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A GENETIC ALGORITHM–BASED APPROACH TO PREDICT PAVEMENT MAINTENANCE STRATEGIES: IRAQI EXPRESSWAY NO.1 CASE STUDY

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ABSTRACT: The present paper articulates the applicability of genetic algorithms (GAs) as an optimization tool capable of supporting decision-makers (DMs) to make the right decisions throughout the selection of an optimal pavement maintenance strategy and to predict future pavement condition. GAs efficiently take advantage of historical information to locate search points with improved performance. In this regard, pavement condition index (PCI) for the in-service pavement of the selected case study (Expressway No.1 (R4/A) in Iraq) is estimated based on ASTM D6433-11 and using MicroPAVER 6.5.2 software. Moreover, the related field measurements of the in-service pavement distresses are carried out and classified. To predict the optimal maintenance strategy for the pavement segments within the selected pavement portion case study, a GA optimization technique is implemented as an application of stochastic approach using EVOLVER 6.3.1 software to evaluate the pavement performance based on PCI. For the required validation process of the predicted PCI results obtained by the GA technique, predicted PCI results obtained by experts' opinions based on the design questionnaire were estimated and applied. The statistical validation analyses showed that the predicted PCI values obtained via EVOLVER 6 Genetic Algorithm software seem to be close to those obtained via the analyses of the experts' questionnaires. Based on the research outcomes, it is concluded that one can recognize using the presented procedure throughout the implementation of stochastic approach in the form of GA to predict the optimal pavement maintenance strategy for in-service pavement.

Keywords: Pavement Maintenance Strategies, Genetic Algorithm, Optimization, Pavement Condition Index.

1. INTRODUCTION

Pavement management requires a large investment and much effort. Accordingly, the related agencies need to maintain and manage the required process effectively. Effective pavement management would yield a safe environment for public users.

The decision-makers (DMs) who have to make these types of choices often do so based on a number of criteria. Such criteria include an application of a proper optimization technique to predict the limited budget for capital and recurrent expenditure and the need to keep the transportation facilities operation at an acceptable level of service.

In many real-life problems, objectives under consideration conflict with one another, and optimizing a particular solution with respect to a single objective can result in unacceptable results with respect to other objectives. A reasonable solution to a multi-objective problem is to investigate a set of solutions, each of which satisfies the objectives at an acceptable level without being dominated by any other solution [1].

There has been a tremendous research effort to solve the complex problems by applying techniques to produce sufficiently precise results given the scope of the problem. These techniques are generally known as soft computing methods, which mainly include computing methods based on artificial neural network (ANN), genetic algorithm (GA), and others. All of these methods have a wide range of applications in engineering problems [2]. GAs are a class of computational models working based on the evolutionary process in nature.

GAs use the adaptation-based random directed search techniques inspired by natural selection to obtain robust and computationally efficient solutions for engineering problems. They have been very popular in the last three decades due to their attractive features, such as the fact that they do not require a previous knowledge of the problem domain, so their robustness has been well established. There are numerous successful implementations in the literature for search and optimization problems as well as machine learning [3].

1.1 Purpose Statement

Rating of the pavement maintenance alternative for selecting the optimal alternative is the largest problem facing pavement management agencies; this procedure is costly and causes delay. DMs are required to select a maintenance alternative that closely meets their criteria. Decision-making in pavement management is a complex process due to budget constraints and multiple criteria. For this reason and to assist the local agencies, it is proposed that agencies use an optimization process throughout the application of a stochastic approach based on GA to simplify selecting an optimal maintenance alternative and predict the future condition of pavement.

