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Slime mould algorithm based approaches to solve traffic insurance gross premiums of Türkiye

Murat Aslan [1]

[1] *Department of Computer Engineering, Faculty of Engineering, Şırnak University, 73000 Şırnak, Türkiye*

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ABSTRACT

Highway traffic injuries are a major public health problem for all nations. As it is seen in the whole world, also in Türkiye, road traffic crashes are among the ones that cause death. As a result, road traffic congestion and fatalities represent a significant cost to national economies. The compulsory motor vehicle liability insurance is one of the most common types of insurance, both because it is compulsory and because the number of motor vehicles in Türkiye is very high. Therefore, estimation of the traffic insurance gross premiums (TIGP) problem is being an important problem for Türkiye as well as the other countries. In this study, in order to make some proper TIGP estimations for Türkiye, three different slime mould algorithm (SMA) methods such as SMA-Linear, SMA-Quadratic and SMA-Exponential are proposed. In the experiments, the population, number of vehicles and number of accidents and the observed TIGP historical data records of Türkiye taken from Turkish statistical institute (TUIK) and Turkish insurance association (TSB) for the years (2009-2020) have been used. First, the models are constructed using the SMA-Linear, SMA-Quadratic and SMA-Exponential methods, and then the methods based on the SMA-Linear, SMA-Quadratic and SMA-Exponential models are used to estimate the TIGP values for the years (2009-2020). According to the experiments, the best fitness values of 20 runs for SMA-Linear, SMA-Quadratic and SMA-Exponential are obtained 13.42221, 7.961962 and 294.3409, respectively. As a result, it is seen that SMA-Quadratic methods produces better or comparable performance on the problem dealt with this study in terms of solution quality and robustness.

1. Introduction

Transportation is one of the most important issues of our life and age. The highway, seaway, railway and airway are used for transportation [1]. The highway is the oldest form of transportation in history. And it is also the foundation of our transportation infrastructure [2]. Therefore, the external costs of road transport have been an important issue for political agenda over the last couple of decades [3]. The demand for and intensity of highway use has been on the rise, particularly as a result of population growth and the expansion of welfare status [4]. Due to the growing need for road transport, investments in road transport as well as appropriations and expenditures are increasing [2]. In general, the quality of inspection systems does not grow at the same rate as the number of vehicles in a country. As a result, enforcement is not at the desired level and traffic accidents occur due to inadequate enforcement [4, 5]. Traffic accidents are an unavoidable, albeit undesirable, consequence of road travel. They create a serious financial situation for individuals and society. Personal injury, property damage and lost time are the most noticeable

1* Corresponding author
e-mail: murataslan@sirnak.edu.tr
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personal costs [6].

Road traffic injuries are a major public health problem. Therefore, it is need of concerted efforts for effective and sustainable prevention [7]. According to the World Health Organization's (WHO), approximately 1.3 million lives are lost each year as a result of road traffic crashes. Between 20 and 50 million more suffer non-fatal injuries, and many are disabled as a result of their injuries [8]. In order to protect the safety of life and property of people and communities on the highways, each country has developed legal regulations according to its own laws. Thus, traffic insurance premiums are legally mandatory for vehicle owners [9].

Automobile liability insurance, which was first introduced in Denmark on March 20, 1918, began to spread to other countries after World War I. In the 1920s, the practice in Denmark was followed by other Scandinavian countries. In the same years, similar practices began to be seen in countries far from Europe. In fact, liability insurance for motor vehicles became mandatory in New Zealand and the US state of Massachusetts in 1927 [9, 10]. Road is the most used mode of transportation in Türkiye. It is used for both passenger and freight transportation. More than 90 % of all the transportation operations have been carried out through the road. As it is seen in the whole world, also in Türkiye, road traffic crashes are among the ones that cause death. As a result, road traffic congestion and fatalities represent a significant cost to national economies [1, 11]. Insurance activities started in Türkiye in 1870 after the Pera fire in Istanbul. Subsequently, traffic insurance became compulsory in Türkiye in 1983 [9, 12].

