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Development of technical and economical models for widespread application of magnetic levitation system in public transport

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Abstract

Magnetic levitation (maglev) is amongst the most advanced technologies that are available to the transportation industries. It has already been noticed by decision makers in many countries around the globe. Contrary to such high levels of interest, there are no practical algorithms available to the engineers and/or managers to assist them in analyzing economics of the maglev systems. Therefore, it has been the purpose of this research to find appropriate answers to such vital questions and also investigate feasibility for practical use of maglev technology in rapid transit systems. The life cycle costs (LCC) for the maglev system including the cost of initiating such projects are included in this survey and are evaluated. To serve the purpose, an algorithm is presented that facilitates the technical and economical analyses of maglev systems. The proposal for a long distance maglev system, Mashhad-Tehran (M-T), is used as a case study by using the proposed algorithm. Moreover, the cost of establishing and operating M-T project is estimated by two other different approaches. These include the already established mathematically based cost estimating method, and the cost estimations based on the international norms and standards. These standards are based on statistical (or provided) data. Such cost estimations assist verification of the proposed algorithm. Comparisons between outcomes of the three methods prove close agreement for the cost estimation by all of them. It is concluded that the proposed algorithm for implementation and operation of maglev route is practical.

Keywords: Maglev, Guideway, Life cycle cost, Mathematical models, Cost estimating method.

1. Introduction

The rapid expansion of transportation industries worldwide, including railways, and the never ending desire to reduce travel time for tradesmen, tourists, etc. have highlighted the need to resort to the advanced transit systems. Conventional railway systems have been modified to make them travel at much higher speeds. Also, variety of technologies including magnetic levitation systems and high-speed railway (HSR) systems has been introduced. Magnetically levitated trains are undoubtedly the most advanced vehicles currently available to the railway industries. Contrary to conventional railways, there are no direct contact between maglev vehicles and their guideway. Such vehicles travel along magnetic fields while enduring no friction therefore, are capable of reaching at considerably high-speeds. Trains with magnetic levitation have reached the speed of $581_{km/hr}$ under the test conditions. This has practically paved the way to manufacture super fast trains.

There are many good reasons to turn to magnetically levitated trains. By consuming lower levels of energy, lower levels of pollution, less noise emission, the maglev vehicles cause fewer disturbances to the nature and have increased compatibility with the environmental issues. Possibility of traveling on elevated guideways means less land occupation. Also, Maglev guideway has lower dead loading. These vehicles can travel at steeper gradients and are capable of traveling at higher speeds with increased accelerations. Maglev vehicles have lower static and dynamic loading, higher passenger capacity and the increased passenger comfort. Such vehicles can travel along routes with lower curve radiuses. They are reliable, reasonably safe and convenient. These are some of the benefits of maglev systems.

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Amongst the most important aspects of using the maglev trains is the possibility of traveling at 10% grades while for conventional HSR trains such as German ICE this grade angle reduces to 4%. This important aspect considerably reduces the total length of the routes for maglev trains. As a further bonus, the cost of constructing and establishing maglev routes at grades and hilly areas considerably reduces. In maglev guideway there is no such issue as access to the route infrastructure. This is achievable at no cost. There is no cost for driving the maglev vehicle because the maglev vehicle is driven automatically. There is no direct contact between the maglev vehicle and its guideway. This is equivalent to reducing the wear and therefore the total cost of maintaining the system. Generally speaking, the total cost of operating and maintaining the maglev trains is lower than the high speed trains, airplanes and intercity buses. The cost of constructing the maglev guideway compared with the HSR tracks in hilly routes is at most 9% higher [1, 2].

Maglev trains are a necessity for modern time transportation needs and vital for the future needs of railways, worldwide. Many countries around the globe are attracted to the maglev trains. This has resulted in the development of a variety of maglev systems that are manufactured by different countries. Maglev systems currently in use have comparable differences. The current models are also changing and improving. It is very important to be vigilant about the economical aspects of any major project during its planning and construction phases. Optimal use of local resources must be all accounted for. The technical and economical evaluation of the projects is a necessity to their success. It is necessary to have prior knowledge for investing into a project and then implementing its goals. Good planning makes it feasible to run the projects with reduced risks and increased return for the investment.

There is no practical algorithm that is openly available for the modeling and financial analysis of maglev systems. Searches into the current status of maglev literature, reveals the lack of open source documents for detailed planning and investment for maglev systems. It can possibly be related to the confidentiality and the desire of companies that hold such advanced technologies to keep the ownership within. An example to this is Shanghai maglev of 35_{km} length that was built by a German company and started operation since Jan. the 1st of 2004. Its' design speed is $500_{km/hr}$ with an effective speed of $431_{km/hr}$. Details of this project have never been released to the Chinese counterpart. Germany and Japan are clearly the front runners of the maglev technology. Shanghai maglev system was built by a German company called Transrapid International (TRI) (a joint venture by Siemens AG and ThyssenKrupp). After that and in 2005, China built its own maglev train. This train reached to the test speed of 150km/hr over a track length of 204m [3]. In Feb. 2006, the Chinese's government announced its intention for extending its maglev route between the cities of Shanghai and Hangzhou (the capital of Zhejiang province). This route is of 170 to 175 km in length. The project will be managed by a German consortium leaded by Siemens Company [4]. The Ministry of Railways chief planner, Zheng Jian, said in March 2010 that China had agreed to build a maglev line between Shanghai and Hangzhou, the capital city of Zhejiang Province. The line will start construction this year, Xinhua news agency reported. The new link will be 199.5 kilometers, about 24 kilometers longer than that included in the 2006 plan. The top speed of the maglev will be 450 kilometers per hour. It will take about half an hour to travel from Shanghai to Hangzhou, a trip which usually takes one and an half hours on the current service. The new line will also contain a downtown section of about 34 kilometers which is expected to connect the city's two international airports, Pudong and Hongqiao [5].

