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Economic risk assessment of concrete and asphaltic pavements in freeways and highways

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ABSTRACT

The greater parts of Iranian roads are of the asphaltic kind. The real reason behind making this type of road lies in the abundance of bitumen and the cheaper price of the substance in past years. The upward spiraling price of oil at the global level and the liberalization of subsidies were responsible for rocketing prices of asphalt pavement. As a result, a motivation was created to investigate an alternative method called concrete pavements. The construction cost of concrete and asphalt pavement hinges on specifications of the project, but one of the main concerns was about the likelihood of fluctuations in spending during the construction phase. According to the importance of price changes, this paper intends to find which type of concrete and asphalt pavements have lower price changes in Iran. To answer this question, the Monte Carlo simulation is applied. Since the Monte Carlo simulation needs a prediction model and the data used for developing the model hinges on historical data, the authors applied regression and time series methods. The results show that firstly, the regression method has better performance than the time series model and the second, the implementation of concrete pavement has less economic risks in Iranian freeways and highways.

1. Introduction

Roads are an effective means of communication between different areas. Human beings have been using roads since many years ago. The length of road networks is much diversified among different countries, for example, the United States has the highest length of roads in the world while Iran ranks 26th with the 214,006 km paved and unpaved road among the countries [1]. The importance of the road as an infrastructure of countries is unavoidable. Several cost parameters affected the cost of constructing this infrastructure such as location, type of construction, number of lanes, type of pavements, etc. One of the costly items in the construction of roads is the type of pavement. The pavement is one of the important components of a road which is directly contacted with vehicles. There are several options for choosing as pavement but some considerations such as costs of construction, maintenance, technology, etc. influence the decision. As an example, most Iranian road pavements were made of asphalt. One of the major reasons for using asphalt as pavement is the wealth of oil resources, including bitumen and its low charge in past years. But according to the price reference of Iran's construction projects (price list), the price of bitumen MC250 was 0.14 dollars per kg in 2006 and 0.2 dollars per kg in 2016. The rate has increased over the past ten years. Therefore, with the upsurge in bitumen prices in the past, other options should be considered. Another type of pavement taking the attention of Iranian administrators into account in recent decades is concrete pavement. Concrete pavement is a concrete layer that is replaced by asphalt and in contact with the traffic directly. Another motivation is the upward trend in the rate of cement production in Iran leads the use of concrete pavement to be economically justified.

The economic considerations are one of the most important criteria for the selection of the type of pavements. As explained, the decision for the selection of the type of pavement has been changed because of economics issues. It seems that

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it is not a realistic approach to select the pavement only based on the minimum cost because it is possible to change during the time. The actual cost is dependent on different cost variables so changing in the price of each parameter leads to change in the actual cost of pavement. It is better to select the type of pavement with the lowest economic risks to increase the level of confidence and minimize the project's cost deviation. A risk is an uncertain event or occasion. It will affect at least one of the objectives of the project such as time, cost and quality can change [2].

There are several risks in the process of constructing a road. Sharaf and Abdelwahab [3] explored the risks involved in implementing highway projects in Egypt. They identified 12 risk groups, which included 73 threats. Then, they evaluated these risks, using fuzzy logic. In 2016 [4], examined the risks involved in constructing highways. They took risks from various sources such as uncertainty in financial markets, threats from project failure, legal debt, and credit risk. The results of their research showed that the process of effective risk management encourages construction companies to identify and reduce risks. In later stages, they could manage financial and interest rebates if the risks were effectively handled.

However, the number of effective risks for the selection of pavements is numerous and diversified, this paper intends to study the economic risks of concrete and asphalt pavement in constructing Iranian highways and freeways. This study not only answers this question which type of pavements (asphalt or concrete) has the lowest economic risks in Iran but also presents a framework for conducting the purpose of this paper in other locations. The subject under discussion specifically tries to make a decision on which type of concrete or asphalt pavement on freeways and highways has the minimum economic risk in Iran. To this end, two points should be considered. The first one is the definition of economic risks applied in this research. The economic risk is defined as the probability of price changes of different components of these pavements based on the history of their price changes. For example, if the cost of one of the components of asphalt pavement changes very much, its economic risk will be high. In other words, this paper considers the economic risks to be able to predict the future behavior of pavement in terms of changing its price by studying the price changes of different components of pavements in the past. It is noteworthy that other parameters, such as cost of maintenance, duration of projects, etc. prone to influence the decision on applying concrete or asphalt pavements have not been taken up in the current research work.

The second point is how the economic risk of pavements can be calculated. To do this, the cost prediction model is developed by using two well-known techniques, including the regression model and the time series since the authors applied the historical data. Different tests will be done to find which type of regression or time series models has better results. According to the developed model, several effective parameters on the cost of each pavement are discovered. To examine which pavement has more cost fluctuation (or more economic risk), the Monte Carlo technique is applied. The Monte Carlo method is a computational algorithm that uses random sampling to compute the results. The results would be shown whether applying the concrete or asphalt pavement is more logical than the other one in the Iranian construction industry with respect to the economic risk or not. According to the introduced concept, the structure of the paper is as follows: The research background was reviewed in the section 2. In the following, materials and methods are described. The results of the research are presented in the next section and finally, the conclusions are explained.

2. Research background

The American Concrete Pavement Association (ACPA) in its 2002 report reviewed four inland state roads (Western Tennesse, Utah, Eastern, Oklahoma and Georgia, North of Atlanta). The association's research results showed that concrete sections in this study between 1.6 and 2.6 times asphalted sections have service life; the average lifetime of pavement concrete is 2.2 times asphalt pavement. Also, the analysis of the cost cycles in these states shows that the concrete pavement is more expensive than 14–250% of the ordinary pavement [5]. A report released by the American Concrete Pavement Association ACPA, entitled "Greenways in 2007," states: "To build a 250 mm Thickness of asphalt pavement, 40,572 liters of fuel per lane-kilometers is required and a 250 mm Thickness concrete pavement 7252 liters of fuel per lane-kilometers is needed. In other words, the fuel needed to pave the asphalt is 5.6 times the fuel needed to build a concrete pavement.