1.2 Research Goals

The main goal of the present paper is to predict pavement maintenance alternatives using a stochastic technique to evaluate and estimate in-service pavement performance and to predict an optimal maintenance strategy for the future based on a GA technique using EVOLVER 6 software to predict the pavement condition index (PCI). Accordingly, the goal is to predict the optimal maintenance alternative for the pavement segments within the selected case study: Expressway No.1 (R/4A) in Iraq**.**

2. PAVEMENT CONDITION ASSESSMENT

Figure 1 presents a simulation between the standard PCI rating scale and the custom rating scale. Accordingly, it is recommended to consider reconstruction pavement maintenance for the PCI range of 0 to 55, and rehabilitation and preventive for the PCI values of 56 to 70 and 71 to 100, respectively.

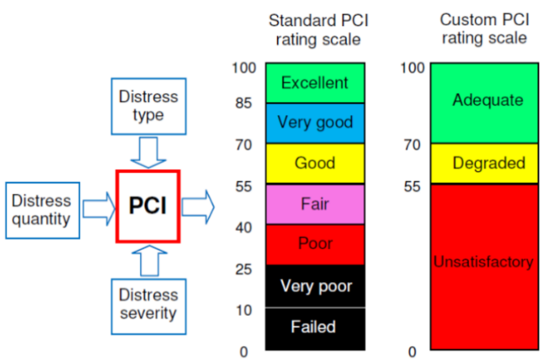

Fig. 1 Simulation between the Standard PCI Rating Scale and the Custom Rating Scale [4].

3. CASE STUDY

The case study represents fifteen asphalt concrete pavement segments of 300 m length each, from the Iraqi Expressway No.1 – (R/4A). Expressway No.1 is the major arterial expressway in Iraq and extends from the Syrian and Jordanian borders to the Kuwaiti border. Section R4 is the segment of Expressway No.1 composed of the contracts R/4A and was constructed in the period of 1979–1989. Section R/4A starts at station 32+000 km and ends at 36+500 km, which is located at AL-Mahmudiya city and serves traffic from Baghdad to Hilla. The pavement section has six lanes, three in each direction, with a standing lane; each direction is separated by an island.

Data include pavement section number and the status of the pavement case study, which is expressed in the form of PCI for each segment based on the field inspections in the current year (2014) and the outputs of MicroPAVER 6.5.2 software. These numbers were used as a base to implement the GA technique, as precisely described in the following subsections. Moreover, the criteria mentioned in section 4 are considered a guide to classify the pavement maintenance strategy for each segment based on its own PCI values.

4. ESTIMATED PCI VALUES OF THE IN-SERVICE PAVEMENT

PCI is analyzed using MicroPAVER 6.5.2 software. The related pavement distresses, such as alligator cracks, lane/shoulder drop-off, longitudinal and transverse cracking, polished aggregate, potholes, rutting, slippage cracking, raveling, and weathering are measured based on ASTM D6433-11. This index can be used to identify when treatments are needed, to define the condition state, for ranking or prioritization, and as the number used to forecast pavement condition and the average PCI of the selected fifteen segments within the pavement selected case study. The estimated PCI values can be seen in Table 1.

Table 1 Estimated PCI's Values (MicroPAVER 6.5.2 software output)

Pavement Segment	PCI Estimate	Pavement Segment	PCI Estimated
1	54	9	63
2	76	10	34
3	53	11	41
4	64	12	58
5	80	13	52
6	76	14	47
7	37	15	58
8	63	---	---

5. PAVEMENT MAINTENANCE DECISIONS USING GENETIC ALGORTHIMS

GA is an optimization method based on biological principles of evolution to provide an interesting alternative. This method is related to the stochastic approach, which is particularly useful for highly nonlinear problems and models, when computation time is not a primary concern.

The search process of GAs for solutions that best satisfy the objective function involves generating an initial random pool of feasible solutions to form a parent solution pool, followed by obtaining new solutions and forming new parent pools through an iterative process.

The fitness value of each solution is used to determine its probable contribution in the generation of new solutions, known as offspring. The next parent pool is then formed by selecting the fittest offspring based on their objective function values. The entire process is repeated until a predetermined stopping criterion is reached [5].

