View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by International Institute for Science, Technology and Education (IISTE): E-Journals

Civil and Environmental Research
ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online)
Vol.9, No.2, 2017
www.iiste.org

Prediction of Optimal Maintenance Alternative for Iraqi Pavement Management Based on Multi-Objective Optimization Technique and Constraint Genetic Algorithm

Dr. Namir G. Ahmed[1] Dr. Ali J. Kadhim[1] Amani A. Ferman[2]
1.Assist. Prof., college of engineering/ university of Al-Mustansiriya
2.MSC. Student, college of engineering/ university of Al-Mustansiriya

Abstract
Pavement management systems (PMS) are widely used to assist the transportation agencies to support the decision makers to select the best maintenance alternatives. To maintain a pavement network under a performance-based efficiently and cost-effectively in a long-term horizon, the local related agencies such as SCRB, mayoralty of Baghdad and Ministry of Municipalities need to provide balance multiple objectives (e.g., cost minimum, performance maximum) which are often different from the requirements of the traditional asset preservation practices. Accordingly, the main objective of this research is to develop a multi-objective optimization model to support the multi-year decision making process of the Iraqi pavement maintenance management system. Two optimization objectives are considered; maintenance cost minimization and pavement condition maximization**.** This study selects the flexible pavement section (R4/B-Expressway No.1) as the study area. Different field measurements are carried out to estimate the pavement performance indicators (PPI) which included; Pavement Condition Index (PCI), International Friction Index (IFI), and International Roughness Index (IRI) to formulate multi-objective optimization models to select optimal maintenance alternative for the selected case study**.**
Keywords: pavement management system, pavement maintenance, multi-objective optimization, genetic algorithm.

1. Introduction
Pavement management, in its broadest sense, involves managing all the activities related to the pavement network. These activities include, but are not limited to, planning and programming, design, construction, maintenance, and rehabilitation. A pavement management system (PMS) provides effective tools and methods that can assist decision makers in formulating efficient strategies for providing and maintaining a serviceable pavement network over a given time (the planning horizon). A good pavement management system requires an organized and systematic approach for agencies (state or local, public or private) to conduct pavement management activities.

An ideal pavement management program for a road network is one that would maintain all pavement sections at high level of services and structural conditions, but requires only a reasonable low budget and use of resources. It will not create any significant adverse impacts on the environmental, safe traffic operations and social and community activities. (Fwa, et al, 2000)

Usually two optimization objectives considered in pavement management; minimization of the total maintenance cost and maximization of overall network pavement condition. Therefore, the decision process in programming of pavement maintenance activities requires a multi-objective consideration that should addresses the competing requirements of different objectives.

1.1 Objective of This Research
Formulating multi-objective optimization model to support the multi-year decision making process of the Iraqi pavement maintenance management system and solving the models by incorporating constraint-based genetic algorithm to estimate an optimal maintenance alternative for the current year.

2. Background
2.1 Pavement Management System (PMS)
Pavement management systems (PMS) provide the tools that assist pavement engineers to forecast future pavement conditions and determine the optimal timing for maintenance and rehabilitation (M&R) treatment strategies that will address the requirements identified in the road network. The ability to program the optimal pavement maintenance and rehabilitation strategies is perhaps one of the most useful functions provided by a PMS. (Ningyuan Li, 1997).

2.2 Pavement Performance
According to the American Association of State Highway Officials (AASHO), pavement performance is defined

as the serviceability trend of the pavement over a design period of time, where serviceability indicates the ability of the pavement to serve the demand of the traffic in the existing condition [3]. In other words, pavement performance can be obtained by observing or predicting the serviceability of a pavement from its initial service time to the desired evaluation time. Usually, pavement condition can be evaluated according to four aspects or evaluation measurements: roughness, surface distress, structural capacity, and skid resistance. Various indices have been developed to measure pavement performance in terms of either these individual aspects or a combination of them. (Zhang, et al, 1993)