Bellow, an economical comparison was made to provide lighting for two types of pavements. It was argued that the cost of supplying lights for concrete pavement was approximately 24 % less than the asphalt pavement, resulting in maintenance and energy costs (electricity required) to be approximately 24 % less than asphalt pavement [6]. Mack [7] criticized the previous approach used for pavement selection. He proved that the discount rate in LCCA analysis is variable for concrete and asphalt pavement. He suggested a procedure based on the escalated cost of material to calculate the real discount rate. In 2014, Sullivan and Moss examined the cost of making Mix Asphalt Warm (WMA) and Mix Asphalt Hot (HMA) with concrete pavement. As a result of their work, the following conclusion was drawn: "Yes, WMA is more cost-effective than HMA, but still not comparable to concrete pavement" [8,9]. reviewed the usual procedure for LCCA and LCA in Colorado and proposed a modified approach for pavement selection with respect to the greenhouse gas emission. They applied the model for highway reconstruction and rehabilitation. [10] explored the economic impact of concrete and asphalt pavements. Their approach was based on informal interviews and the calculation of the bill of quantities for roads. The results of their research show that concrete pavement costs less in life cycle costs than asphalt pavement. Although their results indicate that concrete pavement is less costly, they did not pay attention to risks. Mohod and K.N.Kadam (2016) investigated rigid and flexible pavements. The results of their efforts show that rigging pavements are more conducive to flexible pavements. Asphalt pavement life cycle cost is 19 % more than those of concrete pavement [11,12]. examined the costs of the life cycle of concrete pavements and asphaltic roads, taking into account the cost of lighting in tunnels of 750 m to 2000 m in length. They made the comparison based on the standards used in Italy. The results of their research show that concrete pavement, with consideration of the required lighting, has a lower life cycle cost than the asphalt pavement in the tunnels. [13] proposed a framework to evaluate different types of pavement based on LCA and LCCA analysis. They assessed the uncertainty of the cost of construction and maintenance activities. They concluded that the flexible design has lower cost and environmental impact in their case study. An integrated framework combined with LCCA and LCA was developed by [14]. They applied fuzzy composite programming to model the uncertainty in the decision-making process and ranking different types of pavement [15]. examined four scenarios in terms of the selection of pavement and lighting systems in Italy. Their framework was conducted by LCA and they concluded that the concrete pavement and LED lamps are the most environment-friendly scenario. [16] developed a decision support system based on the multi-criteria decision-making approach to rank several types of asphalt mixture for wearing courses in terms of the sustainability concept. They applied the proposed model in a real case study and they showed that a foamed warm mix asphalt mixture with a reclaimed asphalt pavement content of 50 % is the most suitable.

Ramezanianpour and Aarabi [17] in their book (published in Persian) examined concrete and asphalt pavements. These two pavements were examined in terms of technical, economic and environmental considerations. The results of their research regarding the two types of pavements show that concrete pavement in comparison with the asphaltic pavement according to the catalogs of 2009, has a lower cost of construction in all ways [17]. One can find the problems of previous research that were observed by studying other articles, which are mentioned as follows, is the lack of economic risk assessment. Different research has been carried out in relation to economic comparison, but they did not take this subject into account by considering the price variations. None of the researchers examined the economic risks of concrete pavement and asphalt pavement.

3. Materials and methods

This research type is based on an experimental study, because in this study the independent and dependent variables affected the cost of highways and freeways pavements in Iran, which are based on the available information from the past to the present, have been considered. Based on the proposed model, the economic risk evaluation of the concrete and asphalt pavements was done using Monte Carlo simulation.

The research method is divided into two parts: The first part presents the model to be able to forecast the price of concrete and asphalt pavement by examining the independent and dependent variables in the specified period.

The second part is based on the obtained model in the previous section. Since the definition of the economic risk has been set on the probability of price changes of pavements, by combining the developed model for calculating the price of pavements and Monte Carlo simulation the level of price changes of pavements will be calculated. The pavement with a high level of change has a higher economic risk than the other. Different steps to reach the paper's goal are shown in Fig. 1.

The research method is described in detail as follows:

3.1. Presenting price model

To discover the cost prediction model, two methods, including regression and time series, were applied. The following descriptions explain these two method in detail.

3.1.1. The regression model

Regression analysis studies the dependence of a variable (Dependent-Variables) on one or more explanatory variables by estimating or predicting the average value of the variables. The first type is defined in the case where the values of the second type variable are known or determined (in repetitive sampling) [18]. To identify the best independent variables, Stepwise, Forward, and Backward methods are used. In the Forward method, some of the independent variables are represented by the leading method in the linear regression model. In the Stepwise method, some independent variables are included in the linear regression model in a step-by-step method. In the Backward method, some independent variables are included in the linear regression model in a regressive way [19]. The result of the above-mentioned methods is the regression models. After determining the regression model, some methods were used to validate the obtained models by analysis of variance (ANOVA) and Student t-test. The models rejected for these tests were excluded from the set of models. After confirmation of the models based on the test data (2014–2016), the error rate (PE) of each year was calculated based on Eq. (1) and the mean error percentage (PE_A) computed according to Eq. (2) for each model. To make the first model with a lower average error rate and responses, linear regression model was selected as the appropriate model.

$$P.E = \frac{Y_c - Y_f}{Y_c} \times 100 \tag{1}$$

$$P.E_A = \frac{|P.E_{2014}| + |P.E_{2015}| + |P.E_{2016}|}{3} \times 100 \tag{2}$$

where Y_C is the price calculated for pavement construction in a real situation (Table1) and Y_f is the cost calculated for the pavement according to the regression model (equations 4&5).

