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Calculation Optimum Advance Rate and Productivity on TBM Tunneling A case study in Iran

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Abstract: Productivity and profitability have been previously noticeable subjects for classic economists. Nowadays, optimization and productivity are main challenges of industry and development.
It is estimated that drinkable water consumption in Tehran city will increase during the next 25 years. In order to decrease probable crisis and to prevent lack of water in the future, many projects have been designed and executed. Karaj-Tehran water supply tunnel is a sample of these projects. In this paper, optimum advance rate will calculate through economical view and productivity. Optimum advance rate is calculated for Hara Co (Contractor) according to fix and variable costs. In the conclusion, it was observed that slope of the cost graph is nearly horizontal and the advance rate is between 1200 to 1500 meters per month. Therefore, decrease in graph and also productivity increases by means of advance rate are not noticeable. According to current advancement of the tunnel, (average 400 meters per month) if the project is finished within 35 to 40 months, total productivity will be 1.07 to 1.09.
Hence, the contractor will achieve an interest of 9% at maximum.

Key words: Tunnel, Advance Rate, Productivity, Optimization, Break-even rate.

1 INTRODUCTION

Importance of productivity has been discovered for economists and diplomats since 1945[1]. The reason was the full-time occupation after Second World War. Productivity calculation has been common since 1970. Nevertheless, this subject is new in Tunneling projects.
Technical optimization of advance rate has been studied in different researches. In NTNU University of Norway, economical optimization advance rate had studied according to fix costs. In this paper, we will calculate total productivity and optimization advance rate in the Karaj-Tehran water supply tunnel. This tunnel will be approximately with a length of 16000 meters [2], which is now under excavation by full-face machine to conduct water from Amir Kabir dam to No.6 refinery of Tehran.

2 OPTIMUM ADVANCE RATE

In this paper, optimum advance rate defines as follows:
The advance rate in which cost of each meter advancement in a tunnel will be minimum for the contractor. For calculation of this index, all the costs and incomes in the project should be determined. Costs of this project are divided into two groups: Fix and Variable.

2.1 Fix Costs

Fix costs will not change in special capacity of production or during a short time [3]. Even in the case of stoppage of execution operations, fix costs will remain unchanged. In this project, fix costs are as follows:

Table 1- List of fix cost in Karaj – Tehran water supply tunnel

Investment Costs	Buildings
	Equipment of Segment Manufactory
	Tunnel Equipment
	Technical Services Equipment
	General Equipments
	Office Equipments (Administrative Equipment)
Material of Segment Manufactory	
Sit installation Cost	

Table no.1 presents equipment for technical services. They are comprised Generators, Compressors, Pumps, etc. In addition, Load and transport machines classify as general equipments indices. Office utensil and vehicles classify as office equipments.

Segment manufacturing factory consumables will remain fixed during the project. With increase or decrease in project time, segment manufacturing factory consumables will not change. (Consumables are changeable in the unit of time in accordance with the advance rate).

2.2 Variable Costs

Variable costs will change with the variation of production capacity [3]. In other words, variable costs will change continuously with production of each unit. This type of cost is divided into two parts: Consumables (which are directly involved in the project) and cost of productive work (wage of labors). List of this cost is shown in Table no.2.

Table 2- List of variable costs in Karaj – Tehran water supply tunnel

Usage Items of TBM	Usage Items else TBM
Cost of Replacement and Maintenance	Energy
Cost of Overall Maintenance	Technical services
Man Power	

Technical tasks and goods consumed, which was shown in Table 2 differ from Table 1. Table 2 compromises rails and adjuncts, pipes, cables, etc., In other words, some part of energy consumption belongs to this classification. Water and electricity costs are divided to fix and variable cost. In this paper, cost of electrical energy, water and gasoline without considering previous months usage, are determined as a function of advance rate.

2.3 Income

In the time of contract, client has to pay 8% out of total price of contract in advance (3,132,000,000 Toman). 6.5% at the time of sit installation (2,544,000,000) and 5.5% will be paid with 30% of advancement of the project (2,153,000,000). The remaining amount will be paid in accordance with the contract and based on the project advancement. In each payment, 10% will be deducted as safe-conduct and will be kept by the client up to the time of completion of the project. Advance payments will depreciate during the project time out of total price. For instance, when project advance is less than 30% and 14.5% had paid in advance, 14.5% will be deducted from the total amount paid to the contractor (in addition to 10% of safe-conduct). In this project, the regulation rate is zero.

