

Developing a cost-effective model for evaluating the efficiency of weigh in motion system

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Abstract— While passenger and freight transportation are growing up in developing countries, traffic congestion, accidents and environmental pollution are getting to be a serious concern for policy makers. Using Intelligent Transportation Systems (ITS) has been recently introduced as a main solution to overwhelm the above problems. Since, Weigh In Motion system (WIM) is known as a very important component of ITS, its usage is increasingly to be applied for overloading enforcement. Huge investment in construction and maintenance of pavement lead policy makers to tackle overloading using weigh in motion systems. Installing weight in motion system is a constructive project with high investment in terms of special pavement, electronic devices, data transferring devices and human resource to overloading reduction and save pavement condition in the proper situation. Following the above mentioned, it is necessary to develop a trade-off model between pavement cost repairing and installing weigh in motion system. So, in this research will be presented on the basis of break-even at the cost of purchase, installation, operating and maintenance costs of the system and saves the cost to repair the pavement as the top model in terms of the income. The average overloaded axles under enforcement performed by authorities to tackle overloading is studied a criterion and the proposed model determines the minimum average overloaded axes in which installing WIM would be a profitable project. The proposed model is a parametric pattern and an installed WIM system has also been selected as case study and the number of required enforcement. Results will help decision-makers in the field of transport, as in the operation of WIM to achieve a balance between costs and revenues from it the right decision to take.

Keywords— *Intelligent Transport System; Weigh in Motion; pavement; break-even*

I. INTRODUCTION

Transportation planning is an issue that the attention of many decision-makers and custodians of this area to be allocated and their minds have shifted to the management, controlling traffic congestion and also to promote road safety. Consequent problems of transportation such as congestion, accidents and environmental pollution increase spiritual damage, lack of supervision and legal controls problems, management of transportation within and outside the city and etc has led the creation of safe and efficient transport become one of the concerns of developing countries and growing. Due to lack of required resources and time and costs, use of new technologies such as Intelligent Transport Systems (ITS) may be the best option to manage traffic and transport problems. Significant sum will cost annually on roads and pavement maintenance and repair. Such capital need to maintain and manage in order to optimize its operation. According to investigations conducted additional load carrying in addition to the destruction of roads and technical buildings and reducing pavement life reasons such as (increased roughness, cracking, creating holes and etc), safety and traffic is difficult [1]. In order to control the heavy vehicles it used different surveillance methods [2]. Including those in the form of intelligent transportation systems projects are defined can be noted Weigh In Motion system (WIM). WIM is one of intelligent tools for vehicle weight control passing through one point [3].

The benefits system include reducing downtime vehicles through weighing without stopping and moving vehicles, reducing the number of vehicles overloaded, increasing the life of the pavement, reducing maintenance costs, etc. Since the issue of how much to use of Weigh In Motion systems is considerable, the study will examine what role of this system to reduce damages, including costs related to the damages of road pavement and technical buildings but it is important that in recent years, the use of WIM in the country by the authorities of road transport, caused a considerable

sum to launch and annual maintenance of these systems and to determine at what level of the operating system is economical. In this study has been used from the breakeven point method for installation of the system's economic assessment to determine to what extent to use of WIM to the costs of installation and income resulting from use of these systems can be justified. Based on the above, a model will be developed which can be used in different locations and in a case study will be used and the results will be examined.