The compulsory motor vehicle liability insurance is one of the most common types of insurance, both because it is compulsory and because the number of motor vehicles in Türkiye is very high [13]. The insurance sector is developing under the influence of the rapid development of information technologies and product diversity. Forecast studies have also been carried out on the premium production of the sector and the premium production of the following year [4, 14].

Metaheuristic methods have been extensively studied by researchers in recent years for dealing with forecasting problems [4, 5, 15-22]. Main reasons of choosing meta-heuristic methods to solve optimization problems are that though meta-heuristic algorithms do not ensure to find the optimal solution, they provide the optimal or near optimal result, they are problem independent and easily adaptable to any optimization problem [23]. Therefore, in this work, linear, quadratic and exponential statistical regression forms are integrated with slime mold algorithm (SMA) for solving the traffic insurance gross premiums (TIGP) problem of Türkiye. In the experiments, observed traffic insurance gross premiums (OTIGP), population, number of vehicles and number of accidents historical records of Türkiye for the years (2009-2020) have been used. The OTIGP historical data records of Türkiye are taken from the Turkish insurance association (TSB) [4, 24], and the other data samples such as population, number of vehicles and number of accidents are taken from Turkish statistical institute (TUIK) [4, 25].

The rest of the paper is organized as follows: The basic SMA algorithm is explained in Section 2. The problem of the traffic insurance gross premiums is described in detail in Section 3. The experimental results of the proposed algorithms are presented in Section 4. Finally, the conclusions are presented in Section 5.

2. Slime Mould Algorithm (SMA)

Slime mould algorithm (SMA) is one of the stochastic optimization algorithm inspired from the concept of slime mould. In the absence of complete information, slime mould decide to the change its location with adopt heuristic or empirical rules based on the insufficient information currently available. A slime mould needs to move from its current location to a new location when the quality of the food source is being insufficient. According to the past experience when a slime mould encounter high-quality food, the probability of moving the current location decreases [26]. In addition, because of slime mould have some unique biological characteristics that allow them to consume different food sources simultaneously. Therefore, even if the slime mould has found a better food source, it can still split a component of the biomass to utilize both resources simultaneously if higher quality food is found [18, 27]. The mathematical scheme of the SMA is described in detail as follows:

2.1. Approach food

The slime mould can close the food source with the odour in the air. The mathematical expression of approaching behavior is provided in Eq. (1) and Eq. (2). The position of the current slime mould will be changed depending on the value of p. r is a random value in range of [0,1]. If the value of p is greater than the value of r, the current position of slime mould is updated according to Eq. (1), otherwise the current position of slime mould is updated according to Eq. (2).

$$\overrightarrow{X(t+1)} = \left\{ \overrightarrow{X_b(t)} + \overrightarrow{v_b} . \left(\overrightarrow{W} . \overrightarrow{X_A(t)} - \overrightarrow{X_B(t)} \right), \ r < p \right. \quad (1)$$

$$\overrightarrow{X(t+1)} = \overrightarrow{v_c} . \overrightarrow{X(t)}, \ r >= p \quad (2)$$

Where, $\overrightarrow{v_b}$ refers to a parameter in range of $[-a, a]$, $\overrightarrow{v_c}$ value decreases linearly from one to zero. t refers to current iteration, $\vec{X}$ represents the slime mould population, $\overrightarrow{X_b}$ refers to position of slime mould with best fitness value, $\overrightarrow{X_A}$ and $\overrightarrow{X_B}$ positions represents the two different positions randomly selected from slime mould population. $\vec{W}$ shows the weight of slime mould population. p value is calculated with the fitness values of slime mould population and the fitness of $\overrightarrow{X_b}$ position.

$$p = \tanh |S(i) - DF| \quad (3)$$

Here, $i \in 1,2, \ldots, n$ and S(i) refers to the fitness values of $\vec{X}$ population, DF refers to the fitness value of the best position. The value of a is calculated as follows:

$$a = \operatorname{arctanh}\left(-\left(\frac{t}{\max_t} \right) + 1 \right) \quad (4)$$