2.3 Pavement Maintenance strategies and Repair Technique

Pavement maintenance is broadly identified as work accomplished to preserve or extend the pavement's service life until major rehabilitation or complete reconstruction applied. (Prithvi S. Kandhal, 1998)
There are three types of pavement maintenance strategies:
1. Preventive Maintenance: Pavement preventive maintenance treatments preserve, rather than improve, the structural capacity of the pavement structure Thus; preventive maintenance treatments are limited to pavements in sound structural condition. In addition, in order to be effective, preventive maintenance should be applied before pavements display significant amounts of environmental distress such as raveling, oxidation, and block cracking. To be cost-effective, pavement preventive maintenance treatments should be applied before most engineers, or project decision-makers, would normally consider their use. Timely treatments prove to be most cost effective. (Mamlouk MS, et al, 1999)
2. Corrective Maintenance: applied after a deficiency occurs in the pavement, such as moderate to severe rutting, raveling or extensive cracking. This may also be referred to as "reactive" maintenance. preventive differentiate corrective maintenance in the timing and cost. Corrective maintenance is reactive, i.e., it is done after a road needs repair so the cost is greater. Delays in corrective maintenance result in even larger costs since defects and their severity continue to increase. Corrective maintenance treatments include structural overlays (3 inches or greater), milling, patching and crack repair. (Robinson R, et al,1982)
3. Emergency Maintenance: applied during an emergency, such as a blowup or severe pothole that needs repair immediately. This could also contain temporary treatments that hold the surface together until a more permanent treatment can be performed. Emergency maintenance is often related to safety and time, with cost not being a primary consideration. Likewise, materials that may not be acceptable for preventive or corrective maintenance may be the best choice for emergency situations. (Johanns M. and Craig J., 2002)
The differences between preventive, corrective, and emergency repair is the condition of the pavement when the treatment is applied, rather than the type of treatment.
The types of repair techniques are illustrated below.
1. Crack Sealing: Crack sealing is the process of cleaning and sealing or resealing of cracks in AC pavement. This technique is used to fill longitudinal and transverse cracks, including joint reflection cracks from underlying PCC slabs, that are wider than 1/8 in. The main purpose of crack sealing in AC pavement is to prevent surface water infiltration into the pavement foundation. Sealing cracks in a deteriorated pavement is not cost effective. It is more cost effective to use this technique as a preventative measure when the overall pavement condition is good or better (Shahin, M.Y., 2005)
2. Patching: This technique includes replacing the full depth of the AC layer and may include replacement of the base and subbase layers. Full-depth patching is used to repair structural and material related distresses such as alligator cracking, rutting, and corrugation. In the case of slippage cracking where the failure may be limited to the top AC layer, the depth of the patch may be limited to the top AC layer if it can be removed easily. (Shahin, M.Y., 2005).
3. Overlay: This technique includes adding one or more AC layers to an existing AC or PCC pavement. It is used to correct or improve structural capacity or functional requirements such as skid resistance and ride quality. The use of an AC overlay is usually more economic when the existing pavement is still in good condition.(Shahin, M.Y., 2005).
4. Asphalt Seal-Coat: Asphalt seal coats are composed of a thin layer of an asphalt material such as cutbacks, asphalt emulsions, or paving-grade asphalt cement. Modifiers are often added to the asphaltic liquid mixture and may include rubber, latex, polymers, and rejuvenators. Sand, aggregate, mineral and synthetic fillers, and rubber crumbs can be applied after the asphaltic mixture is applied to the pavement surface. Some seal coats such as slurry seals and microsurfacing incorporates the sand, aggregate, and fillers in the mixture before placing it on the roadway(Yamada A.,1999). There are different types of surface treatments such as fog seal, sand seal, scrub seal, chip seal, multiple chip seals, slurry seal, cape seal, microsurfaceing and pavement dressing.

2.4 Multi-Objective Optimization

Single-objective optimization identifies the best feasible solution in terms of a single measure of value. In contrast, the multi-objective optimization (MOO) problem involves finding a vector of decision variables that satisfies constraints and optimizes various objective functions that form a mathematical description of performance criteria, which are usually at least in partial conflict with each other.

A solution to a multi-objective problem is considered to be more a concept than a definition. In multi-objective optimization problems, what is optimal in terms of one of the objectives is usually non-optimal for the remaining objectives. Consequently, there is in general no single global solution for a multiobjective optimization problem. Hence, theterm "optimizing" means finding such a solution that would analyze the trade-offs and give values of all the objective functions acceptable to the decision maker. (Osyczka, A.1985)

The solving of multi-objective optimization problems requires that the decision maker articulate preferences regarding the relative value of the various objectives. Decision makers can express their preferences before, after, or during the solution process .(Goicoechea, A,et al, 1982).