II. REVIEW

Abbas et al. [4] proposed an effective procedure to determine the best location(s) for installing Weigh in Motion systems (WIM). A proper mathematical model has also been developed to achieve objective function. The number of once-checked trucks, unnecessary actions and average installing costs are defined as criteria measures. The proposed procedure was applied in a road network using experimental data, while the results were compared with the usual methods of locating enforcement facilities. Finally, it was concluded that the proposed procedure seems to be more efficient than the traditional methods and local experts' points of view. Mahmoudabadi et al. [5] Pointing out that sufficient human resource and adequate time scheduling are to be planned for surveying trucks' overloading; hence, it seems required to prepare an all-around model to be able to predict the number of overloaded vehicles. In the research work, the concept of chaos theory has been utilized to predict the ratio of trucks which might be guessed overloaded. The largest Lyapunov exponent was utilized to determine the presence of chaos using experimental data and concluded that the ratio of overloaded trucks reflects chaotic behavior. The prediction based on chaos theory was compared with the results of simple smoothing and moving average methods according to the well-known criterion of mean square errors. The results had also revealed that the chaotic prediction model would act more capably comparing the analogous methods including simple smoothing and moving average to predict the ratio of passing trucks to be possibly overloaded. Mahmoudabadi et al. [6] had developed a genetic algorithm (GA) for clustering the performance of weighing stations in an Iranian case study. Available data for six parameters in 126 stations had been analyzed, and stations had been clustered using the developed GA -based model. To solve the problem of existing different dimensions of parameters, the collected data had been standardized. The proposed GA had been analyzed in the different number of clusters, iterations, and population size and the associated results have been discussed. Validating had been done based on the comparison between fitness values of the algorithm and the same criteria in mathematical clustering known as between the sum of the square errors. Mohamed et al. [7] specifically focused on the effect of vehicle by-pass and static weigh station enforcement capability on the overall effectiveness of vehicle weight enforcement system in a developing country. Results from this study suggested that the WIM system will significantly enhance the effectiveness and efficiency of the current vehicle weight enforcement, thus generating substantial revenue that would greatly off-set the current road maintenance budget that comes from tax payers money. If there was substantial reduction in overloaded vehicles, the public would still gain through reduction in road maintenance budget, less accident risks involving heavy trucks, and lesser greenhouse gases (GHGs) emissions. Heather et al. [8] addresses CBA as an evaluation tool and its major weaknesses. They concluded that the treatment of residual value (RV) was inadequate and needed further research. RV represents the value of the infrastructure at the end of its project lifetime and the value that the asset generates over time. The current methods for calculating RV do not properly reflect the true value. James et al. [9] in a paper developed and demonstrated that economic evaluation of ITS projects in the road sector is possible. The authors used the Oslo toll cordon as a case example, where semi-automatic toll collection was replaced by a full-fledged ITS-based toll collection. The results showed that ITS-based toll collection is highly profitable from an economic point of view. The reasons were that the ITS-based toll collection relieves congestion at toll points thereby leading to (i) time savings for road users, (ii) reduced noise and pollution associated with slow movement of vehicles at toll points, (iii) improvement of the city's landscape because toll booths and signposts are removed and (iv) reduced costs associated with operating tolls. The study urged ITS proponents to start using economic evaluation when assessing the merits of their projects.

III. BREAKEVEN ANALYSIS OF PROJECTS

The purpose of the break-even analysis is to determine the level of production or part of the required capacity has been used, so that total income is equal to the total cost. According to Figure 1, break-even occurs in B, where income is equal to the total cost, at every level of production, lower than point B, losses. The break-even can be determined by calculating from the following equality [10]:

$$Q \times P = F + (Q \times V)$$

The loss or gain by, the $Q \times P - Q - (Q \times V)$ is determined if the amount of expression is negative, losses and if the amount of expression is positive we have profit.

These calculations can be applied to every level of production, and is therefore plotted in Figure 1.

(Q) Some that produced or sold, (P) selling price per unit of product, (F) total fixed costs in the period, (V) Variable costs per unit of product, so at every level of production, income and total costs were calculated: (QP) is total income, $(F + (Q \times V))$ is total cost.

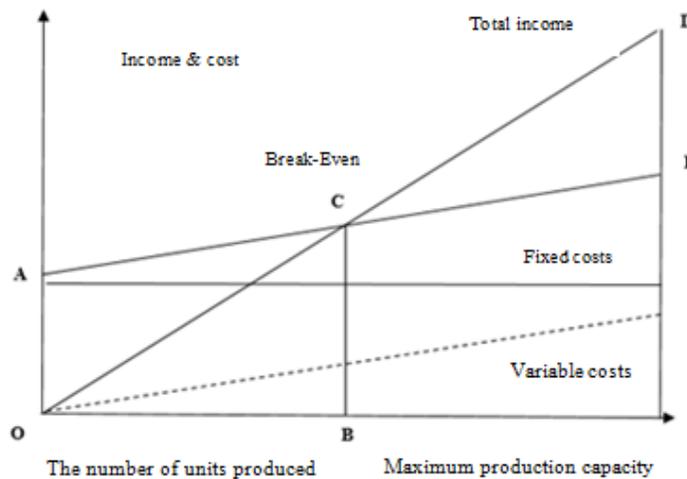


Figure 1. Determining Breakeven

IV. THE EFFECT OF THE WEIGHT OF VEHICLE ON THE PAVEMENT

After Heavy trucks and buses are responsible for much of the damage to pavement [11]. Engineering data suggests that a five-axle truck loaded with allowable weight, equivalent to 9600 sedans damage to the surface [12]. In general, the relationship between overload and damage on the pavement was significant and overloading vehicles damage pavement surface and have negative impact on the movement of other vehicles [13].