Another part of income relates to non-merged equipments completely. Depreciation of some equipment depends directly on advance rate. Total value of depreciation will be fixed in the project. Depreciation of segment factory was supposed to be fixed. Depreciation of available equipments in the factory will be fixed during the project, and by increase or decrease of advance rate, it will totally remain fixed

2.4 Break-Even Advance Rate

In this paper, Break-Even point is the advance rate in which advantages and disadvantages will be zero for the contractor. In the computations, monthly time interval was analyzed. Cost of advance rate will change according to the advance rate per month. This quantity is calculated based on value stuffs and work force.
The variable and fixed costs were shown on Fig. 1. (FC: Fixed Cost, VC: Variable Cost, TC: Total Cost).
Segment manufacturing factory produces 24 rings of segment per day. The width of each segment equals 1.3m [2]. If working days of a segment-manufacturing factory are 28 days per month, the factory will be able to provide required rings, while monthly advance rates are less than 874m. Otherwise, the number of segment frameworks has to increase.

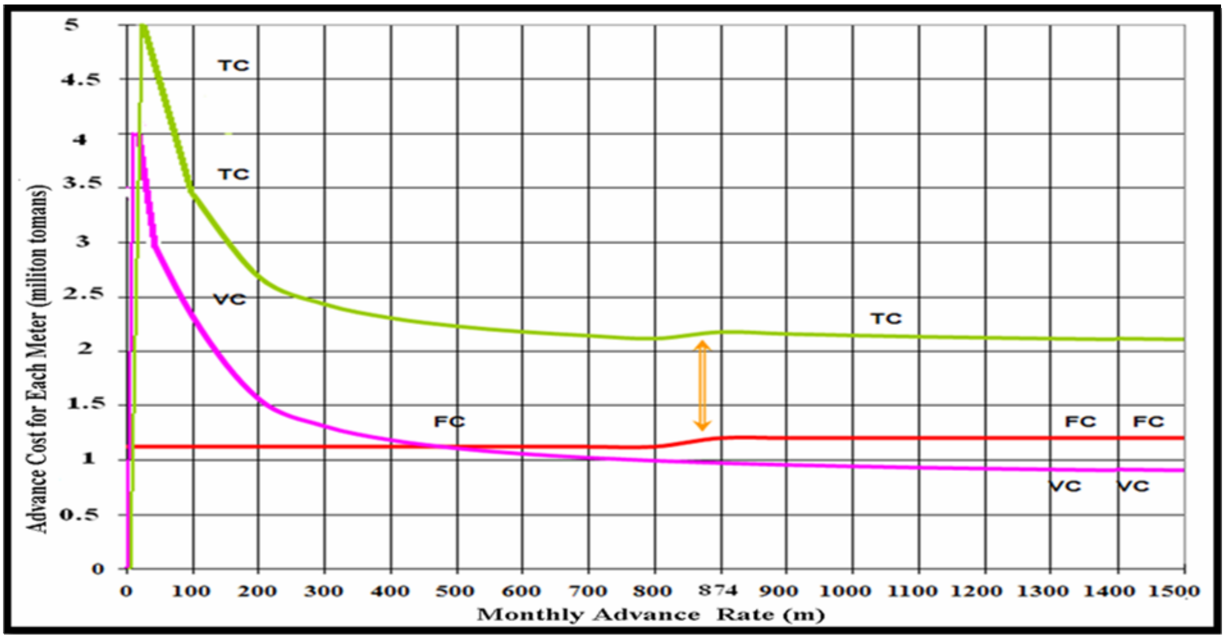

Fig 1- Advance Cost for Each Meter at the Karaj- Tehran Tunnel

It is evident that monthly income and benefits depend on the related advance rate. According to Fig. 2, if advance rate is less than 294m per month, the project will have no benefit or advantage. The reason is high shares of fixed cost on the project. The income per meter is fixed, because, the project price is fixed. However, account statement payment and depreciate between methods are different in monthly periods. The Break-Even advance rate was calculated according to project price, payment method and site cost. The equation shown in Fig. 1 is achieved by polynomial regression.

2.5 Optimization of advance rate

The cost of one-meter advance will decrease horizontally after 700 meters per month (Figure 3). Increase in advance rate has a reverse effect on the project cost. With a decrease in project time, some part of costs such as work force and energy and some part of operational costs will decrease remarkably. The benefits will not increase noticeably. The reason is increasing of operational cost by the growing advance rate.
The advance rate is limited to capacity of segment manufacturing factory and advance rate is more than 874 meters per month. Therefore, segment-manufacturing factory will not be able to provide the requirement segments