2.5 Optimization Systems Components

There are three main components of optimization systems. The following is a brief description of these components (Miettinen, K. 1999):

1-Objective function: it represents the agency's goal, can be minimized or maximized. For example, minimize the agency's cost.

2-Decision variables: include different decisions. Each decision variable associated with maintenance and rehabilitation alternative. The variables usually represent things that you can adjust or control to find best value of the objective function.

3-Constraints: system constraints ensure the feasibility of the alternatives for the pavement management optimization problem. Constraint can be in the form of budget limitation or the system preservation.

2.6 Genetic Algorithms

Genetic Algorithms (GAs) are stochastic search methods that are based on the mechanics of natural selection and genetics (14). GAs combine survival of the fittest among string structures with structured yet randomized information exchange to form a search algorithm, Darwin’s theory of the survival. In each generation, new set of strings is created by the selecting process involving with their level of fitness, which uses the operators borrowed from natural genetics. GAs efficiently exploits historical information to consider on the new search points, which provide the better performance than the previous generation (O. GH. Smadi, (2000) and Goldberg, D.E. (1989).

3. Case Study

The study area is a part of section R/4Bwhich starts at station 49+000 Km and ends at station 53+500 Km, the total length of the study area is 4.5 km which is located at the beginning of section R/4B at AL-Latifiya city.Plate (1) shows the location of section R4.

Plate (1) Location of Section R4/Expressway No.1 in Iraq

4. Field Measurements

The following factors were obtained by the aid of field measurements to evaluate pavement;

1- Pavement condition index (PCI): a numerical rating of the pavement condition that ranges from 0 to 100 whereas, 0 being the worst possible condition and 100 being the best possible condition (ASTM D6433) as shown in Figure (1).

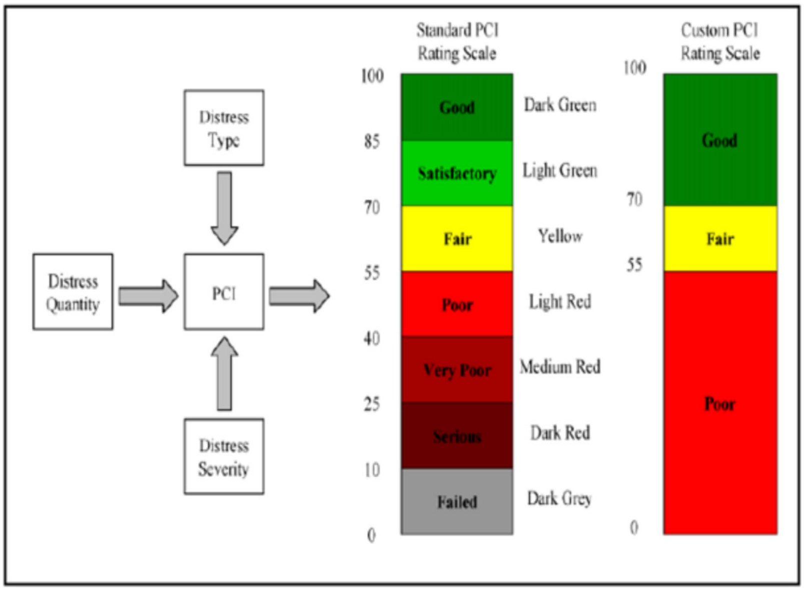

Figure (1) Pavement Condition Index (PCI) Ranges (U.S. Army Corps of Engineers-USACE, (2012).

2- International Friction Index (IFI):

Skid resistance was assessed based on (IFI) (International Friction Index). A scale ranging (0.0-0.6) as shown in Figure (2), IFI of 0.6 indicates that the pavement seems to be in a good texture.

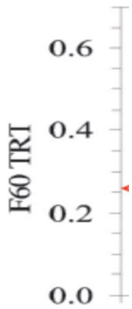

Figure (2) F60 Scale. (McDaniel, R. S., and K. J. Kowalski, 2012)

3-International Roughness Index (IRI):

The longitudinal profile is measured to identify the deformations that affect user comfort and safety. The quality indicator generally used for ride quality is the International Roughness Index (IRI). Scale rating can be shown in Figure (3).