Safety is amongst the most important factors for ensuring the operational integrity of high-speed trains [6]. The high-speed maglev is one of the safest means of transportation in the world. The concept of maglev has essentially eliminated the safety risks associated with the operation of HSR systems. Compared to the operating experiences of HSR, maglev technology has a scarce record. On the other hand, the German Transrapid Test Track in Elmsland has been operating for more than 20 years and close to a million passengers has ridden around the 40-kilometer closed loop. The maglev vehicle wraps around the guideway beam and therefore is virtually impossible to derail. Redundancies achieved through the duplication of components as well as the automated radio-controlled system ensure that operational safety will not be jeopardized. The principle of synchronized propulsion on the guideway makes collisions between vehicles virtually impossible. If two or more vehicles were ever placed simultaneously in the same guideway segment, they would be forced by the motor in the guideway to travel at the same speed in the same direction. The grade separated, flexible route alignment ensures that no other obstacles can be in the way. Energizing only the section of the guideway on which the train is traveling enhances operational safety and efficiency. The maglev is absolutely weatherproof and masters wind and adverse weather easily. Regarding the aspect of fire protection the maglev meets the highest requirements of the relevant standards. No fuels or combustible materials are on board. All used materials within the vehicles are PVC-free, highly inflammable, poor conductors of heat, burn-throughproof and heat-proof. Fire proof doors can be optionally used in order to separate vehicle sections [7-9].

It is the purpose of this research to include the effects of all costs. Therefore, it will be possible to make better choices during system life cycle. In general, final goal of this research is to develop a synchronous and integral methodology for evaluation of real costs of maglev life cycle. These costs include investment costs, costs due to interaction between guideway and maglev vehicles, and environmental costs. This process can lead to a proper tool for producing precise and reliable algorithm that includes importance of the guideway and its governing conditions and the allocated financial support. Analysis of LCC is an important tool for such algorithm. Upon precise and logical simulation of LCC such a tool can be used as Decision Support System (DSS) for managers.

The life cycle costs including the costs of establishing maglev systems in different parts of the world are studied in this research. The same costs are then calculated for executing same projects by different choices of using local or international contractors, or by using mixes of such contractors. In what follows, mathematics is used to propose an algorithm to analyze technical and economical aspects of maglev projects. Investment costs, time for return of capital, annual number of passengers, etc. are also included in the analysis. Also for the same reasons and for accurate evaluation of the cost of constructing and implementing maglev systems in Iran, a case study is exercised. This includes using in house developed algorithm for technical and economical feasibility analysis, for Mashhad-Tehran maglev system (M-T). The followings are included in this study, cost estimating method, number of proper tracks that are to be constructed for the route, selection of proper vehicles and their passenger capacity, estimation of distances to travel and optimum design speed for the vehicle, technical and economical analysis, how to be competitive with air travel, estimation for annual demand to use the system and annual traffic load, estimation for total travel time, etc. Results prove applicability and practicality of the proposed algorithms.

2. Life cycle cost (LCC)

LCC can be interpreted as "evaluating cumulative costs of a product during its service life". General characteristic of LCC is to provide a clear relation between investment and operation decisions. It also includes measuring total cost of delivering a product. This total cost takes into account all procedures for producing, installing, operating and abandoning a product. Eventually, it takes account for the value of scrapped. The philosophy behind studying LCC for maglev systems is that it encourages managers to act, step by step, toward pre-active processes regarding operation and also to have better understanding for costs incurred. This study has an exploring nature. In other words, the purpose of it is that the decision makers with the help of facts and contents of analyses recognize and accept strategies for design and operation by considering the effects of life cycle. Strategic managing of maglev systems include three important periods. It includes implementation of new systems, operating the system and replacing the investment. Such periods are presented in Figure 1.

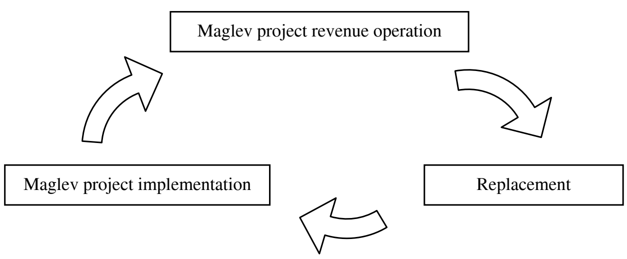

Fig. 1. Life cycle periods for the maglev systems

The guideway and its functional components are designed for a useful life of 80 years [10]. Therefore, for a maglev system, the preliminary period is much shorter than the operation period. Its operation period generally lasts for 80 years. Also, the third period that is called abandoning or replacement period, is generally short. As LCC models are specified on the basis of annual investments, considering time period for system life, normally the first and third periods are considered as one year in the calculations. External costs are normally considered during the 2nd period of the system life, during its operation period, and are implemented in cost modeling. Looking into new investments, like any other industry that relies on infrastructure, maglev systems have the same problem of having to spend big chunk of investment during life cycle for preliminary investments. In such a way, that by increasing preliminary investment, operation costs decrease. Therefore, the need to reach to a balanced condition in order to optimize system LCC becomes specifically important. To reach to this goal, many factors need to be considered. Resources are usually naturally dispersed therefore, need to be used to the best possible ways. The possibility of comparing initial investment against future savings is one of the principals of predicting LCC. This is presented in Figure 2 for a maglev project. As presented in Figure 2, type of spending for assets during different stages of possession and operation on one hand and budget limitations on the other hand result in total cost for assets possession and setting the limit for lowest LCC. Processes for the analysis of maglev LCC are presented in Figure 3.

Elements that are selected as costs are payments that are made during system life time or are related to it. These elements must include all payments from the time of possessing the system till the time it is cast out or substituted.

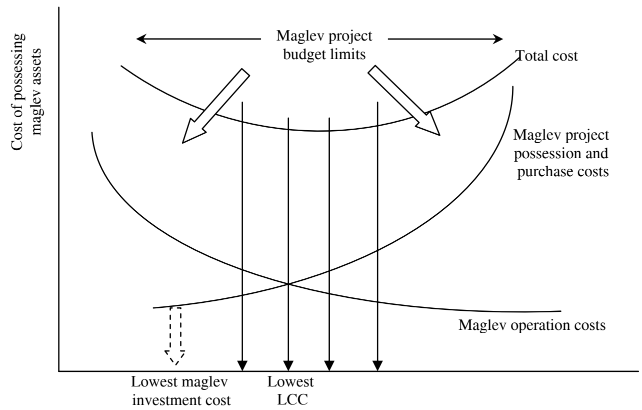

Fig. 2. Interchange of the costs during investment life cycle for the maglev project

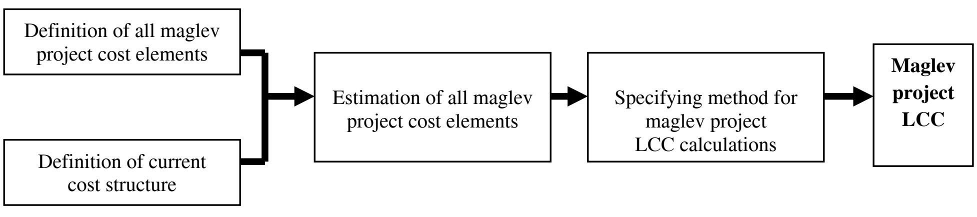

Fig. 3. The cost processes for the maglev project life cycle

The costs inflicted on managers include investment and operation costs. It is very hard to collect all real cost data. Therefore, it is emphasized to collect some statistical data in order to back up LCC calculations. External LCC is amongst other cost items that are incurred by system managers. It means that normally those parameters such as investment, revenue operation, delay and scrape are included in system LCC, and environmental costs are less attended to. This happens while this parameter has effective role in system LCC and needs to be included in order to draw a clear and precise view for modeling costs.