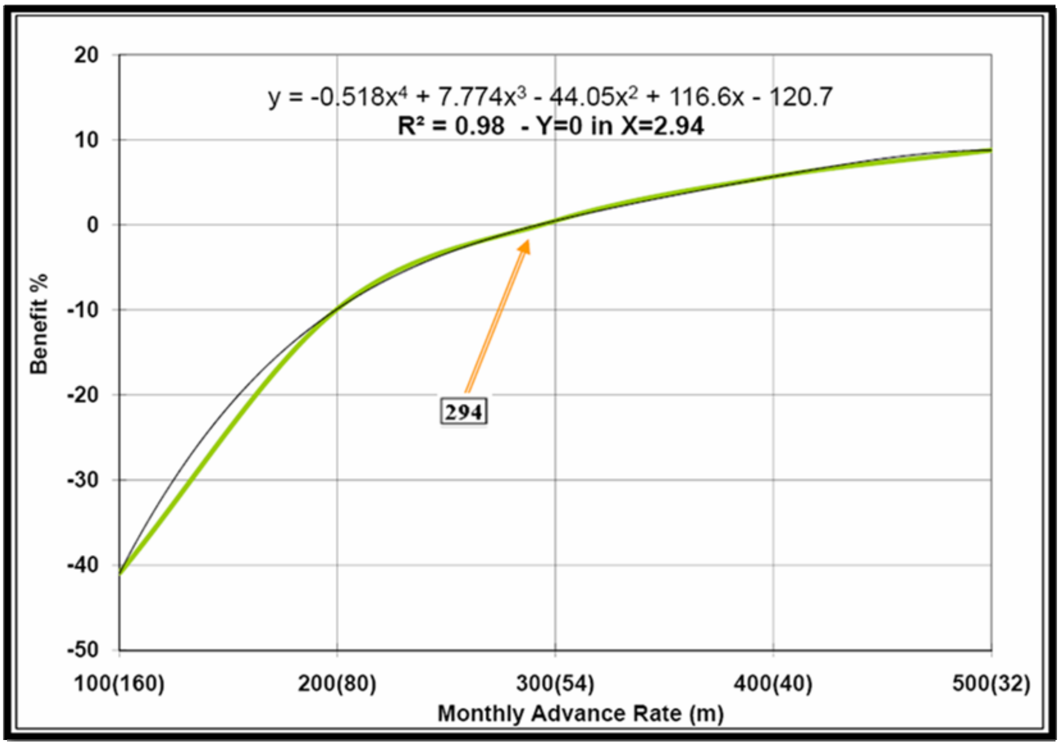

Fig 2- Break-Even Advance Rate at the Karaj-Tehran Tunne

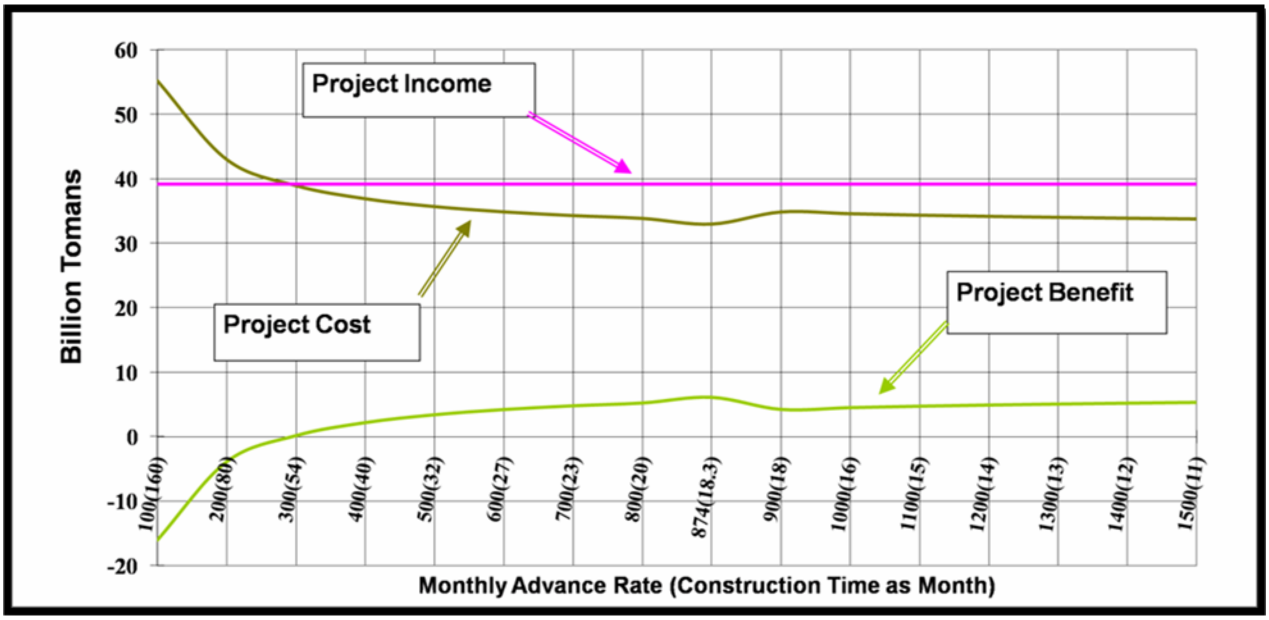

Fig 3- Optimum advance rate on the Karaj-Tehran Water supply tunnel

3. PRODUCTIVITY

There are many definitions for Productivity. Productivity means:

