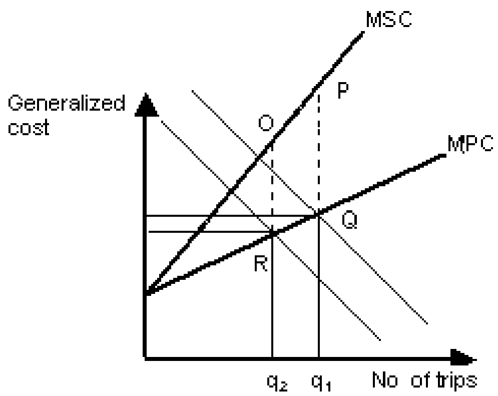


**Figure 4. Improvements in quality of road service**

where

RUB = benefits gained by rail users from the scheme over the project life

$Q_{without}$, $Q_{with}$ = number of rail trips without and with the scheme

$GC_{with}$; $GC_{without}$ = generalised cost of travel by rail with and without the scheme.

*Road user and environmental benefits* Generally speaking, the external costs of transport (such as loss by environmental damage, accidents and congestion delays) of road transport are considerably higher than those for rail. A European study of the external effects of transport (Rothengatter and Mauch, 1994) shows that in the 17 European countries considered, external costs amounted to 272 billion ECU or an average of 4.6% of GDP (gross domestic product). Overall, 92% of these costs is attributable to road traffic, with only 1.7% attributable to railways.

In this context, road user and environmental benefits are the potential net benefits accruing to non-users of the railway, arising as a result of trips which would otherwise take place on the highway network diverting to railway because of electrification. In other words, they are the external costs of road transport that would have been accruing to the society in the ‘without’ case. These types of benefit include decongestion on the road network, and reduction in road accident costs and air pollution.

As shown in Figure 4, the marginal private cost (MPC) of travel by road is below the marginal social cost (MSC) of travel. This is mainly explained by the fact that there are external costs for road vehicles, in the form of time delays, and noise, air pollution and accident costs. Road users do not include these externalities in their travel cost.

When electrification of railways leads to a transfer of some road users to rail, benefits will emerge. These are the savings in the external costs of road transport of those trips that transfer to railways. In Figure 4, if ($q_1q_2$) were the number of trips moved to rail, the benefits gained by road users and the community would be the area OPQR. This benefits could be measured mathematically using Equation (3):

$$RUEB = 1/2\ (q_1 - q_2)\ (REC_{with} + REC_{without}) \qquad (3)$$

where:

RUEB = road user and environmental benefits of the electrification in terms of time, accident and pollution costs which would otherwise be imposed on road users and society if electrification did not happen (without case)

$REC_{with}$, $REC_{without}$ = difference between marginal social travel cost and marginal private travel cost of road transport reflecting the external costs that road users impose on each other and on the rest of society for with and without situations.

*Community benefits* A variety of other benefits associated with mode switching are also attributed to the proposed electrification scheme and have to be included in the economic appraisal benefit algorithm; these are:

reduced road vehicle capital and ownership costs;
reduced road maintenance and capital costs;
reduced fuel consumption on road.

*Traffic forecasting*

Estimating future transport flows of passengers and freight can be considered as the most important issue in transport planning. This can be attributed to their major role in assessing the investment plans and evaluating different improvement policies to any transport system such as railways.

*Rail passenger forecasting* To estimate different types of benefit of the scheme as well as capital and maintenance costs, the number of passengers using the Cairo–Alexandria rail line over the project life in the with and without situation is required. The methodology used to derive rail passenger forecasts involved a sequence of analytical steps.

Based on the forecasts of the main study of Egypt rail (JICA, 1996), which predicted the number of passengers using different railway lines for the period 1995–2012 inclusive, and using regression analysis, the figures for the Cairo–Alexandria line are used to predict the demand of passengers on the line over the project life for the without situation. A previous study (JICA, 1979) concluded that an electrification scheme would lead to an extra 9% of normal demand for the Cairo–Alexandria line, which is mainly assumed to be otherwise using the Cairo–Alexandria agriculture road. Adding this percentage to the demand in the without situation would give the demand of the line in the with situation.

