Original Article

Applied Science

Review of Application of Genetic Algorithms in Optimization of Flexible Pavement Maintenance and Rehabilitation in Nigeria

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ABSTRACT [ENGLISH/ANGLAIS]

This article reviews the application of genetic algorithms optimization model for pavement management. The objective is to generate a suitable model that will guide the development of optimization model for road maintenance and rehabilitation in Nigeria. The techniques of genetic algorithms from first principles as well as Highway and Transportation engineering were reviewed. A candidate model (PAVENET-R) was selected to guide the development of optimization model for road maintenance and rehabilitation in Nigeria based on its merits over other models. The model considers distress deterioration functions, which invariably determines the warning levels for maintenance interventions. The major reason is that the model considers rehabilitation action which is relevant to the proposed work, while other models stop at maintenance level. The proposed work considers prediction of potholes model, while other models stop at cracking models. An integer coding scheme is selected for parameter representation in the model. Two genetic algorithms operators, namely the crossover and the mutation operators were chosen because of their importance in coding representations

Keywords: Genetic Algorithms, optimization model, distress deterioration functions, maintenance and rehabilitation, integer coding

RÉSUMÉ [FRANÇAIS/FRENCH]

Cet article examine l'application du modèle d'optimisation génétique des algorithmes pour la gestion des chaussées. L'objectif est de générer un modèle adapté qui guideront le développement du modèle d'optimisation pour l'entretien des routes et la réhabilitation au Nigeria. Les techniques des algorithmes génétiques à partir des premiers principes ainsi que l'autoroute et de l'ingénierie des transports ont été examinés. Un modèle de candidat (PAVENET-R) a été choisi pour guider le développement du modèle d'optimisation pour l'entretien des routes et la réhabilitation au Nigeria en fonction de ses mérites sur d'autres modèles. Le modèle considère une détérioration des fonctions de détresse, qui détermine immanquablement les niveaux d'alerte pour les interventions de maintenance. La raison majeure est que le modèle considère l'action de réhabilitation qui sont pertinentes pour les travaux proposés, tandis que d'autres modèles d'arrêt au niveau d'entretien. Le travail proposé considère la prédiction du modèle de nids de poule, tandis que d'autres modèles s'arrêtent à des modèles de fissuration. Un schéma de codage entier est sélectionné pour la représentation des paramètres dans le modèle. Deux algorithmes génétiques opérateurs, à savoir le croisement et la mutation des opérateurs ont été choisis en raison de leur importance dans les représentations de codage

Mots-clés: Algorithmes génétiques, modèle d'optimisation, la détérioration des fonctions de détresse, d'entretien et de réhabilitation, le codage entier

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Accepted/Accepté: November, 2011

Citation: Chikezie CU, Olowosulu AT, Abejide OS. Review of Application of Genetic Algorithms in Optimization of Flexible Pavement Maintenance and Rehabilitation in Nigeria. World Journal of Engineering and Pure and Applied Sciences 2011;1(3):68-76.

INTRODUCTION

Optimization fundamentally is the process of finding the conditions that give the minimum or maximum value of a function with several variables usually subject to equality and/or inequality constraints, where the function represents the effort needed or the desired benefit [1, 2].

Optimization models are grouped into two distinctive models [3] viz: static models and dynamic models. The static models are those where the system parameters such as pavement performance as well as planning for rehabilitation and maintenance are static i.e. remain unchanged with time. While dynamic models consider variable pavement conditions at different state or time,

which is more realistic. In the class of static optimization models are integer programming [4] and linear programming [5]. While dynamic models include probabilistic dynamic programming [6] and dynamic programming with the Markov process [7, 8, 9].
The rigidity and computational complexity of traditional optimization methods makes it difficult to solve real world problems, where changes to the problem characteristics are often inevitable and also result to long computation time [2]. The artificial intelligence approach to network level programming is able to overcome these limitations

ARTIFICIAL INTELLIGENCE APPROACH

New research in artificial intelligence has made a breakthrough on pavement management system, with applications in almost all levels of decision making.