Ratio between system outputs and inputs [5]. Use of available resources or ratio of outputs to production factors (input). In other words, productivity is a quantization of qualify progress [4]. General equation for productivity is as follows:

$$P = \frac{ouput}{input} \qquad (1)$$

Where:
P: Productivity

Total productivity is a fraction of all products to all input components. In the productivity computation, it is necessary to consider available recourses and ingredients (not all of them). Otherwise, the productivity will have the same meaning like efficiency.

All values in the fraction numerator (and denominator) have to be of similar kinds to be summated. In total productivity, to integrate all entries and or issues with the system will not be without any mistake. For example, change of services act or time to the financial units is difficult. Therefore, some indices of detail productivity which are impressionable from two or more parameters (direct or indirect), are computed and considered as main indices for operation analysis.

The main output is the advance meter in the Karaj-Tehran water supply tunnel. In this paper, input data in the productivity equation is the financial value of equipments, manpower, energy, etc.

3.1 Computation of manpower productivity

Manpower productivity consists of the ratio between advance rates (as production) and value of work performed by manpower. Increases in manpower productivity indicate improvement in production and also effects of various parameters to each other [5]. The manpower productivity shall be computed in two types: the first is productivity of meter per person. This index is just a comparative index and is used to compare similar projects.

In the second technique, productivity is the ratio between advance rates and manpower expenses. This index is used to compare similar projects and indicates the work unit performances in the various time intervals. If values had converted, share of manpower costs in each meter of advancement would have been shown.

In this project, 295 persons are involved in different units. It is necessary to consider that productivity computation is directly related to construction time. Increase in monthly advance rate (decrease of construction time) impress directly to manpower productivity. Equation 2 is presented for computation of manpower productivity.

$$P_H = \frac{ouput}{input} = \frac{16000}{N_U \times N_M \times P_M} \qquad (2)$$

Where:
P_H: Man power productivity in each meter per man – Toman
16000: Length of tunnel
N_U: Number of staffs in each unit
N_M: Number of construction months
P_M: Cost of each staff

The base for all computations is 500 meters of advance per month (32 months for construction time) and all costs computed by 11% of the inflation rate. Table 3 shows the result of calculation separately. So, the productivity of total manpower was computed 1.1× 10^{-5} meter for each man-Toman (productivity for different advance rates was computed in the sensitivity analysis part).

Table 3- Manpower Productivity

Part	No. Manpower	Productivity (meter/ person)	Productivity (meter/ each man- Tomans)
Segment Factory	33	475	0.093×10^{-5}
Tunnel	43	372	0.047×10^{-5}
Equipments	42	381	0.042×10^{-5}
Operational	139	115	0.054×10^{-5}
Official	38	421	0.064×10^{-5}
Total	295	52.237	0.00113×10^{-5}

3.2 Fix costs productivity

Input data for system are divided into two groups: Fix cost and variable costs. Advance rate will not influence on fix costs productivity. In Table 4, the result of calculation of detailed productivity of fix costs has shown separately. Equation 3 is presented for fix cost productivity.

$$P_F = \frac{ouput}{input} = \frac{16000}{FixCost} \qquad (3)$$

Where:
PF: Fix costs productivity in each meter per Toman
16000: Length of tunnel

Table 4- Fix cost productivity

Costs	Productivity (meter per Tomans)
Site Installation	1.06×10^{-5}
Buildings	0.76×10^{-5}
TBM	0.21×10^{-5}
Total Equipments	0.158×10^{-5}
Material	0.39×10^{-5}
Total Fix Costs	0.09×10^{-5}

Total productivity of fix costs was computed 0.9× 10-6 meter per Tomans. Main parts of fix costs are related to the investment data. It is evident that values of depreciation for investment issues are different. In this paper, costs of depreciation for investment issues were supposed as a percentage of purchasing cost.

3.3 Variable costs productivity

Productivity of variable costs is impressed by advance rate and manpower productivity. The main energy conveyors are electricity and gasoil (in the computations used for the costs of energy conveyors). Equation 4 is presented for computation of variable cost productivity.

$$P_V = \frac{ouput}{input} = \frac{16000}{\text{Variable}\, cost} \tag{4}$$

Where:
P_V: Variable costs productivity on meter per Toman
16000: Length of tunnel

In this project, productivity of total variable cost was computed 2.3× 10^{-6} meter per Tomans. Table 5 shows the productivity of variable cost separately.