The meaning of cost structure, is to specify cost groups in order to recognize and appreciate inter relations between all such components and eventually reaching at optimized LCC. Nature of such structure depends on parameters that are needed to study LCC. In order to estimate each element of costs one needs to consider description of the element and structure for the cost.

An important step for analysis of LCC is to use powerful databases that contain time, finance and quality information related to reliability, benefiting from the capacity and operation processes. This should result in more precise recognition of the relations between external costs including environmental effects. After estimating all cost elements and specifying methodology for LCC calculations, it becomes feasible to obtain LCC. Figure 4 presents a model for maglev LCC.

There is no doubt that maglev projects are huge and very important. Maglev is considered as one of the safest and most effective transportation systems. Therefore, it is necessary to workout all cost involved before implementing and operating maglev trains. Competition in transportation and multiple choices to reach to higher and more economical shares of the market, added to the pressure from governments, have forced the managers to think of optimizing allocated costs. They also need to think of more stability by using stable cost mechanisms.

Guideway is the structure that maglev trains run over it. Guideway is vital for the design of maglev system and holds big share of costs for the system. Maglev train levitates over single or double track guideway. Guideway can be mounted either at-grade or elevated on columns and consists of individual steel or concrete beams. Elevated guideways occupy the least amount of land on the ground. Moreover, with such systems there is guarantee of meeting no obstacle while along the route. To guarantee safety for maglev trains necessitates guarantee that there will be no intersection between guideway and other forms of traffic routes. To serve the purpose, general proposition is to have elevated guideways [4]. The cost of implementing and operating maglev projects in some parts of the world are presented in Table 1. The cost is evaluated per kilometer of single track elevated guideway.

According to international norms, cost of implementing civil projects by employing local companies and contractors is about 50% of what it can cost by employing foreign contractors [19]. This may include construction of structural parts such as guideways. It is worth nothing that supply of electric energy for maglev vehicles can provide another big chunk in cost saving, if provided locally. In this regard, some of the maglev systems in Table 1 are investigated. Row 5 in Table 1 shows that 61% of the items that are related to guideway structure and supply of energy can be reached by domestic means. In other words, by employing domestic forces there will be 30% reduction in total cost. In this case, the total cost dropped from \$11m to \$8m. In the 1st row, cost of guideway that is structural cost of maglev, is 62% of the total cost of the project [11]. This means that apart from the other parameters that domestic forces can fulfill in parts or in total, about 62% of the project can be completed locally. Meaning, there is 31% reduction in the total cost by employing local forces and the cost drops from \$9.5-11.5m to \$6.5-8m. In row 6, 81% of the project items are fulfilled by the local forces. By employing domestic forces, there is 40%

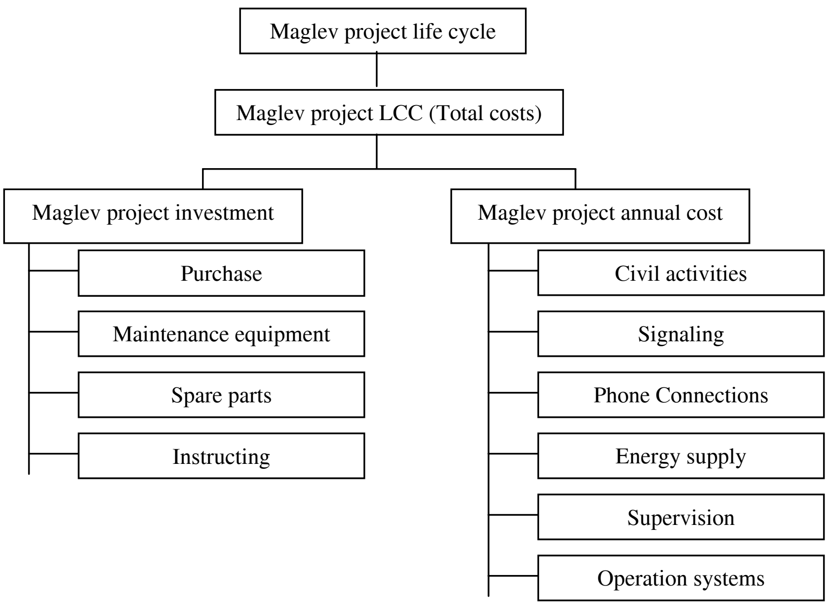

Fig. 4. A model for the maglev project life cycle cost (lcc)

Table 1. The cost of constructing and implementing 1 kilometer of single track elevated guideway

	Maglev System	Route Length (km)	Cost per kilometer ($m)	Structural Parts	Other Equipment	Supply of Energy	Total %	Share of Domestic Force %	Final Cost ($m)
1	Colorado, US [11]	252.6	9.5-11.5	85	10	5	100	-	6.5-8
2	Maglev 2000, Type 1[a], US [12]	-	10.49	84	2.55	13.45	100	68	7
3	Maglev 2000, Type 2[b], US [12]	-	11.37	85	2.5	12.5	100	71	7
4	AMT[c], EMMI[d], Los Angeles [13]	240	-	53	21	26	100	79	-
5	US Government [14]	-	11	50	39	11	100	61	8
6	California, US [14]	639-664	13	63	8	29	100	81	8
7	Southern Cal-Las Vegas [14]	368	9	-	-	-	-	-	-
8	San Francisco-Los Angeles [14]	737-1082	13-14	-	-	-	-	-	-
9	Chennai-Bangalore, India [15]	360	6.25-6.5	65	-	-	-	-	-
10	GA[e], US [12]	-	10	-	-	-	-	-	-
11	AMT, Edgewater, Florida [16]	-	9.5-12.5	-	-	-	-	-	-
12	Maglev 2000 [17]	-	7.5				-	-	-
13	Maglev 2000 [18]		9-12.5						
14	AMT [18]	-	6-7.5	-	-	-	-	-	-
15	AMT, ODU[f], Virginia [18]	-	10-13	-	-	-	-	-	-
	Average	-	10	-	-	-	-	-	7