When an axle weight increase of 20,000 pounds to 22,000 pounds (about 10 percent), this 10% would be a five percent reduction in pavement life. When the increase is 20 per cent, the damage is doubled. On the effectiveness of weight in bridges, increased by 5% by weight it caused 33% increase in damage to bridges and significantly reduce their lifespan. The level of damage caused by overload exponentially rises [13] [14].

V. WEIGH IN MOTION

Due to the increasing truck traffic and commercial vehicle overload in recent years and also the adverse effects of this type of vehicle on the road network, the use of new technologies is necessary in order to prevent the destruction of ways.

A suitable system for controlling weight of vehicle is Weigh In Motion (WIM). These systems have the ability to measure weight of vehicle in a range of speeds. In addition to deploying systems for law enforcement weight of vehicle, have the ability to collect traffic information [15]. The main objectives of the Weight In Motion can be divided on two major objectives, including the collection of traffic data and the law enforcement.

Traffic data collection has a lot of applications in planning, design and management of roads. Information obtained from WIM including: The classification of traffic flow and types of vehicle, Determine the speed vehicle, The total weight and the weight of each axis vehicle, The distance between the front axle to the rear axle the vehicle, The equivalent axial load, etc. [16, 17]

VI. THE INITIAL DEFINITIONS OF THE MAIN PARAMETERS OF ECONOMIC EVALUATION OF THE EFFECTIVENESS OF THE WEIGH IN MOTION:

A. *Pavement life:*

Pavement life including the design life and operational life Is as follows:

Period or design life, how long the road is not a major failure. Design life According to the general conditions of the maintenance of the ways of the country is different, so that the urban with high traffic 15-25 years and the intercity with low and average traffic 20-25 years.

B. *Operational life:*

Operational life, how long the primary pavement lasted without facing unacceptable quality.

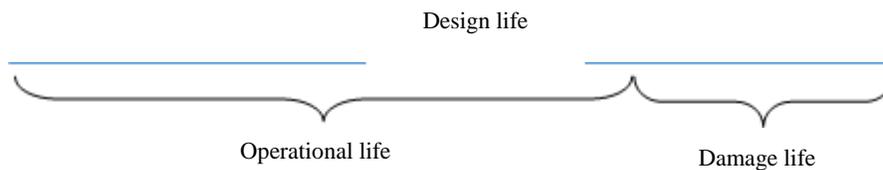


Figure 2. Pavement life

Traffic is one of the most important parameters in pavement design. By determining the traffic volume, vehicle type, weight and axle, they can be converted to standard weight or base axle [18].

C. *How to influence the load on pavement failure:*

The three main parameters of the type of platform, the lifetime of the design and the number of equivalent axial load is considered. As a result, if the number of equivalent axle load passing to more than load predicted pavement, the lifetime of the design is reduced. In Figure 2, the effect of increasing the load on the pavement has been demonstrated by the increase in the failure rate. The diagram with 10 percent load, 45 percent increase in road crash [19].

In fact, by dividing the number unauthorized of axial load to allowable pavement degradation rate is calculated.

$$\frac{ESAL_{Overloaded}}{ESAL_{Allowed}} \quad (1)$$

$$M - 1 = \text{Pavement damage rate} \quad (2)$$

$$N \times (1 - (M - 1)) = N-n \quad (3)$$

N-n is pavement Operational life.

D. Developing a cost-effective model for evaluating the efficiency of weigh in motion system:

Step One: Determine the costs and benefits of WIM:

At this stage, costs and benefits of WIM is determined that its cash flow was identified in Figure 3.