Table 5- Productivity of variable

Type of Cost	Productivity (meter per Toman)
Technical Service	0.65× 10^{-5}
Equipment spares	1.8× 10^{-5}
Stuffs and Material	0.52× 10^{-5}
Energy	16.13× 10^{-5}
Total Variable costs	0.23× 10^{-5}

3.4 Total Productivity

Total productivity is the unique concept, shows the actual picture of productivity. All sources used, are involved in total productivity computations. If total productivity computes on Income to Cost basis (percentage), it shows the financial profit and disadvantage.

Total Productivity = Total Production / Total Input
Total Productivity = Total Production / (Equipment Costs+ Material Costs+ Energy Costs+ etc)

It indicates the interaction of different data on each other; therefore, detailed computation of productivity shall not be a suitable index to assess an operation of a unit. Detailed productivity indicates the performance of related data.

3.4.1 Total Productivity (Meter- Cost)

With this total productivity, advance rate will be shown for each unit of money. If this index inverses, cost for each exploitation meter will be shown. Total productivity is computed as follows:

Total Productivity = 0.044 × 10^{-5} meter / Toman

3.4.2 Total Productivity (Income - Cost)
This kind of productivity is noticeable as an economical issue and has more efficiency to other indices. A project will be advantageous only if the value of total productivity is higher than one. So:

Total Productivity = 1.095 %

If the average advance rate is 500 meters per month, the project will be cost-effective. It is evident that change in advance rate will cause variation on productivity.

4. SENSITIVE ANALYSIS

Relationship between the decline of construction time and increase in benefits is not liner. After advancement of 700 meters per month, the benefit graph slopes will be horizontal. If advance rate increases, manpower cost will decrease and the operation costs will increase. Manpower productivity is calculated 1.1 × 10^{-8} (meter / Tomans) for 32 months of construction. Fig. 4 shows the sensitive analysis results for manpower productivity. It needs to mention that manpower productivity is fixed in all construction times.

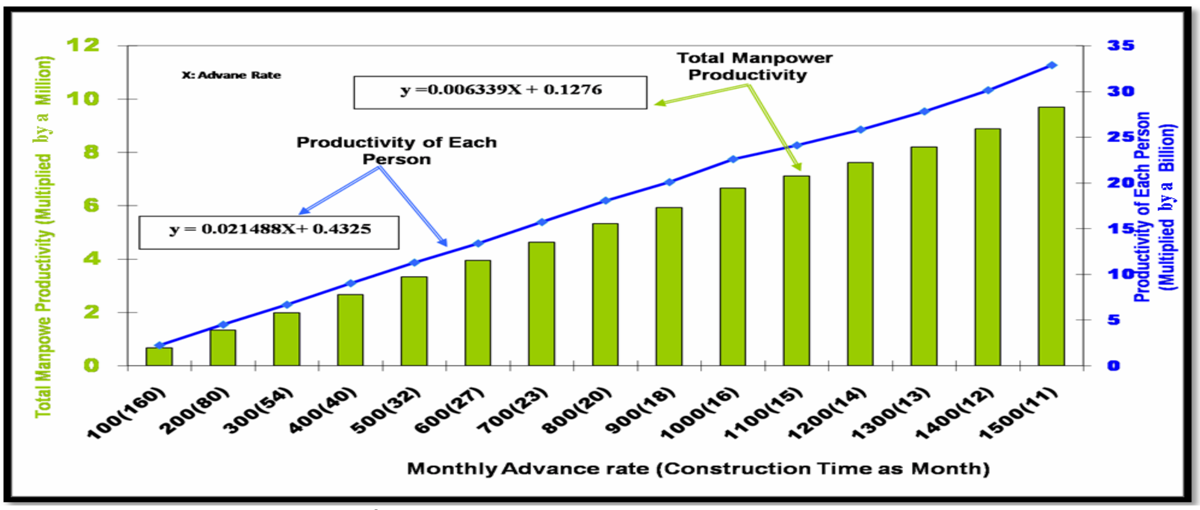

Fig 4 – Variation of Manpower Productivity toward Advance Rate (meter / Toman)

Equations are results of liner regression. Energy productivity will increase by promotion of advance rate (Fig. 5). Here productivity of electrical energy is calculated separately. Figure 6 shows variable cost productivity vs. advance rate variations.