In fact, there would probably be some extra traffic induced by the electrification, especially as a result of a potential improvement in the rail service quality with the project. However, this was not estimated in this paper. It is also appropriate for the forecasts to take into consideration potential technology improvements, both for rail and for road. However, given the complexity of this issue, this was not considered.

*Road traffic forecasting* For the purpose of estimating the benefits associated with mode switching (road user, environmental and community benefits), traffic flows on the Cairo–Alexandria agriculture road (the direct alternative substitute) are required. The base-year demand is obtained from the main transportation study of Egypt (JICA 1993), and a growth factor of

**The period of evaluation for the electrification scheme is assumed to be 30 years, including four years of construction work and 26 of operation: this is compatible with the expected production life of fixed installations and rolling stock**

1.5% per annum is used to predict the traffic volume on the road over the project life for the without situation. This value is chosen according to the general trend of traffic growth on Egyptian roads similar to the Cairo–Alexandria road (Al-Tony and Al-Maksoud, 1999).

## Evaluation of costs and benefits

The evaluation process of costs and benefits of the scheme included a sequence of analytical steps. Transport investment schemes are usually evaluated over a period of 25–30 years. The period of evaluation for the electrification scheme is assumed to be 30 years. This includes four years of construction work and 26 of operation. This is found to be relevant with the expected production life of fixed installations and rolling stock. Also it is consistent with other countries' experience in the evaluation of rail electrification projects (WS Atkins, 1990; DTp, 1984).

### *Capital and maintenance costs*

The costs of electrification of the Cairo–Alexandria rail line consist of the capital costs of fixed installations, rolling stock and their maintenance cost. Capital costs of fixed installations are estimated at £E 816m, which is expected to be spent equally over four years of construction. Table 2 shows the breakdown of these costs. The estimated costs are based upon various sources of information and expertise such as Egypt Rail experience in Cairo underground, previous studies (JICA, 1979; NEDCO, 1981), as well as information supplied from worldwide companies and consultants.

**Table 2. Capital costs of fixed installations for Cairo–Alexandria railway line electrification**

| Type of installation | Quantity | Estimated total costs (millions £E) |
|---|---|---|
| Sub-stations | 5 stations[a] | 100 |
| Overhead catenary system | 238 km[b] | 216 |
| Workshops | | 200 |
| Signalling | | 50 |
| Track (civil engineering work) | | 250 |
| Total | | 816 |

*Notes*: [a] Approximately one substation every 50 km located in Cairo, Benha, Tanta, Damanhor and Alexandria
[b] Include 208 km on both sides as a main line and 30km as sublines needed for the completion of the system

Rolling stock required for the scheme comprises electric locomotives and coaches. The number of electric locomotives required for the 'with' situation is based on the total number of passengers forecasted, train capacity and the average daily kilometres the locomotive can do. The latter is estimated based on 16 hours work per day (allowing for servicing) and average travel speed. Information about the current train operation on the line helped also in identifying the required number of locomotives. The electrification of the line will lead to improvement in both travel speed and train frequency as well as better utilisation of locomotives. These issues are taken into account when estimating the required number of electric locomotives.

This process results in the need for 38 electric locomotives (1850 horsepower) at a total cost of £E 272m at the beginning of operation (year 2007). In addition it is found appropriate to take account of the cost of additional locomotives over the project life required to cater for the expected annual increase in passenger demand; this is found to require about one locomotive each year.

Passenger coaches required are estimated only for the 9% extra passengers attracted to the railway line as a result of the electrification. Considering the extra number of passenger trips, train capacity, load factor, and train kilometres per day, this results in the need for 110 coaches costing £E 418m in the first year of operation. In addition, there will be about ten coaches required every four years of operation to accommodate the growth of passenger demand.