(a) 20 metric ton vehicle
(b) 40 metric ton vehicle
(c) American Maglev Technology (AMT)
(d) Environmental Mitigation and Mobility Initiative (EMMI)
(e) General Atomics (GA)
(f) Old Dominion University (ODU)

of total cost reduction and the costs drop from $13m to $8m. Row 8 of Table 1 is for maglev system capable of reaching at speed of $320_{km/hr}$. This was selected by the Californian Intercity High-speed Rail Commission. Assessment results prove that profitability with total length of 1082_{km} is more compared to total length of 737_{km} [14]. For maglev system in row 9 of Table 1, costs are evaluated based on German Transrapid International (TRI) maglev systems. For this case, 65% of total cost belongs to guideway [15]. Therefore, according to above discussions and the results presented in Table 1 the average cost per kilometer for construction of single track elevated guideway without resorting to domestic forces is estimated to be $10m while use of local forces reduces this cost to $7m.

Shanghai maglev project was contracted by TRI and became operational since Jan. 2004. The Shanghai maglev with double track elevated guideway, connects Lang Yang Station in Shanghai trade centre to Pudong International Airport. This maglev train has effective speed of $431_{km/hr}$, average speed of $268_{km/hr}$ and maximum speed of $501_{km/hr}$. On Feb. 2006, Chinese government announced that they decided to extend Shanghai maglev to Hangzhou city the capital of Zhejiang province. The contract was singed with a German consortium lead by Siemens [4]. The cost of construction and implementation of double track guideway per kilometer by employing local forces was estimated to be $12.5m based on TRI and $13m based on Shanghai-Hangzhou project [15]. EMMI maglev project that has been started by US AMT maglev system on 2007 includes double track guideway with operating speed of travel equal to $320_{km/hr}$. Cost of construction and implementation of double track elevated guideway per kilometer, by employing domestic forces, was $10m [13]. Considering some common parts between single and double track guideway, such as infrastructure, cost of construction and implementation of double track elevated guideway is less than twice the cost of single track guideway. On the average, the cost of such project is estimated to be $17m without employing local forces and $12m by employing local forces.

3. Mathematics of Maglev Economics

In recent years, transportation LCC methods have found enormous acceptance, throughout the world. Output from analysis based on such methods provides vital input for the strategic decisions to be taken by the managers. These inputs can be used to optimize long term investment strategies. Such optimization task has to take into account design purposes for the infrastructure that is supposed to provide a strong foundation to support the investment. It needs also to take into account applications for such investment, ways of developing it, evaluation of its performance and attempts to benefit from experiences of related strategies.

LCC analysis is an economical process that takes place to evaluate total cost of possessing maglev, for the whole duration of its life time. In economical theories, usually elements of cost change according to the output from economical analysis and investment decisions are considered separately. LCC principals consider variable costs and provide background for long time investments, simultaneously. This relation is presented in the following equation:

$$LCC = I + [CC+OC+DC+EC] \quad (1)$$

In Eq.(1) "I", stands for initial proposed investment, CC represents capital costs, OC is for operation costs, DC is for delay costs and EC is for environmental costs. The 1st part of this equation represent net investment while other terms inside the brackets represent variable costs of providing services for specified levels of production, capacity and quality. All parameters that are acclaimed with current values can change according to interest rate and the selected time periods. Annual LCC can be calculated by the following equation.

$$LCC_{annual} = I \times k / [1-(1+k^{-m})] + [ACC + AOC + ADC + AEC] \quad (2)$$

Where ACC represents annual capital costs, m represents years of operation, k is rate of annual return that is calculated by subtracting rate of reduction from interest rate, AOC is for annual operation costs, ADC is for annual delay costs and AEC is for annual environmental costs.

Traffic volume can be calculated by using Eq.(3):

$$T_v = K \frac{f(absorbing \quad parameters)}{g(non \quad absorbing \quad parameters)} \quad (3)$$

In this equation, T is for traffic between geographic districts i&j, f is a function of absorbing parameters, g is a function of non-absorbing (resistance) parameters between i&j and k is a model adjustment factor. If population is considered as an absorbing parameter and costs considered as non-absorbing parameter, traffic between two geographic districts i&j can be calculated with the following equation:

$$T_v = K \frac{P_i P_j}{(Cg_v)^{\gamma}} \quad (4)$$

Where Pi is population in district i, P_j is population in district j, Cg_v is total transport cost in districts i and j and γ is traffic flexibility related to total cost. Eq.(4) can be adjusted by calibrating constant value of k and flexibility (elasticity) parameter γ. After applying changes to the delivered services, change in traffic δT_v can be related to total cost by using Eq.(5):

$$\frac{\delta T_v}{T_v} = \gamma \frac{\delta Cg_v}{Cg_v} \quad (5)$$

Transport tariff T_p in \$m per person kilometer is equal to:

$$T_p = \frac{C_e^{lc} \times 10^3}{\sum_{1}^{cr} P_p^t \times L} \quad (6)$$

Where p_p^t is volume of passenger traffic for calculated current year, L is the distance in kilometers that is traveled by passengers in current year, number 1 refers to the 1st year of operating the track, cr is the year of return of capital and C_e^{lc} is total sum of investment costs in \$b.

Considering the fact that operations do not need to start after completing construction of total length of the track but starts after finishing acceptable lengths of track, therefore total sum of investment costs can be calculated by using Eq.(7):

$$C_e^{lc} = \frac{\sum_{0}^{lc} B_e^t \times \lambda_t^c + \sum_{p+1}^{lc} O_e^t \times \lambda_t^c}{1000} \quad (7)$$

Where C_e^{lc} is minimum total cost of investment required to construct and operate total length of delivered track without resorting to domestic force in \$b. Zero refers to the initial year of construction, lc represents the last year that track construction finalized, p is the number of years before completion of each part of the track and start of its operation, B_e^t is construction and implementation costs of track without resorting to domestic force for calculated current year in \$m and can be calculated by Eq.(8).

$$B_e^t = [D \times (C_d)_e] + (C_s)_e \quad (8)$$

Where D is minimum distance between origin and destination in kilometers, $(C_d)_e$ is minimum cost for construction of each kilometer of single track or double track guideway including all equipment and accessories without resorting to domestic forces in \$m and can be calculated by Eq.(9).

$$(C_d)_e = K \times n_g \times (C_g)_e \quad (9)$$

Where n_g is number of guideway tracks in the route. It can be (n_g= 1) for single track and (n_g= 2) for double track guideway. K is non-dimensional modification factor for calculating cost of guideway and $(C_g)_e$ is minimum cost of constructing every kilometer of single track guideway including all equipment and accessories, without resorting to domestic forces in \$m. Cost of constructing double track guideway, is not double the price of construction for single track guideway. This is a result of sharing some common items between single track and double track guideways, especially at infrastructural level. Therefore, one will end up with:

$$K = 1 \quad if \quad n_g = 1$$
$$K = 0.83 \quad if \quad n_g = 2 \quad (10)$$

Where $(C_g)_e$ is cost of constructing stations without using domestic forces in \$m. O_e^t is operational costs without using domestic force for calculated current year, in \$m.