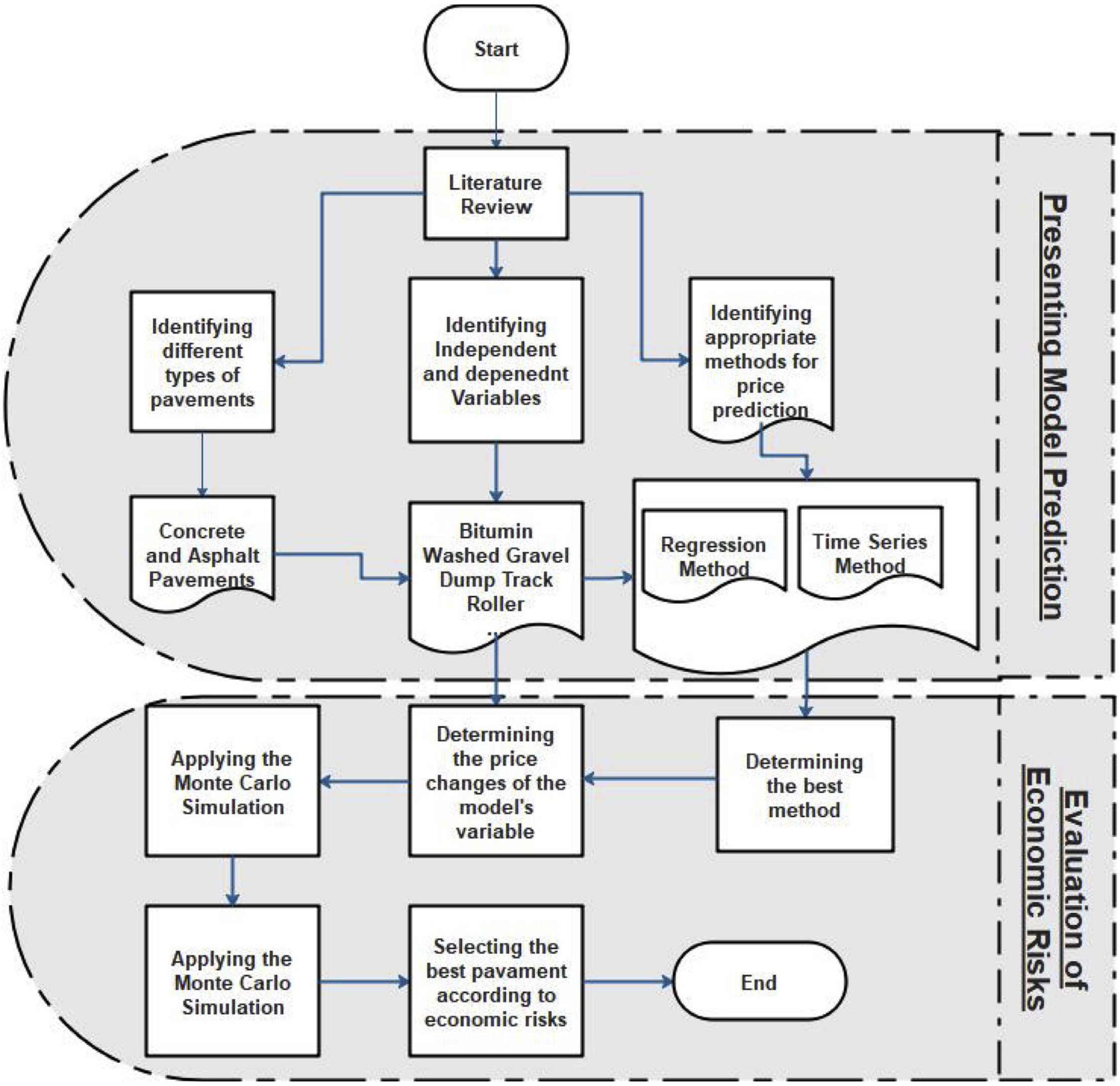

Fig. 1. The overall process of research in this paper.

3.1.2. Time series model

Given that the price data of each year are related to the previous year, the use of time series models can have proper function. In this section, an attempt is made to use the data related to the cost of pavement execution per year to determine the time series associated with each of the pavements.

There are several methods to determine the time series model. One of the most prolific methods is the Box-Jenkins method [18]. In this method, efforts are made to practice a suitable model for the existing data based on ARIMA. If the process

Table 1
Average cost per kilometer*.

Year	1998	1999	2000	2001	2002	2003	2004
Concrete	617,126,255	660,648,564	823,159,650	991,159,069	1,200,205,144	1,385,097,726	1,936,580,937
Asphalt	393,163,049	469,598,696	573,214,725	656,146,388	740,094,849	1,330,059,527	1,490,968,741
Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Concrete	2,161,546,247	2,372,591,140	2,543,655,838	2,858,380,514	3,277,999,343	3,412,894,145	3,953,798,137
Asphalt	1,950,972,823	2,109,593,492	2,216,130,647	3,530,218,925	3,866,575,061	4,027,186,253	5,147,826,421
Year	**2012**	**2013**	**2014**	**2015**	**2016**		
Concrete	4,628,839,160	6,111,502,379	7,154,486,025	8,357,463,113	8,677,374,426		
Asphalt	5,832,131,804	12,866,932,042	13,942,798,118	13,454,064,902	10,877,387,050		

* All amounts are in Rials.

of autoregressive is contemplated to take the form AR (p), the model process of Moving Average takes the form of MA (q), the average motion process of self-regression take the form of ARMA (p, q) and the moving average cumulative motion process of self-regression takes the form of ARIMA (p, d, q) in all of the preceding cases P represents the number of self-regression sentences, d stands for the number of the first-order differentiation technique for implantation of time series moving averages. In this research, the Box-Jenkins method is used to determine the time series. This method is applied by taking the following steps:

- *The first step, identification:*

At this stage, the static (stationary) nature of data should be primarily processed. The data of time series are static when their statistical characteristics are fixed over time such as variance and median. To check the stationary nature of the data, the Kwiatkowski-Philips-Schmidt-Shin (KPSS) test is used [18]. According to reference information [18]. The amount of LM-Stat should be smaller than the statistical data at 5% level. If this amount is greater than the 5% level, the differential technique should be used to stabilize the data. The first order differentiation is carried out in such a way as to deduct the data of the year t from the data of their previous (t-1) year. The results respectively show the first order differentiation. The subsequent differentiation is accomplished by using the data obtained from the differentiation of the previous stage and the difference in the manner described [18]. This process should persist until the data arrives at the stationary stage. To continue, the parameters of Auto Correlation function (ACF) and Partial Auto Correlation Function (PACF) should be used so as to identify p and q. The ACF and PACF reveal contradictory patterns in the processes of AR (p) and MA (q). In AR (p), ACF decreases in geometric form exponentially. But PACF decreases geometrically or exponentially and eventually interrupts after a certain number of intervals [18].