Maintenance costs of fixed installations are estimated at £E 6.6m annually starting at year 2007. The maintenance cost of electric locomotives is about half that for diesel locomotives (NEDCO, 1981). For the 'with' situation this is considered as a type of benefit, which will appear in the benefit side of the scheme. However, it is appropriate to consider the operating and maintenance costs of the extra coaches bought to cater for the extra demand as a result of electrification. This is estimated based on current maintenance and operating costs per km obtained from Egypt Rail records and the expected annual kilometres for coaches.

### *Railway financial benefits*

Railway financial benefits comprise the extra revenue gained as a result of the electrification of the line, the residual value of diesel locomotives currently used on the line and savings in operating and maintenance costs. Passengers attracted to the line as a result of the electrification benefit from the reduction in travel time (approximately 30 minutes less) are split into travellers for the whole distance and local trip makers.

Assuming that whole-distance travellers are served by first and second class air-conditioned trains, and considering the average fare being applied, the total extra revenue is estimated. In fact, one might argue for an increase in fares after electrification to recoup for service improvement. This would improve the financial benefits of the scheme even further.

The electrification of the line would lead to an amount of 'avoidable capital cost' in terms of reuse (on other lines) of the diesel locomotives currently running on the line. This is estimated as a residual value of the diesel locomotives allocated for the Cairo–Alexandria line. Information about the number, models and age of these locomotives as well as the price is obtained from Egypt Rail records. Then the amount of avoidable capital cost is estimated based on a 25-year life for diesel locomotives.

Electrification will also lead to savings in train operating costs. This comprises the difference between the cost of operating trains by diesel and electricity, and savings in lubricant and oil costs. The consumption of electric locomotives in terms of oil and lubricant is only 50% that for diesel locomotives. In addition, there would be savings in terms of fuel consumed in power generation cars, which will not be needed with electrification.

Electrification will also result in some savings in maintenance cost of locomotives which is half that for diesel. In addition the maintenance of power cars will be avoided completely.

*Railway user benefits*

The principal user benefits from the electrification of the Cairo–Alexandra line would be in time savings. As a result of speed improvement, the potential time saved on the trip from Cairo to Alexandria is 30 minutes. For the purpose of estimating these benefits, railway users are divided into two groups: the first is called 'stayers', referring to travellers using the railway line before and after electrification. The gain to them is quite straightforward. They enjoy the reduction in travel time. However, some of them are whole-distance travellers, and others make local trips. Based on the current percentages of whole-distance travellers and local trip makers obtained from ENR operation records, the time saved for stayers is measured.

The second group is called 'movers'; they transfer from road to rail with electrification. The gain to this group is less than those who were already using the line. This reflects the quantitative difference between the two modes. The travellers using the road before electrification attached some specific value to a feature of it — perhaps its relative comfort. The change of trip time by rail induces them to change mode, because the journey by rail is quicker than it was before, but they lose the relative comfort for example.

It could be argued that movers would also have some benefits in terms of changing to a safer mode of travel compared with the road. In this case, the safety issue in itself would induce switching of passengers to use the electrified railway line. The total gain to movers is, therefore, somewhat less than the change in generalised cost. According to Harrison (1974) their gain could be half that for stayers. The savings are evaluated for rail travellers (stayers and movers) using the value of time for public passenger mode recommended by the study of the transportation system in Egypt, which is based on the average earnings per working hour (JICA, 1993) after updating it to be on the same basis as 1998 prices.

*Road user and environmental benefits*

In addition to benefits to people who transfer from road to an improved rail service, there would be benefits to the remaining road travellers, that is, non-user benefits. These would consist of time and accident cost savings arising from less congested traffic conditions. Also, increased speeds on the road could marginally reduce the operating cost of private cars by reducing fuel consumption. However, this benefit is likely to be small and is not estimated.

To derive an estimate of time benefits accruing to road users, two-way 16-hour annual average daily traffic flows for 'without' the scheme are used to obtain an estimate of average speed on the Cairo–Alexandria road using a relevant speed/flow relationship. The diverting passenger trips are converted to vehicle trips by applying the current vehicle occupancy rates taken from the study of the transportation system in Egypt (JICA, 1993). Then the converted trips are deducted from the 'without' traffic flows to derive the 'with' traffic flows on the road.