Also C_f is cost of rolling stock in \$m that can be calculated by using Eq.(11).

$$C_f = (n_v)_{av} \times C_v \quad (11)$$

Where $(n_v)_{av}$ is number of trains available in the fleet that is related to every section of track before completion and C_v is cost of each maglev vehicle in \$m.

Number of maglev vehicles along the route (N_z) is equal to:

$$N_z = \frac{Q_h}{q_z} \quad (12)$$

Where q_z is maximum passenger capacity per vehicle, Q_h is number of passengers per hour at peak hours that can be calculated by Eq.(13).

$$Q_h = \frac{P_p^m \times K_Q}{365} \quad (13)$$

Where $P_p{}^m$ is the annual number of passengers, K_Q is the ratio of the passengers' volume per hour in peak hours to the total number of average passengers per day. 365 days are accounted per year.

Real cost for the rolling stock is equal to:

$$M_Z = N_Z^m \times K_r \quad (14)$$

Where $N_z{}^m$ represents the number of vehicles at service for the peak hours for the duration of evaluation time (e.g. 1 year) and K_r is a reduction factor related to the number of vehicles not in service. λ_t^c is a time factor. It is related to the time interval between constructions of different parts of the track that take place to form the whole length of the track. This time factor can be calculated by the following equation.

$$\lambda_t^c = \frac{1}{(1+DF)^t} \quad (15)$$

Where t is the operation time for each part of the track per year. DF is a reduction factor that is related to different times of investment between constructions of different parts of the total track. It can be calculated by Eq.(16).

$$DF = \frac{1}{(t_{cr})_e} \quad (16)$$

Where $(t_{cr})_e$ is the time for return of capital without resorting to domestic forces per year.

Figure 5 presents results of evaluations that have taken place to set optimum transportation tariff for maglev systems.

The lower point indicated by letter "I" on the abscissa of Figure 5 represents cost of initial investment that was accounted for when track construction first started. For the obvious reason of the tracks not being operative, revenue at this time is nil. Also, the upper point on the abscissa of Figure 5 denoted as $C_e{}^{cr}$ and $(U_e)_y$ represents total cost of investment and total revenue, respectively, at the time of return of capital without resorting to domestic forces. As presented in Figure 5, at the time of return of capital $(t_{cr})_e$ cost of investment is equal to revenue. Annual revenue can be calculated by the following equation.

$$(U_e)_y = \frac{(n_p)_y \times (C_T)_{ow}}{ER} \quad (17)$$

Where $(U_e)_y$ is annual revenue in \$b, $(n_p)_y$ is the estimated number of passengers per annum, $(C_T)_{ow}$ is the cost of one way ticket (in local currency) and ER is rate of exchange to US dollar.

$$(t_{cr})_e = \frac{C_e}{(U_e)_y} \quad (18)$$

As time goes on and if there is economical justification, revenues will exceed investment costs and acceptable profitability will follow. Figure 6 presents results of evaluations regarding as how the expansion of route length would affect the whole system for final accomplishment of the track.

The curves in Figure 6 present total cost of investment for system and the invested cost from the time construction of the main track started. C_e^i is common point between above mentioned costs in \$b, $(T_i)_e$ is the time to reach to this common point in years and $(T_{cr})_e$ is the time in years for the return of capital without resorting to domestic forces.

All relations presented in passed sections can also be used to evaluate costs by resorting to domestic forces. The difference is that in case of using services of domestic companies and employing domestic contractors in parts of the project, implementation costs for construction projects by domestic companies and contractors will be reduced compared to international norms. Therefore, one will end up with:

$$(C_g)_i = (C_g)_e \times [1-(S_C \times I)] \quad (19)$$

So that, always:

$$(C_g)_i < (C_g)_e$$

Where S_C is part of guideway construction activities and its equipment and accessories that can be supplied by domestic forces. It is estimated to be about 60%. "I" in percentage, is profit resulted by employing local forces at all places where they can perform. As explained earlier, it amounts to about 50%.

$$(C_g)_i \cong (C_g)_m < (C_g)_e \quad (20)$$

Where $(C_g)_m$ is minimum cost of constructing every kilometer of double track guideway including all equipment and accessories while resorting to local forces, in \$m. All

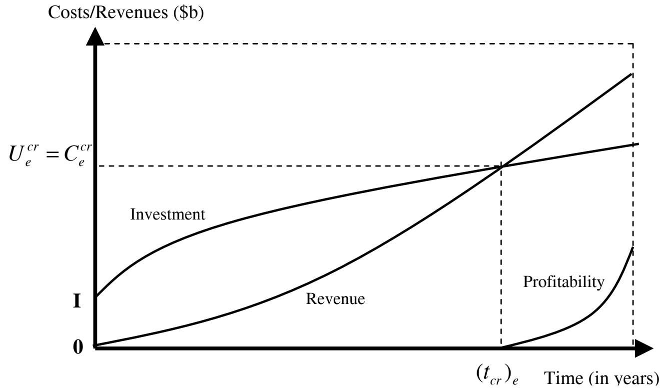

Fig. 5. The optimized transportation tariff for the maglev route

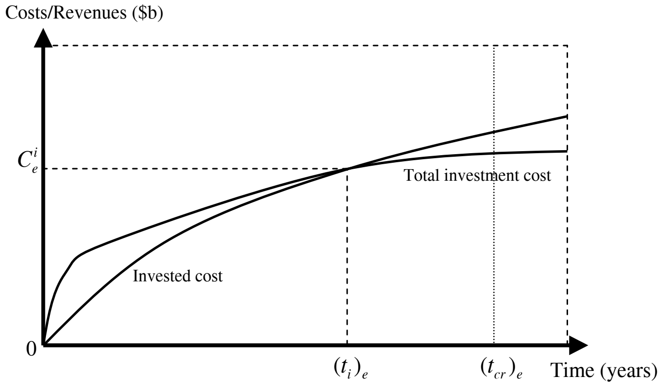

Fig. 6. The effect of expanding the maglev route length on the system

$(C_g)_m$ calculations are based on precise cost estimating method including details of all guideway accessories.