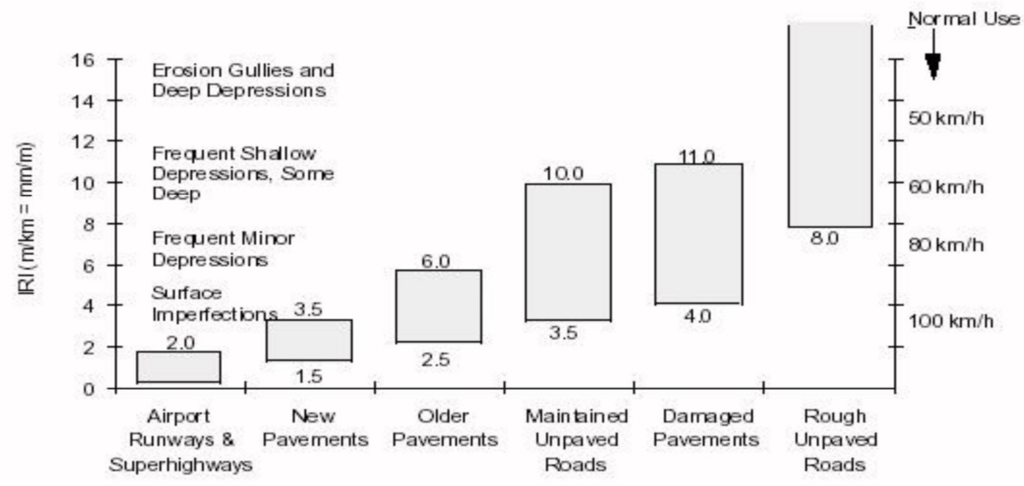

Figure (3) IRI Roughness Scale (Sayers, M. W et al.,1986)

5. Formulation Multi-Objective Optimization Model

Based on the previous discussions, multi-objective optimization model is constructed as follow:

1- Objectives:

The objectives can be carried out as follows;
Minimize strategy cost =C
Maximize condition = (PCI+IFI-IRI)
Where
C: maintenance strategy cost
PCI: Pavement Condition Index
IFI: International Friction Index
IRI: International Roughness Index

2- Constraints

Table (1) shows the field measurements data at current year and previous years. Relate current data with available previous data for the same pavement section to develop the constraints.

Table (1) PCI, IFI, IRI for the Year 2012, 2014 and 2016

Year / indicators	2012	2014	2016 (current condition)
PCI	64	56.5	55
IFI	0.31538	0.28123	0.2668
IRI	1.68778	1.86472	2.008

1-Relate current data of PCI with previous data
(56.5/64)= (PCI next year/PCI current)

PCI next year= 0.88281*PCI current (1)

2-Relate current data of IFI with previous data
(0.28123/0.31537) = (IFI next year /IFI current)

IFI next year= 0.89175* IFI current (2)

3-Relate current data of IRI with previous data
= (1.86472/1.68778)= (IRI next year /IRI current)

IRI next year= 1.10484*IRI current (3)

The pavement condition should be in a better state so at this state treatment needs to bring the pavement condition in to a better condition because all current indicators (PCI, IFI, and IRI) refer to pavement condition in faire state.

So the equations should be limited as follow:
PCI next year= 0.88281*PCI current $\leq$ PCI after a specific type of maintenance
IFI next year= 0.89175* IFI current $\leq$ IFI after a specific type of maintenance
IRI next year= 1.10484*IRI current$\geq$ IRI after a specific type of maintenance
Note: PCI, IFI and IRI (after a specific type of maintenance) obtained from opinion experts.

6. Solving Multi-Objective Optimization Model

Try preventive maintenance
C= 16329600

Table (2) Predicted Indicators from Opinion Experts after Preventive Treatment.

Indicators	Indicators before treatment	Indicators after treatment
PCI	55	66
IFI	0.2668	0.3575
IRI	2.008	1.506

So multi-objective optimization model constructed as follow:
Minc=C
Maxb= PCI+IFI-IRI
s.t
0.88281*PCI current ≤ 66
0.89175* IFI current ≤ 0.3575
1.10484*IRI current ≥ 1.506
Repeat the previous procedures for each type of pavement maintenance alternative, Implementation SOLVER V 2016-R2 software to solve multi-objective optimization model, the results can be shown in Table (3) and (4).