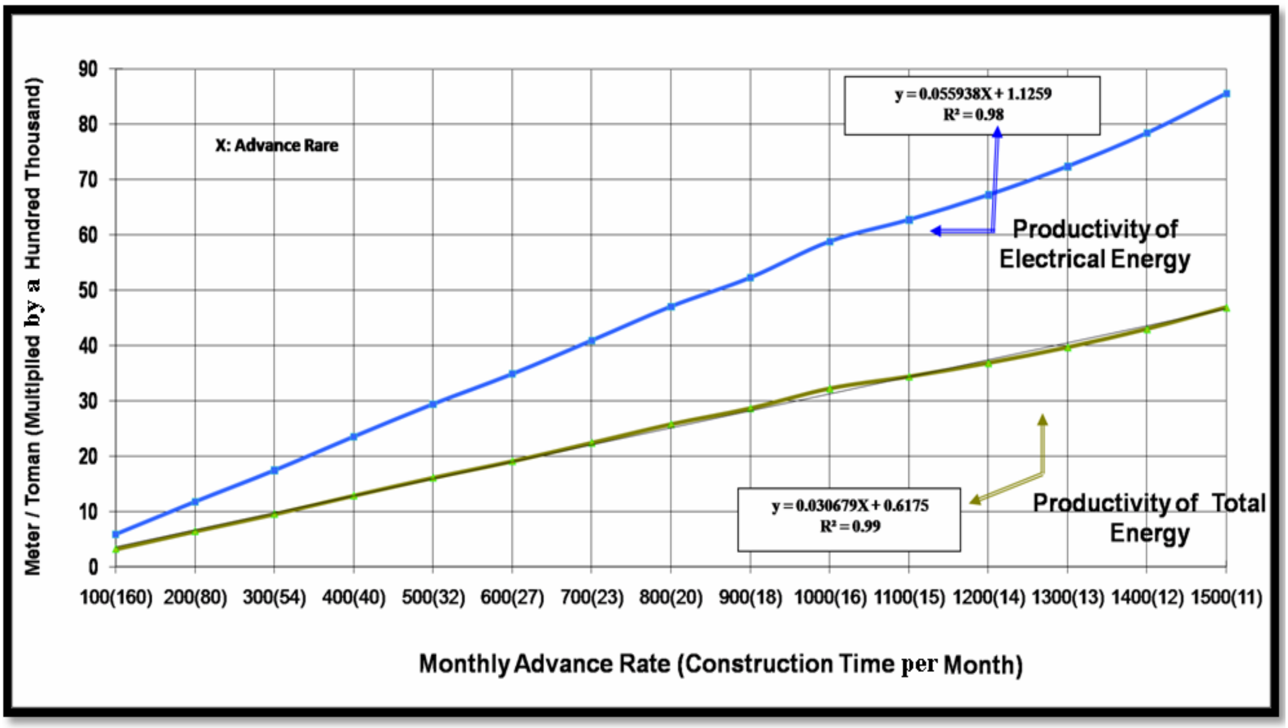

Fig 5- Variation of Energy Productivity vs. Advance Rate

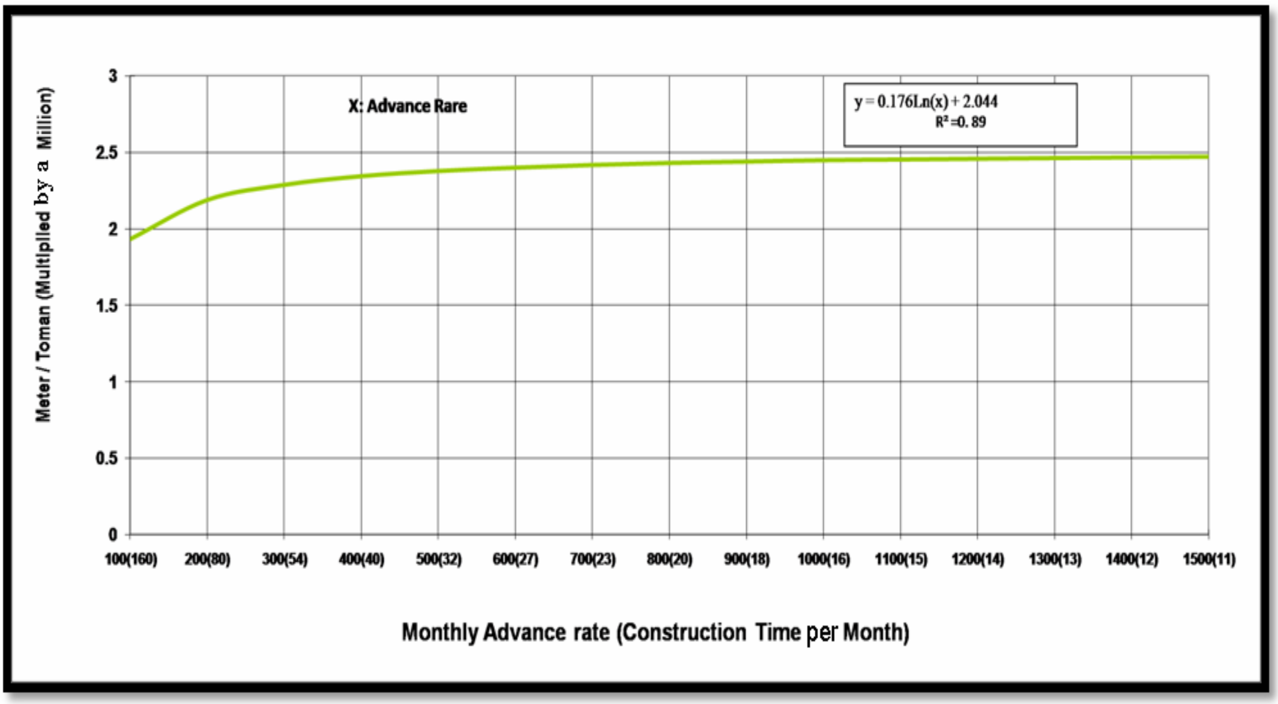

Fig 6 Variation of variable Costs Productivity (without manpower) vs. Advance Rate –

The slope of the variable cost productivity graph is nearly horizontal after 1200 meters of advancement per month. It means that decrease in project completion time for less than 14 months do not make a noticeable change on productivity. It is necessary to mention that change in