(a) Expert System

Sample Article Sample
An expert system comprises of two components, the knowledge base and the interference engine. Theses are designed to perform as an expert human in a particular field. The first component is the power of the expert system where all empirical and factual information are obtained. The second component, the interference engine, searches through the knowledge base to find the optima for each sub-goal and thus the entire problem. The application of expert system to pavement management system can be found in the work of Antoine [10], Sinha [11] and Wang [12].
Expert systems are based on the knowledge oriented system that is better suited for empirical and factual data. This makes it inappropriate tool for network level optimization task, where all computers are performed on numerical data.

(b) Artificial Neural Network

In the same way as humans apply knowledge from past experience to solve new problems, a neural network has the ability to learn from the past experience and apply them in a new problem situation [13]. The neural network is composed of an interconnected assembly of simple processing elements. The application of artificial neural network to the priority rating of pavement maintenance needs was presented by Fwa and Chan [14], while Zhang et al [15], described the application of neural network coupled with genetic algorithms to analyze the application of prioritization in pavement maintenance management.
However, neural network is not meant as a tool for optimization purposes, as there is no functionality in neural for searching and evaluating the search space in an optimization problem.

(c) Fuzzy Logic

Zadeh [16], first introduced fuzzy set theory mathematically to represent uncertainty and vagueness, and provide formalized tools for dealing with the imprecision intrinsic to many problems. The decision making process of fuzzy logic resembles human reasoning in its use of approximate information and uncertainty to generate decision. By contrast, traditional computing demands precision down to each bit.
Fwa and Shanmugan [17] described the application of fuzzy logic to pavement condition rating and maintenance needs assessments.

(d) Genetic Algorithms

Genetic algorithm is a stochastic search method that is formulated based on the principle of natural selection [18]. It is a powerful artificial intelligence optimization technique which has been applied to pavement management [19]. Genetic algorithm operates in the concept of cycling random pool of feasible solution through a number of generations. By this process, the pool containing the best solution is hoped to be obtained at the end of the cycle. The method of moving from one end to another is based on ideas borrowed from Darwin's principle of evolution. Genetic Algorithm is a powerful tool widely used for optimization problems. They are very flexible and do not have the computational complexities of traditional optimization methods. The robust search characteristics and multiple solutions handling capability of genetic algorithm are additional advantages of this optimization approach.

BASIC TERMINOLOGIES AND MECHANICS OF GENETIC ALGORITHMS

Genetic Algorithms borrowed the vocabulary from the natural genetics. Yew [2] explains that in genetic algorithms the most important genetic structure is the chromosome, which is essentially a candidate solution to a problem. The chromosome can be conceptualized as a string made up of blocks of cells called genes. Thus each gene encodes a particular character of the candidate solution (e.g. the colour of the eye) while the possible value of a gene is termed as the allele (e.g. brown, black, green etc), and also that each gene is located at a particular locus (position) on the chromosome. A complete set of chromosome is called the genotype [2].

A group of chromosomes form a population of candidate solutions. The quality of each candidate solution is evaluated based on how well it satisfies a predefined objective function. The evaluation value, represents how "fit" the candidate is in relation to other solutions in the population [2]. From this population, only the fitter of the candidate solution will survive to the next generation. In every generation, new solutions (offspring) are generated from the fitter solutions (parents) using such genetic operation as mutation, crossover, and inversion. As the population moves from one generation to another, better and better solutions are hoped to be evolved until the cycle stops in reaching a certain stopping criterion.

An important step in the Genetic Algorithms process is in encoding the problem parameters to represent the problem as a string of chromosome. The chromosomal representation must ensure that all necessary parameters are completely represented by the genotype [2].