The speed/flow relationship is used to obtain an estimate for average speed on the road with rail electrification. Knowing the average travel distance along the road (220 km) and average speeds for the 'with' and 'without' situations, the amount of time saved for any vehicular trip on the road can be estimated. Then, using the values of time for each vehicle category and vehicle category proportions on the road, the amount of time saved for road users over the project life is evaluated (see Table 3).

The diversion of road trips to rail would also reduce

**Table 3. Value of time for different vehicle categories in 1998 prices**

| **Vehicle category** | **Proportion of vehicle category (%)** | **Personal car unit** (PCU) **equivalent** | **Value of time** (£E/PCU/hour) |
|---|---|---|---|
| Passenger car | 23.2 | 1 | 7.819 |
| Taxi | 32.1 | 1 | 6.578 |
| Bus | 8 | 1.6 | 11.972 |
| Truck | 36.7 | 2 | 0.958 |
| Total | 100 | | |

*Source*: Values of time from JICA (1989) are updated for 1998 prices

**The costing of air pollution benefits of electrification has proved difficult, because of the difficulty of isolating the damaging health and environmental impacts of transport emissions, and the impacts cannot easily be converted to monetary values**

the incidence, and hence the cost, of accidents on the Cairo–Alexandria road. A road accident will incur some or all of the following consequences: people killed; people seriously or slightly injured; damage to vehicles; buildings or other property damaged; costs of policing; administration; and medical, pain, suffering and grief for relatives of victims. These direct and indirect consequences imply costs for individuals and society at large. Quinet has estimated the social costs of road accidents in the UK to be 1.5% of GDP in 1986 (Pearce. 1993).

There were about 27,000 road accidents in Egypt in 1998, in which 5100 people were killed and 22,000 injured (GARB, 1999). Costing accident benefits of electrification would require putting a value on the consequences of road accidents. However, the current research focused on the reduction of the number of people killed as a result of the electrification scheme.

According to the records of the General Authority of Roads, Bridges and Inland Transport, annually about 15 persons are killed on the Cairo–Alexandria road for each million of passenger car units (PCU). This rate is used, with the potential number of PCUs removed from the road as a result of the electrification, to identify the reduction in the number of people killed annually. Then, based on a value of life (estimated from the average annual earnings of potential killed people), the total accident savings are quantified.

The environmental benefit considered here is the impact of the scheme on air quality. In this context, electrification of the Cairo–Alexandria rail line would:

- reduce air pollution of the railway as a result of a transfer from diesel to electric traction; and
- reduce air pollution of the road as a result of transfer of transport demand from road to rail.

Given the potential environmental damage of transporting and storing massive volumes of fuel, it might be argued that electrification would probably lead to a reduction in the amount of disel and oil being transported and stored. So, some environmental benefits would probably emerge as a result of that. However, given the difficulty of identifying and estimating these benefits, it was not considered in this paper.

A full analysis would require that these net effects be considered in the context of complete fuel/energy production and consumption systems. The analysis has to consider not only, say, operational emissions but also emissions at the point of energy production.

It is widely recognised that rail transport, particularly with electrified track networks, consumes less energy per unit of transport than any other mode of transportation. In Japan, railways consume only 5% of the total energy consumption for the transport sector, while the passenger volume accounts for 39% and freight for 5% in 1993 (Ministry of Transport, Japan, 1995). In Switzerland, rail consumes 4% of transport energy for a market share of 13% passenger km and 42% tonne km (Hubner, 1996).

It follows that rail emissions are much lower than other transport modes, especially road vehicles. According to Asano (1993), if all freight traffic currently transported by rail in Sweden were to be transferred by road, $CO_2$ emissions would increase by approximately 70%. Table 4 shows the polluting emissions of road and rail.