variable costs and advance rate will consequently, change total productivity (Fig. 7).

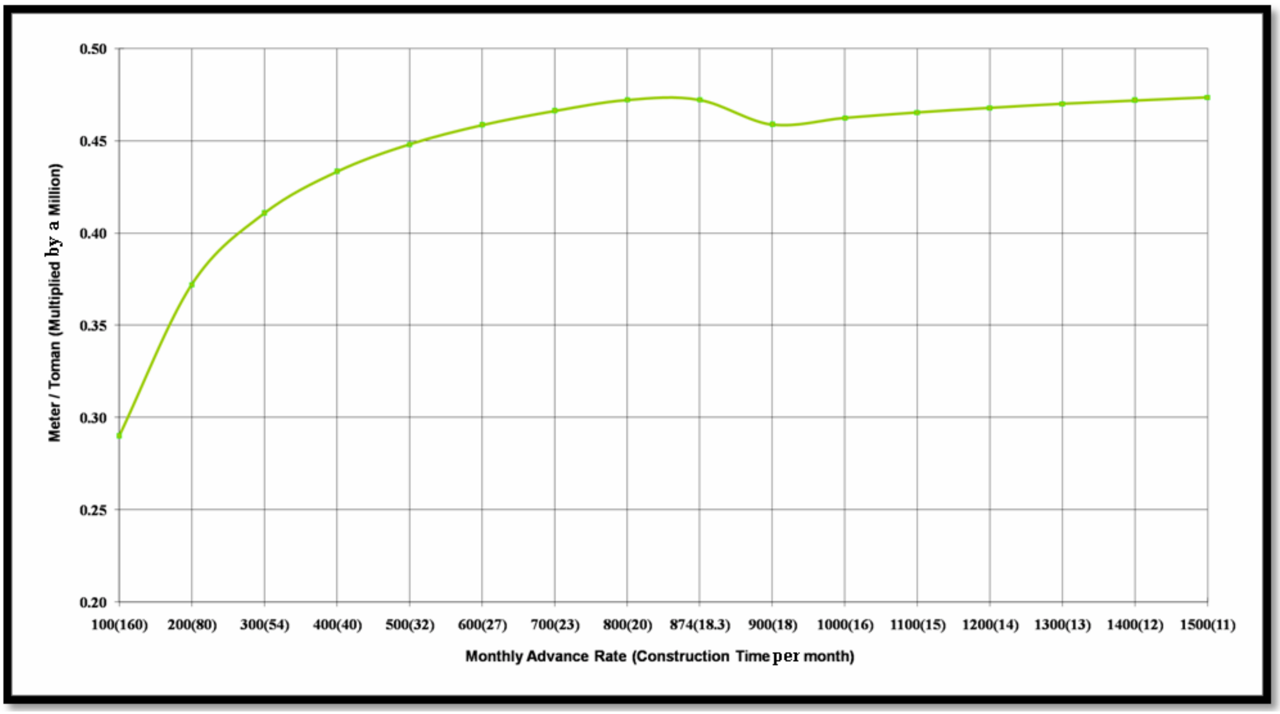

Fig 7- Variation of Total Productivity vs. Advance Rate

Maximum productivity will be 874 meters of advancement per month. The reason for reduction of productivity after 874 meters of advancement, is a requirement for more segment frames. Income - Cost productivity is important for economical point of view. Fig. 8 shows the percentage of profit by a change in advance rate.