▪ **COST:**

C: the annual cost in WIM:

C₁: the cost of purchasing and installing the system

C₂: The annual operation and maintenance costs

$$C = C_1 \times F(A/P, i\%, 4) + C_2 \quad (4)$$

Life of the system is 4 years (20).

▪ **Benefits:**

The annual benefits of the system installation to prevent pavement damage, In fact, this income is due to lower cost of pavement in the years installing system is for preventing pavement destruction, actually reducing costs as income in the ago years is calculated.

C₃: The initial cost to build or re-pavement

KM: The approximate range of impact of device performance

$$B = C_3 \times F(A/P, i\%, N) \times F(P/A, i\%, n) \times F(A/F, i\%, N-n) \times KM \quad (5)$$

Step Two: Determine the operating life of road pavement

At this point, using break-even, ie of equality the costs and benefits of the system operating life of the pavement (N-n) is determined. In fact, N-n is the year in which the costs with the benefits of the system are equal.

$$B=C \quad (5)$$

$$C_1 \times F(A/P, i\%, 4) + C_2 = C_3 \times F(A/P, i\%, N) \times F(P/A, i\%, n) \times F(A/F, i\%, N-n) \times KM$$

Step Three: Determine the amount of damage pavement

The destruction of the pavement in the year is calculated as:

$$2 - \frac{N-n}{N} = M_1 \quad (7)$$

$$M_1 - 1 = \text{pavement damage rate} \quad (8)$$

Step Four: Determine allowed average equivalent single axle load and unauthorized and determine the amount of the destruction of the pavement in the year. In this research work, from 15 vehicle classes, 4 of which have more traffic than others and can cause more damage to pavement, is considered. The four types of the vehicle are shown in Table 1. Information on axial arrangement from the Road Maintenance and Transport Organization of Iran has been collected. Then, for each axial of the vehicle, ESAL value obtained compare with AASHTO factors derived from the regulations for asphalt pavement of roads, ie for each axial (ESAL crossing) / (ESAL allowed) is calculated, if the amount exceeds 1, the axial is unauthorized. Then, the average equivalent single axle load is calculated for authorized and unauthorized axis. Allowed and unauthorized average ESAL obtained put in the following formula to determine the amount of damage pavement in N-n.

$$\frac{\text{Average ESAL}_{\text{crossing allowed axis}} + \text{Average ESAL}_{\text{crossing overloaded axis}}}{\text{Average ESAL}_{\text{Total Allowed}}} = M_2 \quad (6)$$

Step Five: Determine the monitoring WIM for the justified use of system:

The destruction of the pavement which is obtained the ago stage should be identical to the second stage to the unauthorized axial load crossing allowed by the amount of damage (M_1), is achieved.

$$\frac{\text{Average ESAL}_{\text{crossing allowed axis} + X}}{\text{Average ESAL}_{\text{Total Allowed}}} = M_1 \quad (7)$$

X is the unauthorized ESAL crossing that by it pavement damaged amount of M_1 and with the amount of damage (M_1) costs and income are equal and the transportation planners shall not be considered any detriment. Although the standard for the unauthorized crossing the axial load is not greater than X, to the:

$$\frac{\text{Average ESAL}_{\text{crossing overloaded axis} - X}}{\text{Average ESAL}_{\text{crossing overloaded axis}}} \% \quad (11)$$

The percent of monitoring through the WIM should be to use the system according to the costs and benefits become economic.

VII. DEVELOPING OF ECONOMIC MODELS TO EVALUATE THE EFFECTIVENESS OF WIM IN THE AXIS OF ISFAHAN-NAIN:

according to the tender documentation purchase, installation, commissioning, exploitation and maintenance of the Weigh In Motion (WIM) [20] which has been collected from the Road Maintenance and Transportation Organization, costs of the system are as follows:

TABLE I. INFORMATION ABOUT WIM & PAVEMENT

Variable	Costs	Price (10 Thousands Currency)
C ₁	Buy Systems	260829
	Installation and commissioning	42550
C ₂	Operation and maintenance (annual)	14040
C ₃	The initial cost of the construction or renewal of pavement for each kilometer	40000
N	Design life	25 Years
KM	The approximate range of impact of device performance	60KM

$$C = C_1 \times F(A/P, i\% , 4) + C_2$$

$$C = 303379 * F(A/P, 8\% , 4) + 140040 = 81087$$

$$B = C_3 \times F(A/P, i\% , N) \times F(P/A, i\% , n) \times F(A/F, i\% , N - n) \times KM$$