5.1 Optimal Solution Concept

In objective optimization, to measure the fitness of a solution in a given iteration, the process continues until the entire population is ranked, as illustrated in Fig.2. A solution with a lower numbered rank is assigned a higher fitness than that for a solution with a higher numbered rank.

The main goal of the objective optimization process is to achieve a balance between obtaining a well-converged and well-distributed set of optimal solutions. The more diverse the solution is, the better informed the DM is about the range and the spectrum of the possible solutions.

5.2 Solution Representation

Application of the GA technique for any problem requires setting the solution representation by the mean of chromosomes. Chromosome structure is made of a string of values associated with the problem variables. Figure 2 presents the general structure, the solution, and the chromosome production of the GAs. For the problem at hand, each of the chromosome elements has a value from 0 to 100, corresponding to one of the maintenance strategies (70–100 = preventive maintenance, 56–70 = rehabilitation maintenance, and 0–55 = reconstruction).

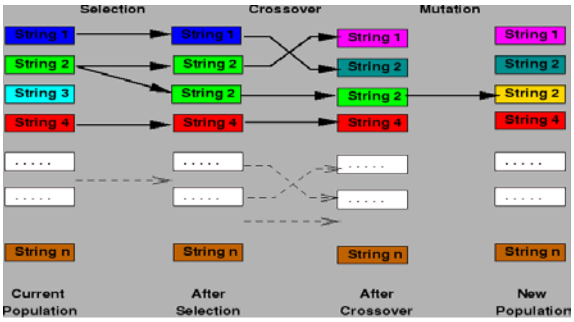

Fig.2 GA Mutation Operation and Chromosome Production [6].

5.3 Objective Function

In the present paper, an objective function optimization model is proposed to maximize the pavement condition. The optimization model outcome is adopted to estimate the values of the objective function. The objective function aims to maximize the condition of the pavement performance, as follows:

Max Average Condition = $\sum_i^n (\boldsymbol{PCI})\boldsymbol{i}/\boldsymbol{n}$,

Where (PCI)i = the pavement condition index of section i and n = the number of pavement segment.

5.4 Genetic Algorithm Optimization

A GA is a method for solving both constrained and unconstrained optimization problems based on a natural selection process that mimics biological evolution. Therefore, it seems like a good idea to mimic the processes of reproduction and survival of the fittest to try to evolve answers to problems. At each step, the GA randomly selects individuals from the current population and uses them as parents to produce the children for the next generation. The following steps describe the optimization process based on the GA:

- Generate a population of possible answers to the problem at hand.
- Choose the best individuals from the population (using methods inspired by survival of the fittest).
- Produce a new generation by combining these best individuals (using techniques inspired by reproduction).
- Stop when the best individual of a generation is good enough (or you run out of time).

5.5 Implementation of Genetic Algorithm

EVOLVER 6 GA software is proposed to be used in this research. Based on the selection of design variables and constraints, this program allows the user to take an Excel spreadsheet with any type of calculation data (no matter how complex) and optimize a calculation outcome. Moreover, the optimization can be performed as a maximization, minimization, or the attempt to reach a target value.

5.6 GA Computation and Results Representation

The predicted PCI values for the proposed maintenance presented in Table 1 are used as input data for the EVOLVER 6 GA software. The results to maximize PCI value depending on the software output can be seen in Table 2.

Table 2 GA Computation–Predicted PCI Values after Proposed Maintenance Strategy for the Case Study Iraqi Expressway (No.1 – R/4A) In-Service Pavement Portion

Pavement Segment	a	b	c	d
1	54	_	_	84
2	76	78	_	_
3	53		_	91
4	64	_	68	_
5	80	83	_	_
6	76	81	_	_
7	37	_	_	76
8	63	_	70	_
9	63	_	71	_
10	34	_	_	63
11	41	_	_	77
12	58	_	65	_
13	52	_	_	83
14	47	_	68	_
15	58	_	65	_
Average	53.7	80.7	67.8	79

a: In-service pavement's estimated (PCI), b, c, and d = (PCI)'s values if Preventive, Rehabilitation and Reconstruction maintenance (respectively) is implemented.