The formulation of $\vec{W}$ is given as follows:

$$\overrightarrow{W(\text{SmellIndex}(i))} = \begin{cases} 1 + r.\log\left(\frac{bF - S(i)}{bF - wF}\right) + 1, \text{condition} \\ 1 - r.\log\left(\frac{bF - S(i)}{bF - wF}\right) + 1, \ \text{others} \end{cases} \quad (5)$$

$$\text{SmellIndex} = \text{sort}(s) \quad (6)$$

Where condition shows that S(i) ranks first half of the population, r is a random value in range of [0,1], $\max_t$ indicates the total number of iteration, bF shows the best fitness value obtained in the current iteration, bF shows the worst fitness value obtained in the current iteration, SmellIndex holds the sequence of the fitness values from the best to worst.

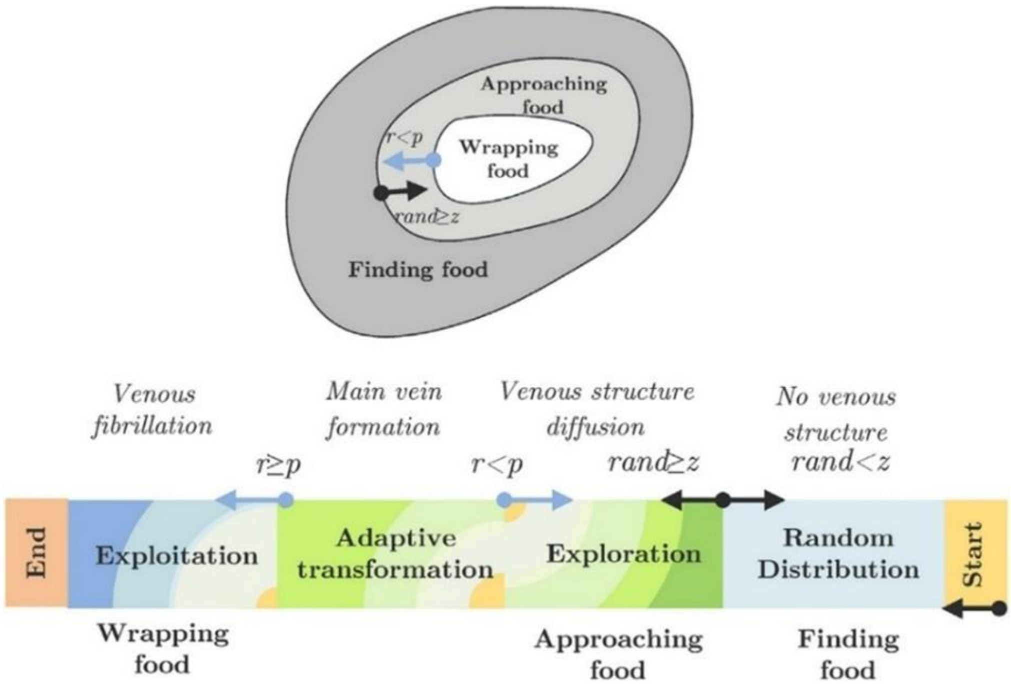

Figure 1 The algorithmic steps of SMA method [27]

2.2. Wrap food

This section presents the mathematical model of the contraction mode of venous tissue structure for slime mould in the search area. The higher the concentration of food contacted by the vein, the stronger the wave generated by the bio-oscillator, the faster the cytoplasm flows, and the thicker the vein. In the searching process of finds quality food sources, sometimes after a while the positions of the slime mould get stuck in the local optimum. In this case, a new position is generated for current position of slime mould individual. New position of current individual is generated with Eq. (7)