NEED FOR GENETIC ALGORITHMS

The issue of maintenance and rehabilitation of highway network involves a huge amount of fund. To this end, rational decision making for conserving money needs to be evolved. Heggie and Vickers [20] reported the study conducted by World Bank, which revealed that spending on road networks can absorb as much as 5-10 percent of a government's recurrent expenses and 10-20 percent of its development budget. This translates to billions of dollars each year. Judging from such magnitude, every dollar spent on highway returns the highest possible benefit to the decision makers [2]. In reality, the process of budget allocation is one of the areas in pavement management where an optimal solution brings about significant financial savings.

The allocation budget is a vital element in the process of managing pavement networks. Non- optimal distribution of funds amongst the sub-units of highway agency definitely will result to sub-optimal performance of the pavement network [21]. Genetic algorithm is used to arrive at an optimal solution for budget allocation problem. This fund optimization approach is highly flexible and can be easily modified to meet different management requirements [21]. This is an ideal fund application approach that will allocate fund to areas where the most benefit can be obtained for the amount of money spent. The genetic algorithm optimization approach has merit over the conventional fund allocation approach because it considers the pavement management needs, constraints and objectives of the highway organization and the agencies under its charge [21]. Also, they are applied to maintenance optimization because of their robust search capabilities that resolve the computational complexity of large-size optimization problems [2]. Also, they are powerful Artificial Intelligence optimization techniques that have been applied to pavement management. The following sets it apart from traditional methods [2]:(i) Genetic Algorithms search a population of points simultaneously; (ii) used in probabilistic tradition rules, not deterministic ones; (iii) they work on an encoding of the parameter set rather than the parameter set itself (except in cases where real-valued individuals are used) and (iv) they do not require derivative information or other auxiliary knowledge; only the objective functions and corresponding fitness levels influence the direction of search.

There has been much interest in using genetic algorithms in science and engineering [22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, etc]. The applications of it in Transportation and Highway Engineering are found in the works of Qishi and Jeffrey, [34], Ayad et al.[35], Foy, [36], Zhiyong, [37], Leena et al. [38], Eungcheol et al. [39], Natsuaki, [40], Itoh and Hammad, [41], and Erol et al. [42].

CRITICAL REVIEW OF GENETIC ALGORITHMS OPTIMIZATION MODEL FOR PAVEMENT MANAGEMENT

The application of genetic algorithms in pavement management was first reported by Chan et al. [43], Tan, [44] and later by Fwa et al. [45, 46, 47]. It was found that Genetic Algorithms can handle the network optimization problem of pavement management activities effectively.

Genetic Algorithms are robust search techniques based on the mechanics of natural selection and natural genetic [19]. These mechanics of evolution are simple yet powerful. What is important in Genetic Algorithms (GA), as in all Artificial Intelligence (AI) techniques, is to have an appropriate and efficient method of representing knowledge in computer and in getting real-world knowledge into an internal representation. The basic idea behind Genetic Algorithms is to generate an initial pool of solutions, represented as string structures, and then through continuous copying, swapping and modifying of partial strings in a manner similar to natural genetic evolution, to allow the solution pool to evolve toward better and better solutions [43].