Generally, guideway and its main components are designed and constructed for a life time of 80 years. Number of permissible traffic over guideway is 130 times per day, equivalent to 47450 trips per year and 3.8m trips of the fleet during guideway life time [10].

$$(C_p)_{av} = (n_v)_{av} \times (n_t)_d \times (C_p)_v \times 360 \quad (21)$$

Where $(C_p)_{av}$ is guideway available capacity for passengers per year, $(n_t)_d$ is current number of trips by each vehicle over each guideway per day and $(C_p)_{av}$ is the capacity for seated passengers per train.

$$(C_p)_{al} = (n_{al})_d \times n_g \times (C_p)_v \times 360 \quad (22)$$

Where $(C_p)_{al}$ is maximum permissible capacity of guideway for passenger transport per year, $(n_{al})_d$ is number of permissible trips over each guideway per day. Recommended value for $(n_{al})_d$ is 130.

$$(C_u)_{av} = \frac{(n_v)_{av} \times (n_t)_d}{(n_{al})_d \times n_g} \times 100 \quad (23)$$

Where $(C_u)_{av}$ is part in percentage of guideway capacity that is used.

Many construction projects do not achieve all their intended goals. Such failure could be realized in terms of severe project delay, cost over runs and poor quality. The presence of risks and uncertainties inherent in project development and implementation plays significant role in such a failure inherent in all stages of project (i.e., planning, bidding, contracting and construction stages). Thus, there is a considerable need to incorporate the risk management concepts into construction practice in order to enhance the performance of the project [20].

Risk of investment can also be calculated by the following equation:

$$R_j = R_f + \beta(R_m - R_f) \quad (24)$$

Where R_f is return without risk, R_j is return for accomplishing the project, β is the systematic risk (political factors, economical factors, etc.) and R_m is return from investment market.

Cash flow forecasting is an indispensable tool for construction companies, and is essential for the survival of any contractor at all stages of the work. The time available for a detailed pre-tender cash flow forecast is often limited. Therefore, contractors require simpler and quicker techniques which would enable them to forecast cash flow with reasonable accuracy [21]. By using net current plan value (NPV), one can compare input and output cash flow by applying timely money value. In other words, net current value, is the difference between current values for input cash flow and its initial investment or generally is the difference between current value of input cash flow and output cash flow of the project.

$$NPV = PV - 1 \rightarrow PV = \sum_{t=0}^{n} \frac{CF_t}{(1+i)^t} \rightarrow NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+i)^t} - 1 \quad (25)$$

If cash flows are on installments, current net value is calculated by the following equation.

$$NPV = CF_t \times PVIFA_{i,n} - 1 \quad (26)$$

Where *CF* is the amount of each cash flow (annual income) and *PVIFA* is the evaluated value.

The current rate for calculating current value of future cash flow is rate of capital cost or minimum rate of expected return. If *NPV* turns to be positive then the project will be selected. In between projects that have same applications, project with highest *NPV* will be selected.

Profitability index or the ratio of profit to cost is a ratio that is obtained by dividing current value of future cash flow to the cost of investment:

$$PI = \frac{\sum_{t=1}^{n} \frac{CF_t}{(1+i)^t}}{ICO} \quad (27)$$

A project will be selected if its PI is greater than one ($PI > 1$), otherwise it will be rejected. Also, if it happens that PI is exactly equal to one (PI=1), decision makers will be indifferent in the selection or rejection of the project.

If *NPV* in a project is positive it means that *PI* is greater than one (PI > 1).

$$\begin{aligned} NPV > 0 &\Longrightarrow PI > 1 \\ NPV < 0 &\Longrightarrow PI < 1 \\ NPV = 0 &\Longrightarrow PI = 1 \end{aligned} \quad (28)$$

When comparing projects, the project with greater value for *PI* will be selected. In this case, it is not necessary that *PI* should be greater than one.

4. Case study for Mashhad-Tehran maglev system

Maglev tracks are normally established in sensitive and important routes. Origin and destination for maglev tracks have traditionally been the capital cities, major trade cities or international airports [22]. In Iran, major travel directions that also cover long distances lay between the cities of Tehran & Mashhad and the cities of Tehran & Tabriz. Traffic wise, the routes for accessing the cities of Tehran, Mashhad and Tabriz have always had the highest priorities in the minds of transportation authorities. Mashhad holds a sacred place and is the second pilgrims' destination in the Islamic world. Annually more than 12m pilgrims travel to Mashhad. It is considered as the most attractive destination for religious tourism in Iran. Average travel time between Tehran and Mashhad by using traditional trains is about 11 hours [23].

M-T double track guideway is supposed to start from Mashhad in Razavi Khorasan province and by going through the city of Shahroud enters Tehran province. With maglev guideways there is the possibility of planting horizontal and vertical curves with the minimal radius possible. Moreover, maglev vehicles can travel at steeper grades compared to other types of railway vehicles. Such choices provide the opportunity for shortening total maglev route length compared to conventional and HSR systems. Estimated length of M-T guideway is 820_{km}. Travel time for this distance at a speed of $500_{km/hr}$ is about 2 hours. Air travel time between Tehran and Mashhad is approximately one hour. In comparison and by including all delay times associated with air travel, travel time with maglev trains is very tempting.

Generally, fatality statistics associated with railway transportation is one passenger per billion. The same statistics for air and road traffic is 25 and 100 fatalities per billion, respectively. Annual road fatalities in Iran are approximately equal to the sum of fatalities reported by European Union and Turkey, together. Road fatalities in Iran exceed average number of annual losses during the last imposed war. It is equal to the losses of lives that occurred during the devastating earthquake in the city of Bam in 1999. Road casualties' costs to this nation are about $7b, per annum.