The costing of air pollution benefits of electrification of the line has proved difficult. This is mainly because of the difficulty of isolating the damaging health and environmental impacts of transport emissions. In addition, the impacts cannot easily be converted to monetary values. Most environmental studies (OECD, 1988; Walsh, 1990; Schulz, 1989, WHO, 1987) concluded that the estimates of air pollution damaging costs should be treated with caution and viewed as minimum estimates.

Based on the emissions per passenger km in Table 4, rail passenger flows and the diverting trips from road to rail, the amount of emissions reduced as a result of the electrification is estimated. Using the most recent estimated damage cost of each unit of pollutants, estimated for Britain (Pearce, 1993), the benefits in terms of air pollution reductions are evaluated. It is worth mentioning that the British damage cost per unit of pollutants was scaled down by a factor of 26 reflecting the *per capita* income in Egypt compared with that of Britain as a proxy for the difference in willingness-to-pay between the two countries.

*Community benefits*

The electrification of the line has some other benefits associated with the number of trips transferred from

**Table 4. Average emissions from road and rail transport (gram/passenger km)**

| Type of emission | Road transport | | Rail transport | |
|---|---|---|---|---|
| | Private car or taxi | Bus | Diesel | Electric |
| Carbon dioxide | 126.7 | 35 | 92.1 | 68.4 |
| Nitrogen oxides | 1.16 | 0.39 | 0.88 | 0.32 |
| Carbon monoxide | 5.57 | 0.29 | 0.62 | 0.030 |
| Hydrocarbons | 0.61 | 0.06 | 0.26 | 0.001 |

*Source*: Harper *et al* (1991)

**Table 5. Summary of appraisal results of Cairo–Alexandria electrification** (30-year project life, 10% discount rate, 1998 prices)

| Items of costs and benefits | **Net present value** (£E millions) |
|---|---|
| **Costs** | |
| 1. Cost of sub-stations | 79.25 |
| 2. Cost of overhead catenary system | 171.17 |
| 3. Workshop costs | 158.49 |
| 4. Civil engineering work | 198.12 |
| 5. Signalling | 39.62 |
| 6. Electric locomotives | 177.70 |
| 7. Maintenance cost of sub-stations | 15.64 |
| 8. Maintenance cost of catenary system | 26.03 |
| 9. Cost of new coaches | 305.22 |
| 10. Operating cost of new coaches | 18.87 |
| **Total costs** | 1190.12 |
| **Benefits** | |
| 11. Increase in passenger revenue for railways | 972.98 |
| 12. Avoidable capital costs for railways (residual value of diesel locomotives) | 73.69 |
| 13. Savings in rail maintenance costs | 27.18 |
| 14. Savings in rail operating costs | 43.03 |
| **Total financial benefits** | 1116.89 |
| **Net financial benefits** | -73.23 |
| **Financial internal rate of return** | 9.20% |
| 15. Time saved for road users | 8.87 |
| 16. Road air pollution reduction | 1.40 |
| 17. Savings in road accidents | 1.62 |
| 18. Avoidable road vehicles capital cost | 87.53 |
| 19. Reduction of road vehicles fuel consumption | 71.22 |
| 20. Rail air pollution reduction | 18.93 |
| 21. Reduction in rail fuel consumption | 123.36 |
| 22. Time saved for rail users (existing and new travellers) | 457.26 |
| **Total economic benefits** | 1887.08 |
| **Net economic benefits** | 696.96 |
| **Economic internal rate of return** | 16.9% |

road to rail: avoidable capital cost of road vehicles; fuel saved of those trips previously made by road; and reduced expenditure for road maintenance and construction.

The benefits in terms of avoidable capital cost of road vehicles are derived from the potential number of passenger trips moved from road to rail, share of road passenger modes (bus, taxi), passenger occupancy rates on the road, daily kilometres per vehicle and the average economic purchase price of different types of passenger vehicles. Fuel savings are derived form fuel consumption rates of passenger vehicles, total number of passenger km moved from road to rail, and fuel price.

As far as saving in expenditure on highway construction and maintenance is concerned, given the strategic importance and traffic levels on the Cairo–Alexandria agriculture road, it was considered unlikely that significant benefits of this kind would arise. In addition, given the current growth rate of traffic on Egyptian Roads (Al-Tony and Al-Maksoud, 1999), it is unlikely that the switch of traffic from road to rail would yield any savings in road maintenance and construction costs.