6. STATISTICAL EVALUATION

The following subsections describe the estimation of PCI values and pavement maintenance alternatives based on expert opinions and statistical analysis to evaluate the PCI results predicted via GA computation.

6.1 Estimating PCI Values and Pavement Maintenance Alternatives Based on Expert Opinions

Based on the previously mentioned criteria (Pavement Condition Assessment), the average opinion regarding the PCI values and the maintenance strategy for the selected pavement segments of twenty-eight experts in pavement maintenance, such as academic specialist staff and professional maintenance engineers, through a designed questionnaire were gathered and can be seen in Table 3.

Table 3 Expert Opinions of Predicted PCI Values after Proposed Maintenance Strategy for the Case Study Iraqi Expressway (No.1 – R/4A) In-Service Pavement Portion

Pavement Segment	a	b	c	d
1	54	_	_	88
2	76	81	_	_
3	53	_	_	86
4	64	_	71	_
5	80	83	_	_
6	76	80	_	_
7	37	_	_	75
8	63	_	70	_
9	63	_	70	_
10	34	_	_	73
11	41	_	_	75
12	58	_	68	_
13	52	_	_	86
14	47	_	_	84
15	58	_	69	_
Average	53.7	81.3	69.6	81

a: In-service pavement's estimated (PCI), b, c, and d : (PCI)'s values if Preventive, Rehabilitation and Reconstruction maintenance is implemented.

Figures 3 and 4 present the comparison between the PCI values from the experts' opinions and GA computation results. It clearly shows that the PCI results seem to be close enough to conclude that the PCI–GA computation results can be considered to predict pavement maintenance strategies.

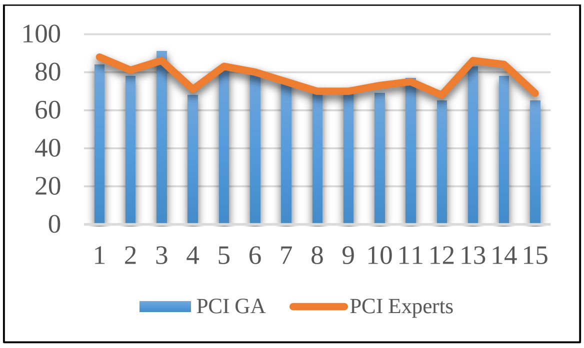

Fig. 3 Comparison between PCI Values of Expert Opinions and GA results for the fifteen pavement segments.

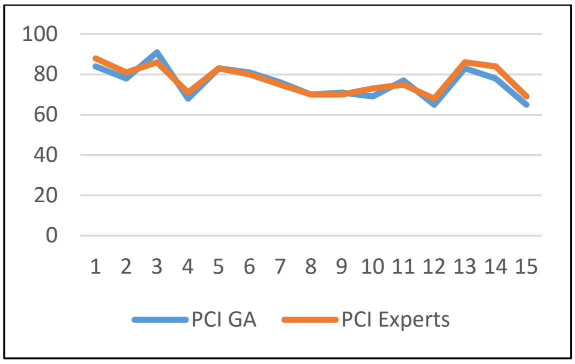

Fig.4 PCI's GA Computation vs. Average Opinion of Experts for Pavement Maintenance Strategy of the fifteen pavement segments,

The average PCI values obtained via expert opinion and GA computation are presented in Table 4. The average PCI results seem to be close to those in Fig. 5. A good fit can be seen in this figure that reflects a strong relationship between the values of PCI, which were estimated by GA computation and obtained from the average opinion of experts.