$$\overrightarrow{X^*} = rand().(UB - LB) + LB, \quad rand < z \qquad (7)$$

Where UB and LB show the upper limit and lower limit of a problem in search space, respectively, rand() represents a random value in range of [0,1] and if rand() value is smaller than the value of z, a new position is generated for current position of slime mould individual. After these explanations, the steps of the SMA and the framework of the SMA are presented in Figure (1) and Figure (2), respectively.

```
The initialization of algorithm
    Set the dimension of the problem (D)
    Set the number of individuals (N)
    Set the termination condition (max_t)
    Set the parameter z
    Generate N random position on the D-dimensional search space
    Calculate fitness value for slime mould population
    Sort slime mould population and find SmellIndex
    Find the best solution X_b, best fitness and worst fitness
    Set iteration counter t = 1
Searching process in solution space
  WHILE t <= max_t
    Calculate S value
    Calculate the fitness weight of each slime mould individual with Eq. (5)
    Calculate the value of a with Eq. (4)
    Calculate the value of b  (b = 1 − t/max_t)
    FOR Each individual of slime mould (X_t)
        IF rand < z
            Generate a new position for current individual with Eq. (7)
        ELSE
            Calculate p value with Eq. (3)
            Determine v_b and v_c
            Select randomly two different position ( X_A and X_B)
          FOR Each dimension of candidate solution
              IF rand < p
                 Apply the Eq. (1) for creating a new position for current position
              ELSE
                 Apply the Eq. (2) for creating a new position for current position
              END IF
          END FOR
        END IF
        Calculate fitness value for each individual of slime mould population
        Update the current position of the candidate solution
    END FOR
        Sort slime mould population and find SmellIndex
        Find the best solution X_b, best fitness and worst fitness
        t =t +1
Testing the termination condition
    IF Termination condition is not satisfied
       Go to Step searching process in solution space
    ELSE
       Report the best solution
    END WHILE
```

Figure 2 The framework of the basic SMA method [27]

3. Traffic Insurance Gross Premiums (TIGP) Problem

In this study, to create the estimation models of TIGP problem, three types of mathematical forms such as linear, quadratic and exponential forms are utilized with SMA technique. The population, number of vehicles and number of accidents indicators are used as input parameters, and the OTIGP indicator is used as an output parameter of linear, quadratic and exponential models. The linear, quadratic and exponential models used in this study are presented in Eq. (8), Eq. (9) and Eq. (10) respectively [17, 19, 28].

$$T_{\text{linear}} = W_1 + W_2.X_1 + W_3.X_2 + W_4.X_3 \qquad (8)$$

Where, T_{linear} denotes to obtained TIGP value, W_1 denotes to independent coefficient, W_2, W_3 and W_4 denote to population, number of vehicles and number of accidents, respectively. X_1, X_2 and X_3 indicate to data samples for per a year. The calculation of quadratic model is presented in Eq. (11).

$$T_{\text{quadratic}} = W_1 + W_2.X_1 + W_3.X_2 + W_4.X_3 + \ldots \\ W_5.X_1.X_2 + W_6.X_1.X_3 + W_7.X_2.X_3 + \ldots \\ W_8.X_1^2 + W_9.X_2^2 + W_{10}.X_3^2 \quad (9)$$

Here, $T_{quadratic}$ denotes to obtained TIGP value, W_1 denotes to independent coefficient, $W_2 - W_{10}$ denote to population, number of vehicles and number of accidents indicators and their different combinations. X_1, X_2 and X_3 indicate to data samples for per a year. The calculation of exponential model is presented in Eq. (12).

$$T_{\text{exponential}} = W_1 + W_2.X_1^{W_3} + W_4.X_2^{W_5} + W_6.X_3^{W_7} \quad (10)$$

Where, $T_{exponential}$ refers to obtained TIGP value, W_1 denotes to independent coefficient, $W_2 - W_7$ represent denote to population, number of vehicles and number of accidents indicators and their different combinations. X_1, X_2 and X_3 indicate to data samples for per a year. The mathematical formulation of the fitness function between OTIGP and estimated traffic insurance gross premiums (ETIGP) is performed according to the Eq. (11) [16, 28].

$$\min \quad f(v) = \sum_{h=1}^{H} \left(T_h^{observed} - T_h^{estimated} \right) \quad (11)$$

Here, h denotes to a year of historical data samples and it is $h = 1, 2, \ldots, H$, H shows the total number of historical data samples. $T_h^{observed}$ and $T_h^{estimated}$ denote the OTIGP and ETIGP of hth data sample, respectively.