- *The second step is to estimate the coefficients:*

After the identification stage, the model parameters are estimated. To estimate the parameters, the minimum squares method can be used. But when the model is nonlinear towards the parameters, the nonlinear approach is applied to estimate the parameters.

- *Third step, Verification:*

After estimating the model, the accuracy and pertinence of the model should be considered. A model will be suitable when the residuals of the model bear the properties of independent normal random variables commonly distributed with zero median and fixed variance. To verify the accuracy of the model, the statistical report of (BOX-pierce Q) test is employed [18].

After developing two models including regression and time series, their results will be compared to each other to find the best cost prediction model.

3.2. Evaluation of economic risk

Monte Carlo simulation allows the analyst to allocate all possible uncertain components to mathematical models of a probability statement and then use random sampling from this. The distributions identify the distribution of all the different outcomes that occur as a result of these uncertainties [20]. To apply the Monte Carlo simulation, the following steps should be taken into account:

- Identifying the model: the first step is to develop a model for dependent variables based on some independent parameters. This step was done in the earlier section for both concrete and asphalt pavements.
- Determining the distribution of independent parameters: According to historical data, the distribution of parameters can be calculated. Checking the normality of data is a good starting point to determine the type of distribution.
- Setting the number of iteration: The Monte Carlo is based on random sampling from the distribution of independent parameters. By setting the iteration and doing the sampling process, the distribution of dependent variables can be calculated.

4. Research results

As shown in Fig. 1, field studies and literature reviews were done to determine the method of designing and recognizing the types of pavement systems. After selecting the appropriate method for designing Continuous Reinforced Concrete Pavement (CRCP) and hot mix asphalt pavements, the most adapted in the Iranian environment, efforts were made to use the national pricing system of Iran under the name of road pricing to determine the price of concrete and asphalt pavements. The prices of the parts were used as well. For this purpose, the price lists were considered between the years 1998–2016. In the review, the authors encountered the fact that in certain years, the prices were not available due to the lack of publication of the list of prices by the government, so to solve this problem, efforts were made to increase the prices by the rate of inflation declared by Central Bank of the Islamic Republic of Iran annually in the previous year. The estimated prices for the previous year had to be used for the year in question. After this process, the effort was made to present a model based on dependent variables (the price of pavement) and independent variables. Using the proposed model in the previous step, a quantitative economic risk was assessed. The results are presented as follows:

4.1. Presenting price model

4.1.1. The regression model

According to the collected data the steps of regression model were implemented. In Table 1, the average cost of each kilometer road for concrete and asphalt pavements on freeways and highways is presented in Iran. The method and the process of calculation and the list of variables affecting the price of concrete and asphalt pavements are presented in the appendix. The authors applied the data presented in Table 1 as real data for developing the regression model. The readers should pay attention to two considerations when they want to interpret the information provided in Table 1. The first one is considering the source of data, which is based on the national pricing system of Iran under the name of road pricing. Usually, this method of calculating prices is used by the government to pay in Iranian projects. It is possible that the cost of construction is different from the payment but the authors applied for the payment since all of the experts agreed to this approach. The second one is that the calculated prices are for freeways and highways. In other words, they would differ when other types of roads are considered.

At first, the estimated base cost of the materials used in each of the calculations, for example, the estimation of the base cost of tack coat used for asphalt pavement in 2012 have been calculated as Eq. (3):

$$y_1 = \frac{((V \times x_{150301}) + (d \times a \times V \times x_{200201}) + (d \times a \times V \times x_{200202}) + (d \times a \times V \times x_{200203}))}{1000} \tag{3}$$

Where,

y_1 = base cost of prime coat per kilogram
d = hypothetical distance for transportation
a = the available coefficient item affording fine view in the price list
V = the amount of material consumed to calculate the prime rate
x_{150301} = price for supplying and serving as surface coatings (kg)
x_{200201} = price of carrying bitumen from 30 to 75 km (ton/km)
x_{200202} = price of carrying bitumen from 75 to 150 km (ton/km)
x_{200203} = price of carrying bitumen from 150 to 300 km (ton/km)
The numbers shown below x pertain to their row number in the price list.
Finally, y_1 has been calculated as Eq. (3):

$$y_1 = \frac{((1000 \times 7493) + (45 \times 1.05 \times 1 \times 704) + (75 \times 1.05 \times 1 \times 704) + (150 \times 1.05 \times 1 \times 454))}{1000} = 7668\ Rial \tag{3}$$

Considering the data in Table 1 and applying the regression methods, three models for concrete pavement and six models for asphalt pavement were obtained. After applying the ANOVA and t-test, one model of concrete pavement and one model of asphalt pavement were rejected and consequently were removed from the list. For the remaining models, the prediction error of each model was measured and, finally, the following regression models were approved with a mean error of 8% for concrete pavements and 7.1 % for asphalt pavement for freeways and highways. Below, the model of regression of concrete and then the asphalt pavement models are described. It should be noticed that the models were developed based on the price unit Rial.

- *The model of regression of concrete pavement*

For freeways and highways with concrete pavement, the model was calculated as Eq. (4):

$$y = 11248.85839x_1 + 32732.57575x_2 + 92156734 \tag{4}$$

where x_1 is the price of a dump truck with a capacity of about 10 tons with the driver and x_2 is the price of washed gravel. The model depicts that by predicting the price of two mentioned variables, the cost of concrete pavement would be calculated.

- *The model of regression of asphaltic pavement*

For freeways and highways with the asphalt pavement, the model was calculated as Eq. (5):

$$y = 68178.537x_1 + 24955.482891x_2 + 507892.791807x_3 + 29668.94969x_4 - 5851.498718x_5 - 3085.989966x_6 - 10501.50597x_7 + 2236.485713x_8 + 80802486 \tag{5}$$

where x_1 is the price of washed sand, x_2 is the price of washed gravel, x_3 is the price of bitumen MC 250, x_4 is the price of asphalt worker, x_5 is the price of sprinkler tank 20,000 liters with driver, x_6 is the price of rubber wheel loader with a power of about 150 horsepower with the driver, x_7 is the price of grader with 150 horsepower with a driver and x_8 is the price of play asphalt machines - Finger wheel chainsaw with driver. The model depicts that by predicting the price of eight mentioned variables, the cost of asphalt pavement would be calculated.