In this part the annual income of the system is related to years to use the system to prevent the destruction of the pavement. In fact reducing the cost of destruction the pavement by the system in n years, the annual income is calculated in N-n.

$$B = 400000 \times F(A/P, 8\% , 25) \times F(P/A, 8\% , n) \times F(A/F, 8\% , 25 - n) \times 60$$

At this stage, the annual cost of the system is equal to 81,086,847/4, should be equal to the annual income to be determined the age of the pavement destruction.

$$C = B$$

$$81087 = 400000 \times F(A/P, 8\% , 25) \times F(P/A, 8\% , n) \times F(A/F, 8\% , 25 - n) \times 60$$

The pavement operation life is calculated, 22.59 from the above equation.

Now at this stage, the pavement operational life was 22.59 in the previous step. The destruction of the pavement is calculated from the following equation:

$$2-(22.59/25) = 1.096$$

The destruction of the pavement at this stage has been 1.096. At this stage, the information obtained by of the system from of Isfahan, is calculated. Due to the large volume of information, the data for a specified period and was given the number 8859 that among the number of the vehicle crossing, 4 of them have been studied. The types and number in the following table:

TABLE II. CALCULATE THE ALLOWED AND UNAUTHORIZED AXLE LOAD TYPES OF VEHICLES DURING THE PERIOD

Vehicle	Status	Equivalent Single Axial Load			
		8 Tons (0.93)	13 Tons (7.144)	22 Tons (4.799)	24 Tons (1.53)
2-axis heavy trucks	Allowed	0.183	2.65	-	-
	Unauthorized	0	9.04	-	-
3-axis trucks	Allowed	0.196	-	1.46	-
	Unauthorized	1.45	-	5.591	-
5-axis 12-wheel trucks	Allowed	0.265	3.106	-	0.375
	Unauthorized	0.952	19.246	-	0
5-axis 18-wheel trucks	Allowed	0.137	-	0.6366	-
	Unauthorized	0	-	6.352	-

$$Average\ ESAL_{crossing\ allowed\ axis} = 0.602$$

$$Average\ ESAL_{crossing\ overloaded\ axis} = 16.80$$

The damage of the pavement in this year almost is calculated by the following formula:

$$\frac{Average\ ESAL_{crossing\ allowed\ axis} + Average\ ESAL_{crossing\ overloaded\ axis}}{Average\ ESAL_{Total\ Allowed}} = M_2$$

$$\frac{0.602 + 16.80}{3.475} = 5.007$$

In the previous step the destruction of the pavement in the pavement was 5/007, the unauthorized average ESAL should be less and this accepted amount is calculated through following formula:

$$\frac{Average\ ESAL_{crossing\ allowed\ axis} + X}{Average\ ESAL_{Total\ Allowed}} = M_1$$

$$\frac{0.602 + X}{3.475} = 1.096$$

$$X = 3.207$$

The unauthorized average EASL crossing should be 3/207, While in reality this amount is 16/80, to make this unauthorized average ESAL crossing to 3/207, Should be reduced. To accomplish this, the monitoring by the WIM Should be:

$$\frac{16.80 - 3.207}{16.80} = 80.9\%$$

In fact, if the amount of monitoring of the system will be 80/9 percent, the unauthorized average EASL crossing will be up to 3/207. This amount of unauthorized ESAL crossing for the authorities' field of transportation in Isfahan will be economical. Because they have been able due to the costs associated

with WIM, they have the best utilization of the system. That this amount of operation of the system, the destruction of the pavement brings to the extent that the authorities do not insure any loss both the costs associated with the construction or re-pavement and the costs related to the WIM system.

VIII. CONCLUSIONS:

WIM is as one of the monitoring systems in intelligent transport systems with significant advantages in reducing damage to the pavement, transportation planners and authority annual face with a large sum for installation, commissioning and maintenance of the WIM. In this study it was found that the use of the system how to be calculated in order that the costs of installation and with the benefits of using these systems can be justified. Thus, using economic evaluation of projects by methods Break-even amount of operation of the system was estimated for being economical of scheme.

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