4. Experimental results

Linear, exponential and quadratic forms based three types of SMA techniques are implemented on the traffic insurance gross premiums problem: a case study of Türkiye. The historical data samples of Türkiye for the years (2009-2020) are directly taken from the study of Tefek and Arslan [4]. Population, number of vehicles and number of accidents indicators are used as input parameter of proposed models, and OTIGP indicator is used as output parameter of proposed models. Estimation models are created by using the historical data samples of Türkiye for the years (2009-2020) with proposed algorithms. All methods were coded in MATLAB and a laptop with WINDOWS 10 PRO OS, INTEL(R) CORE(TM) I7-6700HQ 2.60 GHZ CPU, 24 GB OF RAM was used in experiments. The SMA-Linear, SMA-Quadratic and SMA-Exponential algorithms are realized with 20 independent run. The number of slime mould population is chosen as 100 and the stopping criteria (max_t) is chosen as 5×10^3 for all methods. The search space for weight coefficients is assumed to be [-100, 100]. The experiments are reported as the Best, Worst, Mean, Median, Standard Division (Std.) of the fitness values for 20 runs and Amount of Errors (Error). Table 1 shows the historical data samples of Türkiye for the years (2009-2020).

Table 1 The OTIGP, population, number of vehicles and number of accidents dataset of Türkiye for the years (2009-2020) [4]

Year	OTIGP (10^9 TL)	Population (10^6)	Number of vehicles (10^6)	Number of accidents (10^5)
2009	1.971735	72.5	14.3167	10.53
2010	2.305579	73.7	15.0956	11.06
2011	2.700477	74.7	16.08953	12.29
2012	3.600106	75.6	17.03341	12.97
2013	4.965999	76.6	17.93945	12.07
2014	5.072925	77.7	18.82872	11.99
2015	6.810611	78.7	19.99447	13.13
2016	12.47027	79.8	21.09042	11.82
2017	12.49827	80.8	22.21895	12.03
2018	15.30191	82.03	22.86592	12.29
2019	18.0185	83.1	23.15698	11.67
2020	19.57144	83.6	24.14486	9.84

4.1. *Compare the results of linear, quadratic, and exponential model based SMA methods*

Table 2 shows the Best, Worst, Mean, Median and Std. of the fitness values of 20 independent runs for the compared algorithms. When Table 2 is examined, it is seen that the SMA-Quadratic has found the better results than compared algorithms in terms of the Best, Mean and Median fitness values. In addition, SMA-Linear method has found the better results for Worst and Std. criteria.

The convergence graph of the compared algorithms for mean fitness values is given Figure 3. As seen from Figure 3, the convergence of the SMA-Quadratic method is better than the other methods. The less convergence result is obtained from SMA-Exponential method. In addition, SMA-Exponential dropped to the local optimal solution in around of 500 iterations.

Table 2 The best, worst, mean, median fitness values and Std. of 20 runs for compared algorithms.

Algorithm	Criterion				
	Best	Worst	Mean	Median	Std.
SMA-Linear	13.42221	**15.08275**	13.91263	13.82632	**0.472677**
SMA-Quadratic	**7.961962**	21.76866	**13.56407**	**13.32446**	2.967005
SMA-Exponential	294.3409	458.0812	442.262	456.117	40.62914