The Eqs. 4 and 5 demonstrate that the cost of constructing one kilometer of concrete pavement and asphalt pavement will be calculated by inserting some of the parameters depicted as x value in the equation. In other words, the regression model developed by Eqs. 4 and 5 is suitable to estimate the cost pavement. Moreover, the authors will apply these equations to evaluate the economic risk of pavements by inserting the price fluctuations of independent parameters (x_i).

- *Checking the validity and correctness of regression models*

In each linear regression model, there are several assumptions that if the models are correct, and regression results are valid, otherwise they should be replaced by another model. These statements include: 1) The average of errors is zero; 2) The error of variance is constant even though it is unknown; 3) The zero is the correlation between errors in different stages; 4) Normal distribution of errors. These claims do not necessarily apply to remnants [19]. In the following, regression analysis and verification of the correctness of the regression equation calculated for concrete pavement is presented.

1. Checking the zero of the mean errors: by applying the data from 1998–2013 the mean errors were calculated as shown in Table 2 for concrete and asphaltic pavements. The results showed that the mean errors are zero.

In Table 2 the value of unstandardized residual is defined in the following terms:

Unstandardized Residual = $y_{calculation} - y_{prediction}$

Where,

$y_{prediction}$ = construction cost calculated in conformity with the regression model
$y_{calculation}$ = construction cost calculated in accordance with Table 1.

2. Check the normal distribution of errors: This control was done based on the Shapiro-Wilk test which is for investigating the normality of data [21]. According to Table 3 and the significance level of the Shapiro-Wilk test in the concrete and asphaltic pavement, being equal to 0.651 and 0.762, are respectively greater than 0.05. One can assume the error distribution with high normal confidence.

3. Checking the constant of variance of errors: It means $V(\varepsilon_i) = \sigma^2\ .\ \forall i$. As can be seen in Fig. 2, the variance of errors is almost constant.

As shown in Fig. 2, errors have been distributed within a specified range on the axis y = 0. In other words, it can be concluded that errors have not suddenly been greatly reduced or decreased. Therefore, the variance of errors is almost constant.

4. Checking the zero correlation between errors: It means $COV(\varepsilon_i\ .\ \varepsilon_j) = 0\ .\ \forall i.j$. According to Fig. 2, it can be seen that the residues are scattered over an x-axis by accident so that the near regression model is independent of each other.

Given that all linear regression models claim the model is correct, then the mentioned models are selected as a suitable model for freeways and highways with the concrete and asphaltic pavement.

- *Investigating the correlation coefficient of variables with output values:* Finding the correlation coefficient of variables with output values was done for more confidence whether the variables presented in the models are correlated with outputs or not.

Table 2
Mean, Skewness and Kurtosis of errors for freeways and highways.

Pavement	Model	N	Mean	Skewness		Kurtosis	
		Statistic	Statistic	Statistic	Std.Error	Statistic	Std.Error
Concrete	Unstandardized Residual - Model 2 Stepwise Method	16	0.0000001	−0.205	0.564	−1.043	1.091
	Valid N (list-wise)	16					
Asphalt	Unstandardized Residual - Model 6 Backward Method	16	0.0000004	0.020	0.564	−0.552	1.091
	Valid N (list-wise)	16					

Table 3
Shapiro-Wilk test for errors for freeways and highways.

Pavement	Model	Shapiro-Wilk		
		Statistic	df	Sig.
Concrete	Unstandardized Residual - Model 2 Stepwise Method	0.959	16	0.651
Asphalt	Unstandardized Residual - Model 6 Backward Method	0.966	16	0.762

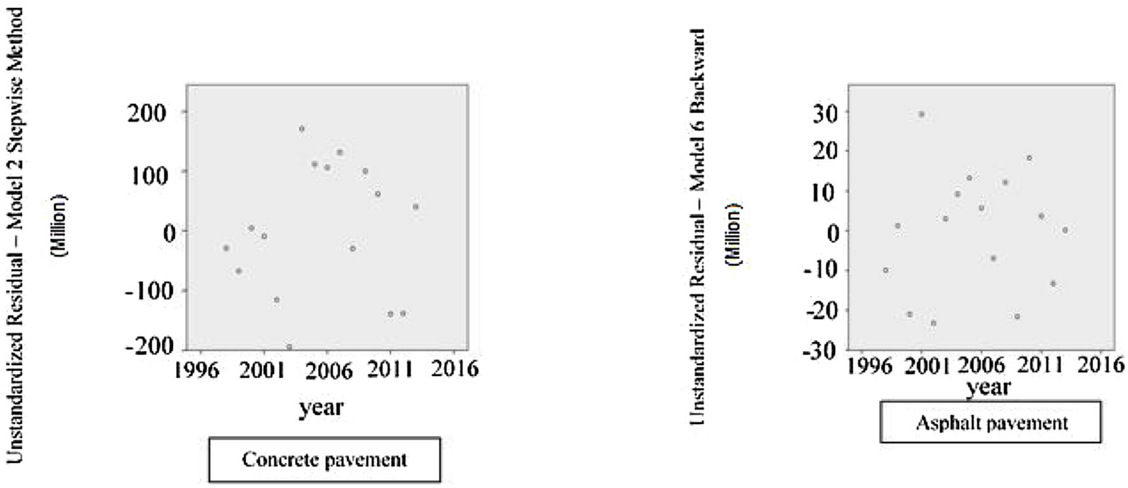

Fig. 2. Shows the distribution of errors for freeways and highways.

Table 4
Coefficient of correlation of independent variables with average construction cost in freeways and highways.