Trade sanctions over the country have become another bottle neck for the nations' transportation systems. It also blocked purchase of planes and air navigation systems and equipment. During the last two decades there have been about 20 fatal plane crashes in Iran. Per capita investment for air transportation systems and their maintenance costs are many folds that of maglev systems. Planes fuel and therefore energy consumption is many times that of maglev systems. Maglev trains, as the most advanced technology in railway transportation while using advanced control and safety systems have never had such causalities reported, during their operation. On the other hand, stagnant demand for domestic flights between the years 1995 to 2004, international sanctions, failure in performing timely flights, loss of public confidence, repeated plane crashes during 2008, etc. have caused huge reduction in the number of air travelers to/from Tehran. This is while majority of travels, by using different means of transport, in this country happen between Tehran and the major cities of Mashhad, Tabriz, etc. It is evident that by considering travel safety issues, equality in fare, and also total travel time, there is close rivalry between maglev trains and air planes.

Shanghai maglev trains, as a result of passing through swamp lands encounter weak infrastructure layers in parts of their routes and have to reduce speed in such zones. German magelv trains between Munich and Franz-Josef airport go through tunnels in 22% of the total length of its route. Consequently it has to travel at lower speed while going through such sections. The proposed maglev route between Mashhad and Tehran comprises of 93% flat lands, 4% rising ground and 3% mountainous areas. This means that there is no need for this train to reduce speed in some sections of the route and it can continuously travel at over 500km/hr. TRI with ElectroMagnetic Suspension (EMS) systems possesses TR01 to TR09 maglev trains. TR08 trains are used for Shanghai project and TR09 trains are used for Munich project. TR08 consists of 2 to 10 car bodies. Shanghai Maglev Train (SMT) of TR08 type consists of 5 car bodies with the capacity of carrying 440 passengers per car body. TR08 is also the proposed vehicle for M-T project.

Maglev is one of the first transportation systems to be specially developed to protect the environment. The system can be co-located with existing transportation corridors and needs a minimum amount of land for the support of guideway beams. Use of elevated guideway minimizes disturbance to existing land, water and wildlife, while flexible alignment parameters allow the guideway to adapt to the landscape. Compared to roads or railway lines, especially the elevated guideway does not affect wildlife movement. Even the ground-level guideway allows small animals to pass underneath due to the clearance planned under the guideway support surface.

Interaction between transport planning, land use planning and regional economy is highly complex. The numerous feedback loops within and between transport, land use and economy are effective on different temporal and spatial levels. Land use is the key for transportation systems to be sustainable in the future [24]. Compared to all other land-bound transport systems, the maglev requires the least amount of space and land. The land areas required for a ground-level double-track by either maglev or HSR are about similar so they are 14 m^2/m and 12 m^2/m, respectively, but for an elevated double-track guideway, approx. 2 square meter of land is needed for each meter of guideway [10]. Considering the densely populated and limited land resources, an elevated structure is a preferred choice.

As consumers of energy, the transportation sectors are vulnerable to environmental and global warming concerns and the increasing volatile oil market. Reducing dependency on foreign oil is also an important criterion. The maglev consumes less energy per seat-mile than HSR trains due to the utilization of lightweight materials and improvement in the advanced technology [8]. The system of the external power supply over the contact rail causes higher investment and operational costs. The energy costs of the maglev despite higher design speed, is lower than that of German ICE3 HSR train [25]. The maglev vehicles running at 400 km/h have lower environmental impact indicators, such as system energy consumption, waste gas discharge, site area and the like, than the ICE trains running at 300 km/h [26].

As maglev is electrically powered, there is no direct air pollution as with airplanes and automobiles. The maglev causes lower CO2 emissions. It is also easier and more effective to control emissions at the source of electric power generation rather than at many points of consumption. Maglev is the quietest high-speed ground transportation system available today. Due to its non-contact technology, there is neither rolling nor gearing or engine noise. The frictionless operation of maglev reduces vibration and maintenance resulting from wear. Comparing the noise levels at different speeds, maglev technology is much quieter than HSR trains. For example, TR07 can travel about 25 percent faster than existing HSR trains before reaching the peak noise restrictions of 80 to 90 dB(A). Such an advantage in speed will yield reduced trip times along noise-limited routes, which is most urban areas. The fundamental reason is that maglev operation does not produce any rolling, gearing, or engine noises. At speeds up to 200 km/h, the noise level compared to other noises from the surroundings can hardly be heard. At 250 km/h, the pass-by noise level is 71 dB(A) and, from 250 km/h upwards, the aerodynamic noises (wind noise) begin to dominate the noise level. The result is that, at a speed of 300 km/h, the system is no louder than a light rail vehicle and, at 400 km/h, the noise level can be compared to a conventional train traveling at around 300 km/h. Even when at "respective" high speeds, data also indicates that maglev is 5 to 7 dB(A) quieter than HSR [8, 10].

All elements and equipments for double track elevated guideway suitable for Mashhad-Tehran route are included in its cost estimating analysis. Ecological conditions of the proposed route, technological principals and related international standards and costs are also considered for the design proposal. Proposal for M-T maglev is an EMS system with an elevated concrete U-girder guideway. This guideway with structural continuity in the deck-shaped section is of single-span type girder. Estimated guideway dimensions are, span of 24.82m , width of beam 2.8m , height of cross section along the span 2m and height of cross section at the supports 2.04m. Cost estimating for guideway for the proposed route is in compliance with its execution plans [27]. Table 2 presents estimations for infrastructural (earthworks + foundation) and structural (guideway + columns) activities. All calculations that are presented in Table 2 are based on cost estimating method. Results of technical and economical estimations for M-T maglev system by using the proposed algorithm are presented in Table 3 to Table 5. In Table 5, it is shown that this system with 32 trains in the fleet and by using 50% of its capacity is capable of moving 20m seated passengers, equivalent to 1/4 of the country's population, per year. At its full capacity, it can transport half of the country's population between Tehran and Mashhad, annually.

5. Conclusions

With maglev guideway it is possible to reach to minimal radiuses for horizontal and vertical curves. A maglev vehicle can also travel at steeper gradients compared with other railway vehicles. This considerably reduces the total length of the track for maglev routes compared to the conventional and HSR systems. The possibility of traveling with higher grade angles also reduces the number of tunnels that are required to travel through the mountainous areas. This can also shorten the total length for the maglev route. Therefore, construction of the maglev routes in hilly areas, in addition to many other advantageous of these systems, can be considered as an attractive choice for the transportation industries. Majority of long distance travels inside this country happen between the cities of Tehran & Mashhad and the cities of Tehran & Tabriz.