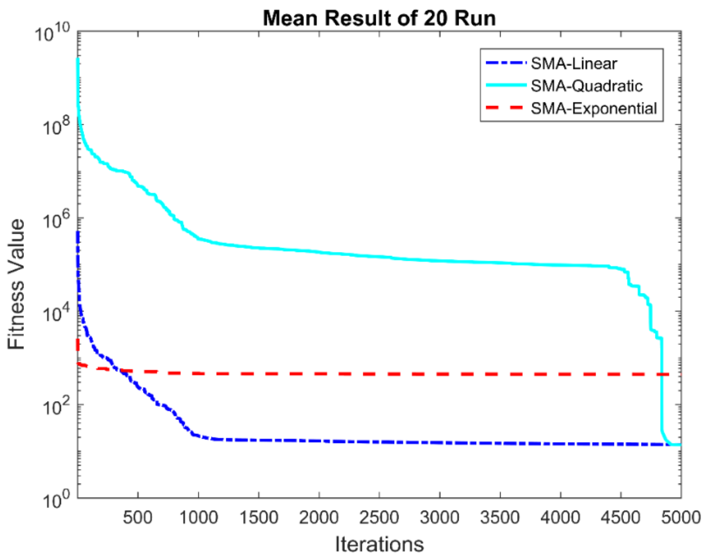

Figure 3 The convergence curves of mean results of fitness values of 20 runs for compared algorithms

Table 3 The OTIGP, ETIGP and Amount of Errors results for the years (2009-2020)

Year	OTIGP	SMA-Linear			SMA-Quadratic			SMA-Exponential		
		ETIGP	Error	Rank	ETIGP	Error	Rank	ETIGP	Error	Rank
2009	1.97173515	1.14774420	-0.82	2	**1.69065404**	**-0.28**	**1**	5.95538043	3.98	3
2010	2.30557857	**2.35800160**	**0.05**	**1**	2.36044617	0.05	2	6.39035949	4.08	3
2011	2.70047692	2.28505940	-0.42	2	**2.50952860**	**-0.19**	**1**	6.91009056	4.21	3
2012	3.60010599	2.81991490	-0.78	2	**3.06225810**	**-0.54**	**1**	7.37123366	3.77	3
2013	4.96599914	5.72164000	0.76	2	**5.01556966**	**0.05**	**1**	7.78759167	2.82	3
2014	5.07292488	7.63363950	2.56	2	**6.65267804**	**1.58**	**1**	8.17384190	3.10	3
2015	6.81061146	**7.69732680**	**0.89**	**1**	7.72610570	0.92	2	8.65016859	1.84	3
2016	12.47027356	**11.34313470**	**-1.13**	**1**	10.82468120	-1.65	2	9.07029012	-3.40	3
2017	12.49826970	**12.70569170**	**0.21**	**1**	13.06206187	0.56	2	9.47795992	-3.02	3
2018	15.30191038	14.33307380	-0.97	2	**15.11109297**	**-0.19**	**1**	9.70129776	-5.60	3
2019	18.01849968	16.91574150	-1.10	2	**17.13225249**	**-0.89**	**1**	9.79946157	-8.22	3
2020	19.57144198	20.33073370	0.76	2	**20.17997758**	**0.61**	**1**	10.12257187	-9.45	3

The OTIGP, ETIGP obtained by the proposed methods for the years (2009-2020) and the Amount of Errors are presented in Table 3. The difference between the OTIGP value and the ETIGP value indicates the Amount of Error. Table 3 shows that the ETIGP results of the SMA method based on the quadratic model are close to the OTIGP results when compared with the results of the other models. Besides, SMA-Quadratic provides the best results for 8 different years, and SMA-Linear provides the best results for 4 different years. Fewer results are obtained from SMA-Exponential method and there is no best result found for any year.