Pavement	Benchmark	Coefficient of correlation with average cost of pavement on freeways and highways
Concrete	dump truck with a capacity of about 10 tons with the driver	0.993
	Washed gravel	0.991
Asphalt	Washed sand	0.978
	Washed gravel	0.905
	Bitumen MC 250	0.991
	Asphalt worker	0.965
	Sprinkler tank (20000 liters) with driver	0.969
	rubber wheel loader with a power of about 150 horsepower with the driver	0.970
	grader with 150 horsepower with a driver	0.966
	Play asphalt machines - Finger wheel chainsaw with driver	0.946

As shown in Table 4, the related variables in concrete and asphaltic pavements have a high correlation with the average cost of concrete and asphaltic pavements on freeways and highways, being present in the regression equation given.

4.1.2. Time series model

The procedure to obtain the time series of the concrete pavement is described as follow:

In the first step, toward the examination of (stationary) data, the following diagram (the process of price changes) of the average construction cost of concrete pavement was drawn.

As shown in Fig. 3 and based on the KPSS test, the amount of LM-Stat is equal to 0.634 which is larger than their critical level 5% and 10 %. Therefore, the zero theory (the data being stationary) will be rejected. As such, the data are not stationary over time. To stabilize the data, the differential technique is employed. The amount of LM-Stat is equal to 0.304 and being smaller than their critical level 5% and 10 % by conducting differential techniques on three occasions and based on the KPSS test. Therefore, the data will become stationary by the employment of differential techniques on three occasions (d = 3). The model type and position of p and q will be determined by using ACF and PACF. Here, the position of p is equal to 1 and q equal to 0. Given the fact that partial correlation will lose its meaningful nature at level 1; therefore, the time series model for the concrete procedure will be ARIMA (1, 3, 0).

After the first step and identifying the model, the estimation of model coefficients is conducted as explained in Eq. (6):

$$y^{3*} = 67833136 - 0.783177y^{3*}_{t-1} \tag{6}$$

Where, y^{3*} is equal to the third order of differentiation of the price of concrete pavements.

In the third step, the BOX-Pierce test was used to verify the accuracy of the model. The results of the Q statistics showed that it has not been meaningful in statistical terms and that residuals from the model practice purely by chance.

Eventually, the Eq. (7) is obtained for concrete pavement by simplifying the Eq. (6), in which the base year would be 2002.

$$y_t = 67833136 + 2.216823y_{t-1} - 0.650469y_{t-2} - 1.349531y_{t-3} + 0.783177y_{t-4} \tag{7}$$

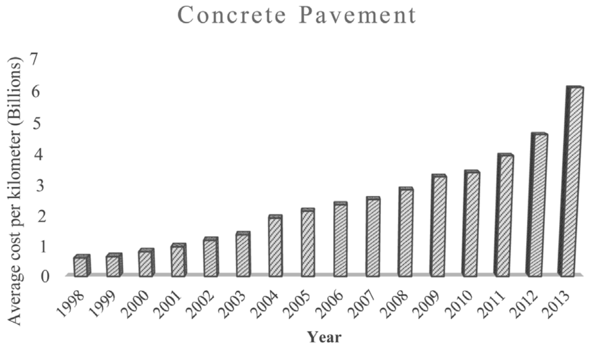

Fig. 3. Trend of price change of concrete pavement during the time.

To carry on with the present attempt, the procedure of achieving asphalt pavement as well as the time series model is elucidated:

In the first step, to investigate the (stationary) nature of the data against the average cost of making asphalt pavement the process of price change was charted in Fig. 4.

As shown in Fig. 4 and based on the KPSS test, the amount of LM-Stat is equal to 0.586 which is bigger than their critical level of 5% and 10 %. Therefore, the zero theory (if data being stationary) is rejected. So, the data are not stationary over time. To stabilize the data, the differential technique is used. By developing differential on two occasions and based on the KPSS test the amount of LM-Stat is equal to 0.288, being smaller than their critical level 5% and 10 %. Hence, the data will become stationary by constituting differentiation on three occasions (d = 2). The model type and position of p and q are determined by using ACF and PACF. As a result, p and q are equal to 1 and 0 respectively. Considering that partial correlation loses its meaningful nature at level one, so the time series model for concrete pavement is ARIMA (1, 2, 0).

After the first step and identifying the model, the estimation of model coefficients is made by Eq. (8):

$$y^{2*} = 591427095 + 1.24593803081 y^{2*}_{t-1} \tag{8}$$

Where y^{2*} is equal to the second order differentiation of the price of asphalt pavements.

In the third step, to verify the accuracy of the model, the statistical BOX-Pierce test was employed. The statistical results of Q showed that the model is not meaningful in statistical terms and that the remainder results from the model practice purely by chance.

Eventually, by simplifying Eq. (8), Eq. (9) is obtained for the asphalt pavement, in which the base year would be 2002.

$$y_t = 591427095 + 0.754619692 y_{t-1} + 1.491876062 y_{t-2} - 1.24593803081 y_{t-3} \tag{9}$$

4.2. Comparison of regression and time series models

In this section, the comparison of regression and time series models is made and the suitable model will be chosen from among these models. To carry on with the present attempt, the results of Table 5 are achieved by using models 1, 2, 3, 4, 6, 8 and Table 1.

As shown in Table 5 the average error percentage of the time series models and the regression of concrete pavement are equal, but considering that the time series models are very sensitive to the data of its previous years and since 2013 with the rise of bitumen price as well as the liberalization of the subsidies (consequently sudden incremental rise in the construction

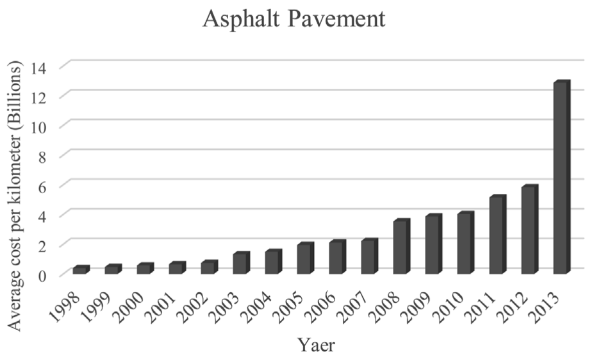

Fig. 4. Trend of price change of asphalt pavement during the time.

Table 5
Percent error of estimation price of pavement for regression and time series model.

Pavement	Model	P.E			$P.E_A$
		2014	2015	2016	Average
Concrete	Regression	7	−8	−10	8
	Time series	−11	−5	−7	8
Asphalt	Regression	0	−10	−11	7.1
	Time series	10	−71	−46	42

Table 6
Standard deviation of independent variables.