## Appraisal results

Table 5 summarises the results of the appraisal.[2]

*Financial appraisal results*

As can be seen from Table 5 based on a 10% discount rate, the scheme financial net present value (NPV) would be £E –73.23m and the financial internal rate of return would be 9.2%. These results are seen to be acceptable from the analysis point of view and consistent with the results elsewhere for railway electrification schemes. For instance, the final report of the British Midland Main Railway Line Electrification Study showed that the electrification scheme achieves about 8% financial internal rate of return (WS Atkins, 1990). However, the estimation process of the financial benefits of the Cairo–Alexandria rail line are based on the current passenger tariff, so the financial results could be improved through a slight rise in rail fares, especially since the scheme would significantly enhance the quality of service provided.

*Economic appraisal results*

Evaluation of the electrification scheme on the basis of broader-based socio-economic criteria (CBA) revealed a stronger case for investment than is apparent from the application of more limited commercial criteria (financial appraisal) as shown in Table 5. The scheme achieved a positive economic NPV of £E 696.96m or about 16.9% economic internal rate of return.

*Other un-quantified costs and benefits*

*Construction delays* The construction of the fixed installations of electrification may cause some disruption of rail service prior to the introduction of the scheme, for instance, some late running due to engineering works and possible cancellation of services. These impacts were not considered in the evaluation framework. However, construction work could be phased to minimise such inconveniences, and disruptions that do occur tend to be temporary and in off-peak periods and then could probably be neglected.

*Vibration* Train movements may result in vibration nuisance; this can be either air or ground borne. Differences between electric and diesel vibration level are not significant (WS Atkins, 1990). Improved streamlining of trains would reduce air-borne vibration.

*Noise* Noise from train movements mainly arises from the rail/wheel interface, panel vibration and train aerodynamics, in the case of diesel locomotive engines. At high speeds, noise from the rail/steel interface will predominate above diesel engine noise. There is therefore little noise advantage in the electrification of a line when trains are running at high speed. However, at lower speeds, diesel engine noise will dominate over rail/wheel noise and there will be localised advantage to electrification.

## Conclusions

Traffic congestion, accidents and air pollution are serious problems in Egypt. Traffic management schemes, efficient pricing policies, and emission controls on road vehicles are effective instruments for reducing congestion and air pollution of road transport. However, they would not provide a complete solution.

Electrification of railways has many advantages for both the operator and society. An electrified rail system can have a number of operational and environmental benefits. In terms of operational aspects, it facilitates the use of high-speed, high-powered, high-acceleration and lower-noise traction motors in comparison with diesel engines.

These factors contribute to an improved level of customer service and help to improve competitiveness with other modes of transport. On the other hand, electrification helps in reducing the external costs of road vehicles through possible switching between the two modes. Then on social grounds, there will be a number of societal benefits for electrification schemes.

The application of the appraisal framework developed in this paper for the Cairo–Alexandria railway line shows that the scheme is marginally not viable on a financial basis. Since the calculations of financial benefits were based on the current fare being applied on the line, the financial results would be improved through fare increases based on the potential for a significant improvement in the quality of service provided. Examining the broad social benefits of the scheme proves that the investment is highly desirable.

Finally, the study may offer some lessons for evaluation procedures. It shows that many social and environmental costs and benefits can, and should, be included in the economic appraisal: this brings out the critical elements in the policy decision within a coherent and consistent framework. True, many assumptions about externalities were required. However, plausible and coherent results were achieved, despite the extreme difficulty of obtaining the required data. It was also possible to draw on international data to make plausible estimates of some social and environmental benefits.

## Notes

1. The research reported in this paper was undertaken as part of a research project entitled Electrification of the Traction System of Egypt Rail conducted by Technical Consultation Bureau on behalf of the Organisation for Energy Planning (TCB, 1999).
2. A more detailed analysis is available from the author.

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