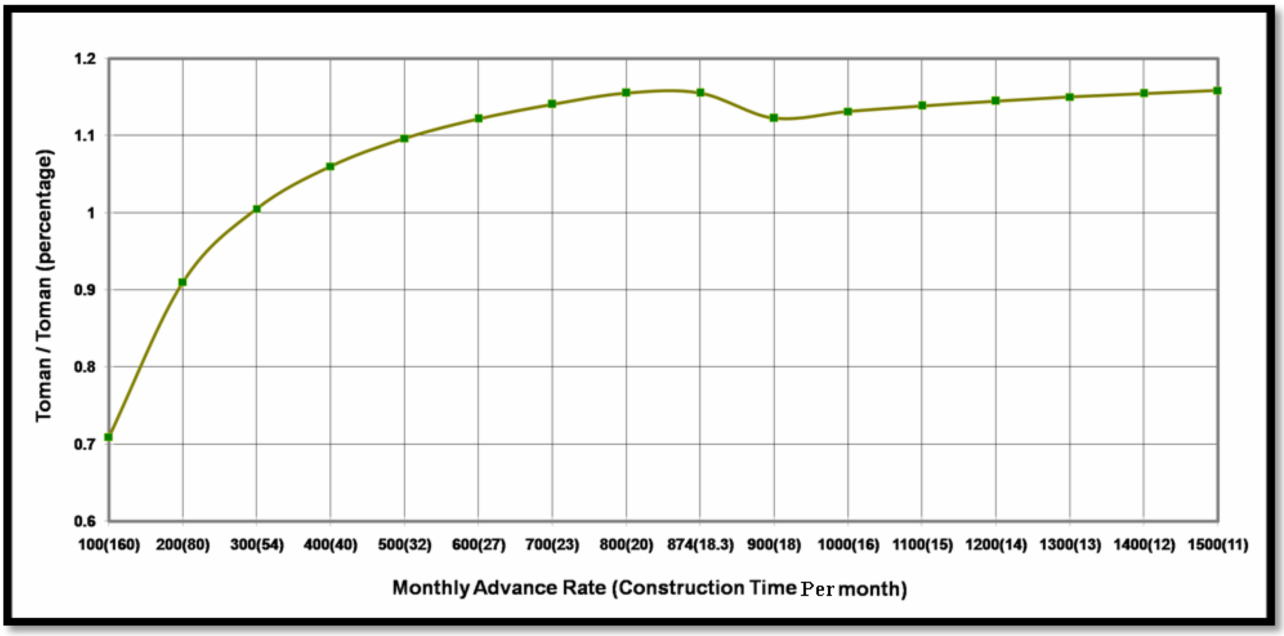

Fig 8- Variation of Productivity Percentage vs. Advance Rate

5. CONCLUSION

In this paper a TBM tunnelling project was studied as economical and optimization issues. Goals of study were definition Break-Even Point, Productivity, Optimum Advance Rate, and benefit of project for contractor.
All the cost classified in the Fix and Variable groups.
In part 2-4, Break-Even advance rate, was computed near 300 meters per month. If construction time increases to more than 54 months, the contractor will incur disadvantage (Fig. 2). The relationship between manpower productivity and advance rate is a liner, and it will change extremely by an increase in monthly advance rate.
Also, productivity of production factors (inputs) was computed as detail and total.
In Sensitive Analysis part studied relationship between variation of advance rate and productivity indexes.
Manpower productivity is calculated 1.1×10^{-8} (meter / Tomans) for 32 months of construction and it is growing by advance rate increase. It needs to mention that manpower productivity is fixed in all construction times.
The sensitive analysis result of variable cost productivity has shown decrease in project completion time for less than 14 months do not make a noticeable change on productivity.
Optimum advance rate was computed 874 meters per month from economical point of view. It is evident that operational costs always increase by growth in monthly advance rate. However, the slope of the total productivity graph is near horizontal after 874 meters of advancement per month. The slope is always positive, except in the range between 874 to 900 meters. The reason is the need to segment frames after 874 meters of advancement per month.
According to current advance rate of the project (400 meters per month), it is predicted that project completion time will be 35 to 40 months, and total financial productivity will be between 1.07 to 1.09 on Toman's basis (part 3-4-2). In another world, the contractor will earn 9% of profit at maximum.

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