Pavement	Benchmark	Standard Deviation
Concrete	dump truck with a capacity of about 10 tons with the driver	74,051.307
	Washed gravel	22,398.139
Asphalt	Washed sand	19102.972
	Washed gravel	22398.139
	Bitumen MC 250	2027.136
	Asphalt worker	10913.199
	Sprinkler tank (20000 liters) with driver	92683.248
	rubber wheel loader with a power of about 150 horsepower with the driver	119353.338
	grader with 150 horsepower with a driver	118394.338
	Play asphalt machines - Finger wheel chainsaw with driver	153284.769

cost of asphalt pavement) this model does not provide a good estimation for asphalt pavement. Therefore, errors in the time series model of the asphalt pavement are very large. Hence, the authors intend to use the regression models of asphalt and concrete pavements for performing the Monte Carlo simulation to assess economic risks.

4.3. Evaluation of economic risk

Now, to evaluate the economic risks of concrete and asphalt pavements, the Monte Carlo simulation was applied. To determine the price fluctuations of independent variables, the historical data would be applied. Since the price of the last three years of independent variables (2014, 2015 and 2016) was due to price fluctuations, they were out of the ordinary. The data in the years 1998–2013 were selected to find their distribution. Since the cost prediction model for both of pavements is clear, the second step, which is determining the distribution of independent variables, was taken. The authors examined their normality and, in the normal case, the standard deviations of the independent variables were discussed. By examining the ten independent variables, the normality of data was proved and their standard deviations demonstrated in Table 6. The parameters depicted in Table 6 are the same as those existing in the cost prediction model for concrete and asphalt pavement.

The results of the Monte Carlo simulation and 10,000 times of the repetition are as Figs. 5 and 6., and Table 7; calculations were carried out in the @RISK software:

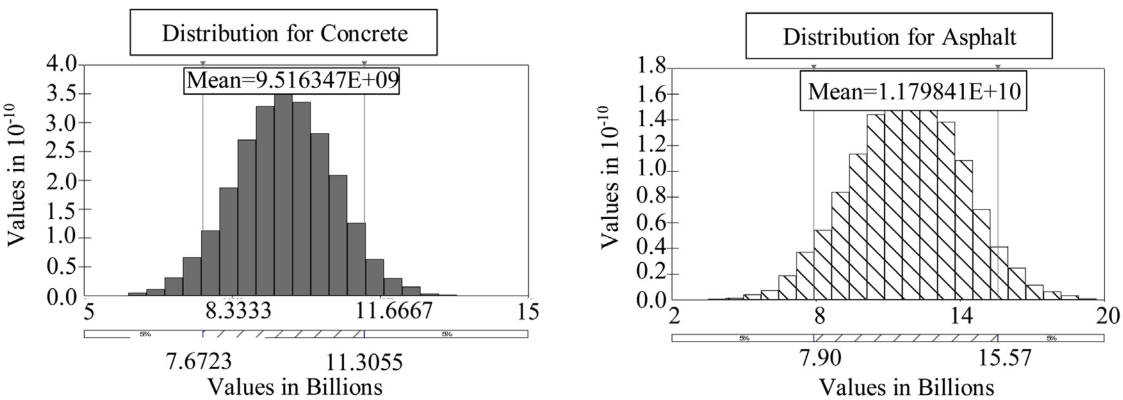

Fig. 5. Estimated histogram for price changes for pavement on freeways and highways.

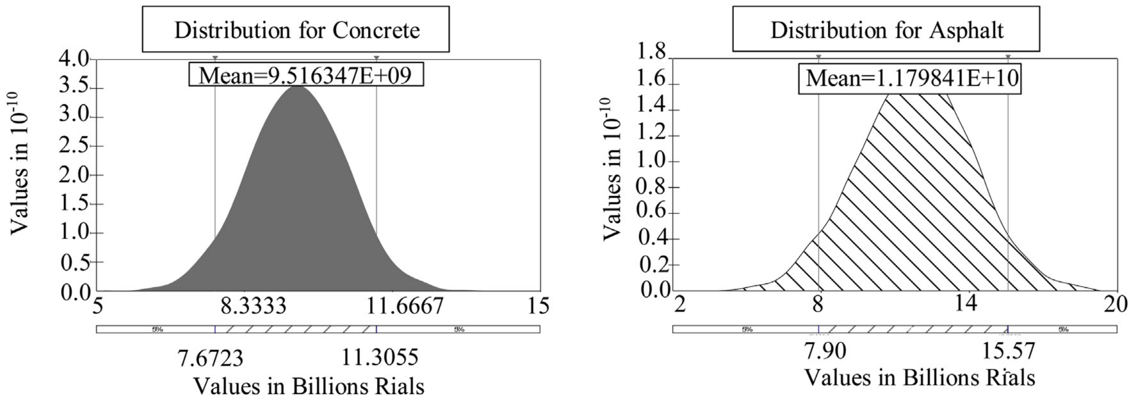

Fig. 6. Predictive curve of price changes for pavement on freeways and highways.

Table 7
Information on the prediction of price changes on pavements in freeways and highways.

Name	Minimum	Mean	Maximum	Std Dev	Variance	Skewness	Kurtosis	Mode	Left X	Left P
Asphalt	3.51E+09	1.18E+10	1.97E+10	2.32E+09	5.38E+18	−3.14E-02	2.932057	8.71E+09	7.90E+09	5%
Concrete	5.17E+09	9.52E+09	1.42E+10	1.11E+09	1.22E+18	−2.19E-02	2.976211	8.58E+09	7.67E+09	5%
Name	**Right X**	**Right P**	**Diff. X**	**Diff. P**	**5th Perc.**	**95th Perc.**				
Asphalt	1.56E+10	95%	7.67E+09	90 %	7.90E+09	1.56E+10				
Concrete	1.13E+10	95%	3.63E+09	90 %	7.67E+09	1.13E+10				