Table 4 Average PCI Values Obtained via Expert Opinions and GA Computation

	A	B	C
PCI Experts	**81.3**	**69.6**	**81**
PCI GA	80.7	67.8	79

A, B, and C : (PCI)'s values if Preventive, Rehabilitation and Reconstruction maintenance is implemented

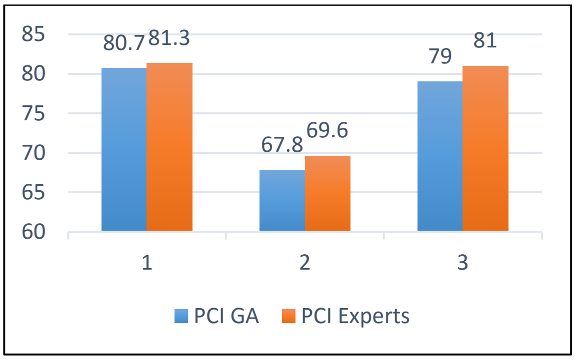

Fig.5 Average PCI from GA Computation vs. Average Opinion of Experts for Pavement Maintenance Strategy

To compare results of PCI obtained by GA computation with those obtained from experts' opinions in the questionnaires, statistical technique is followed through the following two steps: calculating relative error (RE) and graphical techniques.

6.3 Relative Error

To calculate the error between the output results of PCI, the RE technique is proposed. RE is computed as follows [7]:

RE= $|(\boldsymbol{PCI\ Expert} - \boldsymbol{PCI\ GA})/(\boldsymbol{PCI\ Expert})|$ .. (1),

Where: RE = relative error percent,

PCI Expert = estimated PCI based on expert opinion, and, PCI GA = calculated PCI based on GA computation.

Results of the RE analysis are shown in Table 5 and Fig. 6.

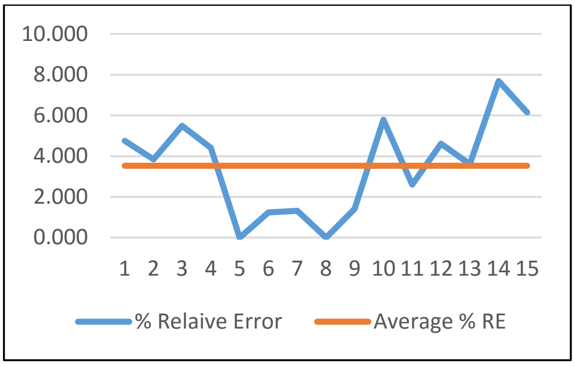

Fig.6 RE Computations for PCI $_{GA}$ and PCI $_{Experts}$

Table 5 RE Computations for PCI$_{GA}$ and PCI $_{Experts}$

No. of	PCI GA	PCI	Relative
1	84	88	4.762
2	78	81	3.846
3	91	86	5.495
4	68	71	4.412
5	83	83	0.000
6	81	80	1.235
7	76	75	1.316
8	70	70	0.000
9	71	70	1.408
10	69	73	5.797
11	77	75	2.597
12	65	68	4.615
13	83	86	3.614
14	78	84	7.692
15	65	69	6.154

Although three out of fifteen RE's values found to be slightly above 5, The percentage of the average RE is found to be 3.53, which is accepted as a prediction error if a confidence level of 95% is adopted.

7. CONCLUSION AND RECOMMENDATIONS

On the basis of the research findings, the following conclusions are appropriate:

1. Optimal maintenance alternatives for the in-service pavement segments within the selected case study (Expressway No.1- (R4/A)) were predicted based on the application of GA optimization technique.
2. Depending on the statistical analyses, it is concluded that the predicted PCI values obtained by expert opinions seem to be in good agreement with these obtained via GA software. Accordingly, it is concluded that using a stochastic GA technique is recommended as a desired optimization approach to predict the optimal maintenance alternative for pavement section.

Based on the study findings, it is recommended to use the presented procedure using a stochastic approach based on GA to estimate the optimal pavement alternatives for in-service pavement and to predict the best maintenance strategy. Furthermore, this approach can assist DMs and local engineers of pavement management systems and highway administration agencies to make the proper decisions during the selection of the proper pavement maintenance alternatives and schedule maintenance allocations for the next years.

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