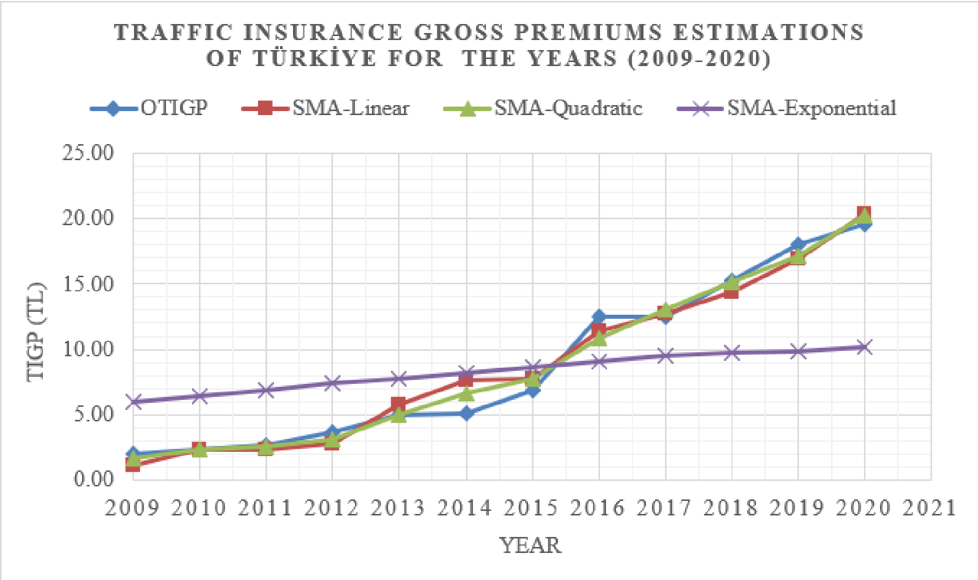

Figure 4 The OTIGP and the estimation values obtained by the proposed methods for the years (2009-2020)

The OTIGP of Türkiye for the years (2009-2020) and the estimation outcomes of linear, quadratic and exponential forms of SMA are illustrated in Figure 4. It can be seen that the TIGP of Türkiye is gradually increasing according to the OTIGP results of Türkiye for the years (2009-2020). Figure 4 shows that the ETIGP results of SMA-Quadratic are more similar to the OTIGP results when compared to the SMA-Linear and SMA-Exponential.

Table 4 The weight values, best fitness values and total error obtained by compared methods

Algorithm	Weight Coefficients	Best Fitness Value	Total Error	Total Rank
SMA-Linear	[-100.00 1.5860 0.0623 -1.3991]	13.42	10.44	20
SMA-Quadratic	[0.5374 -0.0509 -3.7062 0.1792 0.0124 0.0017 0.0025 0.0054 0.0880 -0.0423]	**7.96**	**7.50**	**16**
SMA-Exponential	[71.4774 67.6793 -75.7634 -91.5613 -0.1257 -32.2170 -43.3196]	294.34	53.50	36

The weight coefficients, best fitness values, total errors and total ranks found by the linear, quadratic, and exponential model-based SMA algorithms for the years (2009-2020) are shown in Table 4. The total error is calculated as the sum of the absolute difference between the OTIGP and ETIGP values for each year. According to the Table 6, the experimental results of SMA-Quadratic method is greater than the other compared methods in terms of the best fitness values and total error criteria. If we examine Table 4, we can see that the performance of the SMA-Exponential is lower than the results obtained by the other methods. The second-best results are obtained by SMA-Linear method. The best fitness value, total error and total rank obtained by the SMA-Quadratic method are 7.96, 7.50 and 16 respectively.

5. Conclusions

This study focuses on creating an appropriate estimation model for solving traffic insurance gross premiums problem of Türkiye. SMA is a population based stochastic optimization algorithm proposed by Li et al. (2020) [27] for solving continuous optimization problem. The slime mould expression is represented to Physarum polycephalum and the reason of called as slime mould is it was first classified as a fungus. Road traffic injuries are a major public health problem. As it is seen in the whole world, also in Türkiye, road traffic crashes are among the ones that cause death. As a result, road traffic congestion and fatalities represent a significant cost to national economies. Therefore, in this study, three different SMA methods such as SMA-Linear, SMA-Quadratic and SMA-Exponential are proposed and implemented on traffic insurance gross premiums problem of Türkiye. In the experiments, the population, number of vehicles and number of accidents and the observed TIGP historical data records of Türkiye taken from TUIK and TSB for the years (2009-2020) have been used [24, 25]. After creating the regression models with SMA-Linear, SMA-Quadratic and SMA-Exponential methods, the proposed methods are implemented on the dataset of Türkiye for the years (2009-2020) in order to estimate the TIGP values. When the experimental results and comparisons are examined, it can be seen that the SMA-Quadratic method is obtained competitive and effective results for estimating the traffic insurance gross premiums.

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