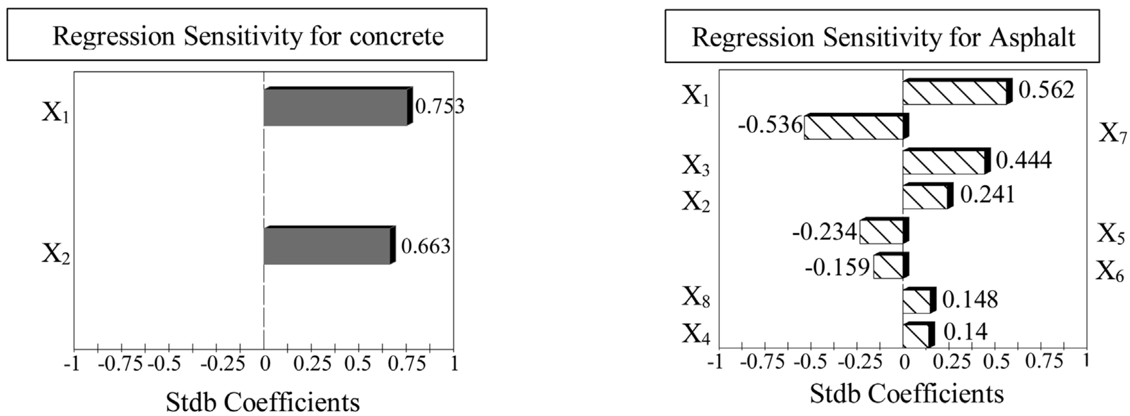

Fig. 7. Tornado Graph Analysis of sensitivity to pavement prices on freeways and highways.

As shown in Figs. 5 & 6, also in Table 7 with more details, it is revealed that the standard deviation of asphalt pavements is greater than concrete pavement. In other words, the economic risk or cost fluctuation of asphalt pavements in Iran will be higher than concrete ones. By referring to Table 1, the cost of concrete pavement in comparison with asphalt pavement has been decreased from 2008 to 2016. This implies that the choice of concrete pavement is more logical than its cost and economic risks on freeways and highways.

For more investigations on results, a sensitivity analysis was done. Fig. 7 presents tornado graphs for each pavement. As shown in Fig. 7, the sensitivity of variables in each pavement is different. The cost of per hour for a dump truck with a capacity of about 10 tons with the driver is more sensitive than washed sand on the cost of concrete pavement but this difference is not considerable. In the same way, the cost of asphalt pavement is more sensitive to washed sand. This analysis is useful when the change in the price of independent variables occurs. The decision-maker can trace the amount of change in the cost of each pavement. In other words, the decision-maker should pay attention to those variables with high sensitivity during the execution phase to decrease its economic risk during the construction.

5. Conclusion

The pavement is one of the most important components of roads since it directly contacts with the vehicles. The structure of pavements is related to their types. There are two most frequently used pavements in Iran, concrete and asphalt. Since the considerable amount of road building cost is dependent on the cost of pavements, it is necessary to answer this question whether the concrete or asphalt pavements are the suitable selection. This paper intends to answer this question in terms of the economic risks. The probability of price changes in constructing concrete or asphalt pavements has been applied as a definition of the economic risks in this paper. Since the Iranian government is responsible for most infrastructures such as freeways and highways, the problem of price changes is very important. As an example, the government budget to complete the freeways projects has been challenged when the price of bitumen has been doubled in Iran. Based on unofficial reports, about 40 % of the Iranian budget in the freeways projects has been consumed to provide bitumen. There is the same challenge for concrete pavements such as the probability of price changes of cement. The findings of this paper can help administrators to decide to implement which type of pavement in their projects with respect to the economic risk of construction.

To determine which type of concrete or asphalt pavements has lower price changes in Iran, two sections were developed. In the first section, developing a model to predict the cost of these pavements was considered and in the second section, the best choice was selected in terms of economic risks for constructing Iranian highways and freeways. In more detail, based on the collected data for the years 1998–2016, two models including the regression model and time series were developed to predict the cost of concrete and asphaltic pavement. To find a suitable model, the regression and time series ones were compared based on their average errors when they estimate the future cost and their ability to work in an abnormal situation. The results showed that although the two models give the same average error in the normal situation, the regression model is more appropriate than the time series model when they are applied in an abnormal situation. The results of the regression model showed that the cost of concrete pavement would be estimated by two independent variables with 8% mean error and eight independent variables with 7.1 % mean error for asphaltic pavement. After finalizing the prediction model, by applying the Monte Carlo simulation, the economic risks of these pavements were assessed. The results showed that the cost of concrete pavement during the construction phase is cheaper than asphalt pavement since 2008 in Iran. This is because of the increase of bitumen prices and the rise of cement production in the country but the main question is which type of pavement has the lowest economic risk. For the year 2016, using the simulation of Monte Carlo and 10,000 times, 90 % of the price range for the cost of concrete pavement ranged from 7.67 to 11.31 billion Rials. For asphalt pavement, this amount stood between 7.90 and 15.57 billion Rials. Meanwhile, the results of the Monte Carlo simulation indicated that the concrete pavement has less standard deviation than the asphalt pavement. It means that the probability of price changes in the concrete pavement is less than asphalt pavement.

However, the authors tried to do their best there are some shortcomings in this research. The first one is that the findings of this paper including the price of two pavements and the result of economic risk assessment are strongly related to the Iranian project specifications but the presented methodology can be applied in every situation. The other shortcoming is that this paper did not consider other criteria such as maintenance costs and the duration of projects. The authors limited their research to changes of these pavements' ingredients and they wanted to conclude the behavior of these pavements in terms of their cost based on the historical data their ingredients. Another limitation was to ignore environmental issues. The results may be altered when the environmental issues were considered.

According to the stated shortcomings, researchers in their future study can develop their works in solving these shortcomings. Moreover, the future works can use Montenegro's neural networks and simulations to evaluate the economic risks of these two types of pavements and compare the results of their work with the present attempt to answer the question as to which method will be preferable. Also, it is possible to evaluate the economic risk of these two pavements using other risk assessment methods such as Real Option and compare the results with the results of the present research work. The other suggestion is comparing the risk of concrete and asphaltic pavements in the life cycle of pavements.

Declaration of Competing Interest

There is no conflict of interest.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.cscm.2020.e00346.

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