Table 2. The estimated minimum cost of construction per kilometer of the double track guideway

Item	Symbol	Value	Unit*	Share (%)
Guideway' Concrete	GC	0.300	\$m	6.25
Column' Concrete	CC	0.080	\$m	1.66
Guidway' Bars	GB	1.100	\$m	23
Column' Bars	CB	0.800	\$m	16.6
Foundation' Concrete	FC	0.060	\$m	1.25
Foundation' Bars	FB	0.400	\$m	8.33
Guideway upper Surface Painting	GP	0.070	\$m	1.46
Foundation Formwork	FF	0.050	\$m	1
Column Formwork	CF	0.030	\$m	0.625
Guideway Formwork	GF	0.300	\$m	6.25
Earthworks with Machineries	EW	0.020	\$m	0.416
Loading of Earthworks Products	LE	0.020	\$m	0.416
Distributing, watering, leveling, regulating and pounding soil layers	EO	0.030	\$m	0.625
Foundation Work	FW	0.020	\$m	0.416
Levitation Rails	LR	0.600	\$m	12.5
Bearings	B	0.300	\$m	6.25
Guideways' stirrups	GS	0.400	\$m	8.33
Columns' stirrups	CS	0.100	\$m	2.08
Foundations' stirrups	FS	0.080	\$m	1.66
Total	T	4.8	\$m	100
Structural Share of Guideway	SS	60	%	60
Total Cost (without Adjustments)	TC	8	\$m	
Total Cost adjusted for (loyalty factor + workshop mobilizing factor + locality factor)	TCF	11.4	\$m	

*Multiply by 1000 to convert to local currency in Tommans.

Table 3. Parameters for constructing the double track guideway without resorting to the domestic forces

Parameter	Symbol	Value	Unit
Minimum Distance between Origin and Destination	D	820	km
Guideway Cost Correction Factor	K	0.83	-
Number of Guideways for the Route	n_g	2	-
Minimum Cost for Constructing Stations (with Two Stations at Origin and Destination)	$(C_S)_e$	60	\$m
Minimum Cost per Kilometer for Constructing Single Track Guideway with all Equipment and Accessories	$(C_d)_e$	10	\$m
Number of Maglev Vehicles Available in the Fleet	$(n_v)_{av}$	32	-
Cost of each Maglev Vehicle	C_v	20	\$m
Fleet Cost	C_f	640	\$m
Minimum Total Cost of Construction	C_e	14	\$b

Table 4. Parameters for constructing the double track guideway by resorting to the domestic forces

Parameter	Symbol	Value	Unit
Minimum Fleet Cost (Including Vehicles)	C_v	0.64	\$m
Minimum Distance between Origin and Destination	D	820	km
Guideway Cost Correction Factor	K	0.83	-
Number of Guideways for the Route	n_g	2	-
Minimum Cost for Constructing Stations (with Two Stations at Origin and Destination)	$(C_S)_i$	40	\$m
Minimum Cost per Kilometer for Constructing Single Track Guideway with all Equipment and Accessories	$(C_d)_i$	7	\$m
Number of Maglev Vehicles Available in the Fleet	$(n_v)_{av}$	32	-
Cost of each Maglev Vehicle	C_v	20	\$m
Fleet Cost	C_f	640	\$m
Minimum Total Cost of Construction	C_i	10	\$b

Table 5. Oher parameters related to the construction of the double track guideway

Item	Symbol	Value	Unit
Estimated Number of Passengers per Annum	$(n_P)_y$	20^7	Persons
Cost of One-way Ticket	$(C_T)_{ow}$	34.3	\$
Exchange Rate from \$US to Local Currency (Tomman)	ER	1000	-
Annual Revenue	$(U_e)_y$	0.686	\$b
Time before Return of Capital without resorting to domestic forces	$(t_{cr})_e$	28	Year
Time before Return of Capital by resorting to domestic forces	$(t_{cr})_i$	15	Year
Current Number of Trips by each Vehicle over each Guideway per Day	$(n_t)_d$	2	-
Capacity for Seated Passengers per Vehicle	$(C_P)_v$	440	Persons
Number of Permissible Trips over each Guideway per Day	$(n_{al})_d$	130	-
Available Guideway Capacity for Passengers Transportation per Annum	$(C_P)_{av}$	20^7	Persons
Percentage of used guideway capacity	$(C_u)_{av}$	50	%

Therefore, in addition to Mashhad-Tehran route, and by considering the amount of the traffic that has to go through the curvy hilly routes between Tehran and Tabriz, this can be a proper 2nd candidate for implementing the maglev train services.

Lower energy consumption of the maglev vehicles in comparison with other railway transportation systems, is amongst the major characteristics of the magnetically levitated trains. This can be easily associated with the absence of the wheels and the resulting situation of no physical contact between the maglev vehicle and its guideway. Therefore, the energy loss due to unwanted friction is out of equations. Also, the vehicle weight is lower due to the absence of the wheels, axles and engine. By establishing the maglev train services, the travel time between Tehran and Mashhad reduces from 11 hours to 2 hours. On the other hand, the reduction in travel time considerably reduces the energy consumption. The limited energy resources that are currently available to the nation have highlighted the fact that every individual has to be energy conscious. The government had to take steps and it started by setting some preventative rules and tightening access to the cheap energy resources. Rationalizing petrol is an example of such actions that started since 2007. The year 2009 has been named the year for trimming consumption patterns for the nation. Clearly, widespread application of the magnetically levitated trains for public transport, in short and long distances, can provide the nation with huge saving in energy consumption. This is not a fact that can be easily ignored nor can it be bypassed.

According to the international norms, the cost of implementing civil projects by employing local companies and contractors is about 50% of what it can cost by employing foreign contractors. This may include the construction of structural parts such as guideways. It is worth nothing that supply of the electric energy for the maglev vehicles can provide another big chunk in the cost saving, if provided locally. Therefore, upon employing the local forces, the total cost of project can drop by 30%. Therefore, estimation for the cost of construction per kilometer of single track elevated guideway is $10m without resorting to the domestic forces while it can cost $7m by resorting to such forces. The cost estimation per kilometer for the double track elevated guideway without using the local forces is $17m and it reduces to $12m by using the local forces.

In this research, an algorithm is presented that facilitates the technical and economical analysis of the maglev systems. The proposal for a long distance maglev system, Mashhad-Tehran (M-T), is used as a case study by using the proposed algorithm. Moreover, the cost of establishing and operating M-T project is estimated in two different approaches. These include the already established cost estimating method, and the cost estimations based on the international norms and standards. Such cost estimations assist in verification of the proposed algorithm. Comparisons between outcomes of the three methods prove close agreement for the cost estimation by all of them. It is concluded that the proposed algorithm for the implementation and operation of the maglev route is practical.

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