Table (3) Effect of Pavement Maintenance Strategy on PCI, IFI and IRI

maintenance strategy / indicators	Preventive strategy	Corrective strategy	Emergency strategy
PCI	74.7613	93.4516	80.9914
IFI	0.4009	0.3979	0.3979
IRI	1.3631	0.9996	1.2722

Table (4) Effect of Pavement Repair Techniques on PCI, IFI and IRI

Repair techniques / indicators	crack sealing	patching	overlay	asphalt seal-coat
PCI	77.8763	77.8763	84.1064	71.6462
IFI	0.3590	0.3590	0.41886	0.3590
IRI	1.5448	1.27222	1.18135	1.45397

7. Conclusion

The conclusions are summarized as follows:

1- The evaluation of pavement performance (which presented in the form of evaluation and monitoring of the main distresses and indicators such as roughness and friction), is an important part of the pavement management to formulate the multi-objective optimization models.
2- Based on the study findings, solving multi-objective optimization models via incorporating constraint-based genetic algorithm, the optimal maintenance alternatives for the selected case study; (pavement portion of section R4/B – Expressway No.1 in Iraq) is found to be corrective strategy and overlay repair technique.

References

American Association of State Highways Officials, AASHO (1962), The AASHO Road Test Report 5, Pavement Research. *Special Report 61 E. HRB, National Research Council, Washington, D.C., 1962.*

Fwa, T.F., Chan, W.T. and Hoque, K.Z. (2000). "Multiobjective Optimization for Pavement Maintenance Programming". *Journal of Transportation Engineering, 126(5), 367-374.*

Ningyuan Li, (1997). "DEVELOPMENT OF A PROBABILISTIC BASED, INTEGRATED PAVEMENT MANAGEMENT SYSTEM", *PHDthesis,University of Waterloo ,Civil Engineering.*

Goicoechea, A., Hansen, D. R. and Duckstein, L. (1982). "Multiobjective Decision Analysis with Engineering and Business Applications". *New York: John Wiley & Sons.*

Goldberg, D.E. (1989). "Genetic Algorithms in Search, Optimization, and Machine Learning". *Addison-Wesley Publishing Company, Inc., USA.*

Johanns M. and Craig J., (2002). "Pavement Maintenance, Manual", Nebraska Department of Roads (NDOR).

Mamlouk MS, ZaniewskiJP.,(1999)."Pavement Preventive MaintenanceDescription, Effectiveness, and Treatments", *Symposium on FlexiblePavement Rehabilitation and Maintenance, ASTM STP 1349121-135.*

McDaniel, R. S., and K. J. Kowalski, (2012): "Investigating the Feasibility of Integrating Pavement Friction and Texture Depth Data in Modeling for INDOT PMS", *Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana.*

Miettinen, K. (1999). "Nonlinear Multiobjective Optimization". Boston: Kluwer Academic Publishers.

O. GH. Smadi, 2000," Knowledge based expert system pavement management optimization". *PHD thesis, transportation engineering, Iowa State University.*

Osyczka, A. (1985). "Multicriteria optimization for engineering design," *In Gero, J.S., editor, Design Optimization, Academic Press, 193-227.*

Prithvi S. Kandhal , Mary Stroup-Gardiner (1998)."Flexible Pavement Rehabilitation and Maintenance Paperback", *American Society for Testing & Materials (ASTM), Special Technical Publication, Stp*

Robinson R. and Roberts P., (1982). "The Cost Effectiveness of RoadMaintenance", *Addis Ababa: UN Economic Commission for Africa.*

Sayers, M. W et al., (1986): "Guidelines for Conducting and Calibrating Road Roughness Measurements", *World Bank Technical Paper Number 46. The World Bank, Washington, D.C.*

Shahin, M.Y., (2005). "Pavement Management for Airports. Roads, andParking Lots". *Second edition. Springer Science Business Media, Inc., New York. NY. U.S.A. Smith, R.E.*

U.S. Army Corps of Engineers-USACE, (2012), "New Dimensions in Pavement Maintenance Management", About File

Yamada A., (1999). "Asphalt Seal Coat Treatments", *9977 1201. San Dimas, CA: U.S. Department of Agriculture, Forest Service, San Dimas Technology and Development Center. 25 p.*

Zalzala, A.M.S. and Fleming, P.J. (1997). "Genetic algorithms in engineering systems".*The Institution of Electrical Engineers, London, United Kingdom.*

Zhang, Z., N. Singh, and W.R. Hudson, (1993),"Comprehensive Ranking Index for Flexible Pavement Using Fuzzy Sets Model,"*Transportation Research Record No. 1397, 1993, pp.96-102.*