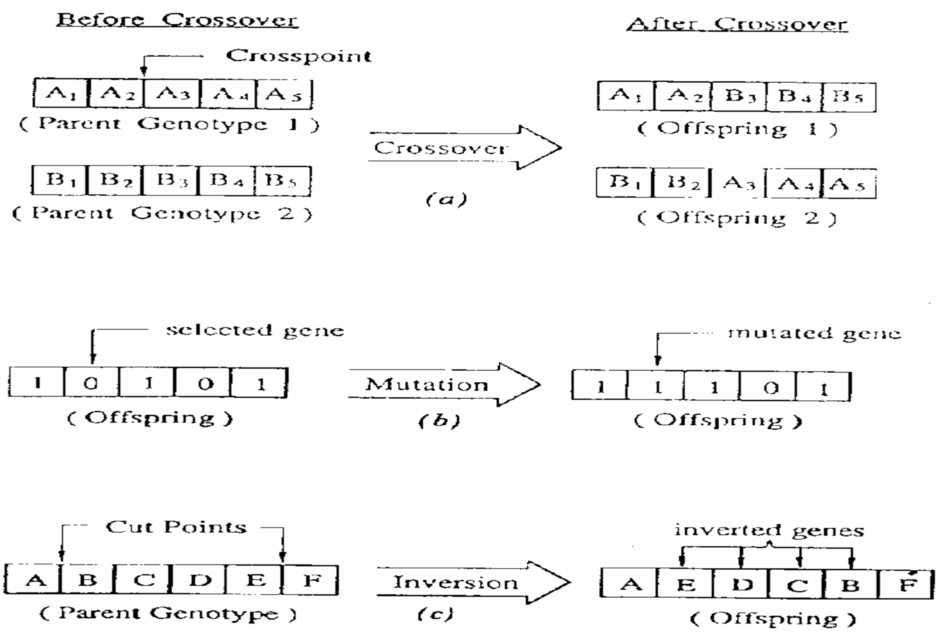
A powerful aspect of Genetic Algorithms is their use as an optimization technique in overcoming the combinatorial explosion of certain problems like road-maintenance management problem at network level. The magnitude of the problem can easily be demonstrated by a simple example. Consider m number of maintenance periods in the planning horizon and n possible pavement defect types. There are (m x 2n) possible defect combinations, and hence (m x 2n) possible repair strategies for a single pavement segment. At the network level, the total number of combinations that needs to be considered increases exponentially with the number of segments in the network. For a network with r segments, the total possible combinations is equal to (m x 2n)r [44]. It can be seen that even for a small local network having r = 20, m = 10, and n = 3, there would be a total of about 1038 combinations. This figure would be astronomical with more segments and more treatment types to be considered at the regional or national level. It would take a computer, centuries to examine all of these solutions. The problem also becomes more complicated when one considers variations in the extent and severity of various defect types. In a situation like this, genetic algorithms have been found to be a useful tool to provide a good and acceptable solution within a practical period of time [19].

GENETIC OPERATORS IN PAVEMENT MANAGEMENT

There are a number of genetic operators in Genetic Algorithms that are used to generate new genotypes [19, 48, 49,].

Among the more commonly used operators are the crossover operator and the mutation operator. In a simple crossover operation on two genotypes, the first step involves taking some alleles from one genotype and some from the other genotype. The allele taken from the two genotypes are then combined to form a new genotype, which is called an offspring. A second offspring can be created by combining the remaining alleles from the two parent genotypes. An example of a crossover operation between genotypes with a cross-point between the second and genes is shown in figure 1(a).

Figure 1: This figure shows examples of Genetic Operators: (a) crossover operator; (b) mutation operator, and (c) Inversion operator [45]



Crossover does not change the values of the genes. It simply arranges existing gene values in different ways. Another way of producing a new genotype is by changing the values of one or more of its genes. This is called mutation. Figure 1(b) shows an example of a mutation on the second allele of a genotype consisting of five genes. Mutation is needed to allow the search to reach new parameter space. We can think of crossover as being the driving force underlying the genetic algorithms and of mutation as being responsible for keeping the gene pool well stocked.

Figure 1(c) shows an example of a so-called inversion operator on a binary genotype with six genes. The inversion mechanism on a genotype involves choosing two points along the length of the genotype, cutting the genotype at those points, and swapping end points of the cut section. A more detailed treatment of the inversion operator and other more complex operators like the partially matched crossover (PMX) operator and the diploid operator can be found in Goldberg [19].

CASES OF MODELS REVIEWED

Herabat and Tangphaisankun [50] developed a computer model formulated on the principles of genetic algorithms to serve as an analytical tool for Thailand pavement management. The coding was applied to the selected 153 road section each year. Therefore 153 genes were generated to be the representative of the selected road network in each chromosome.

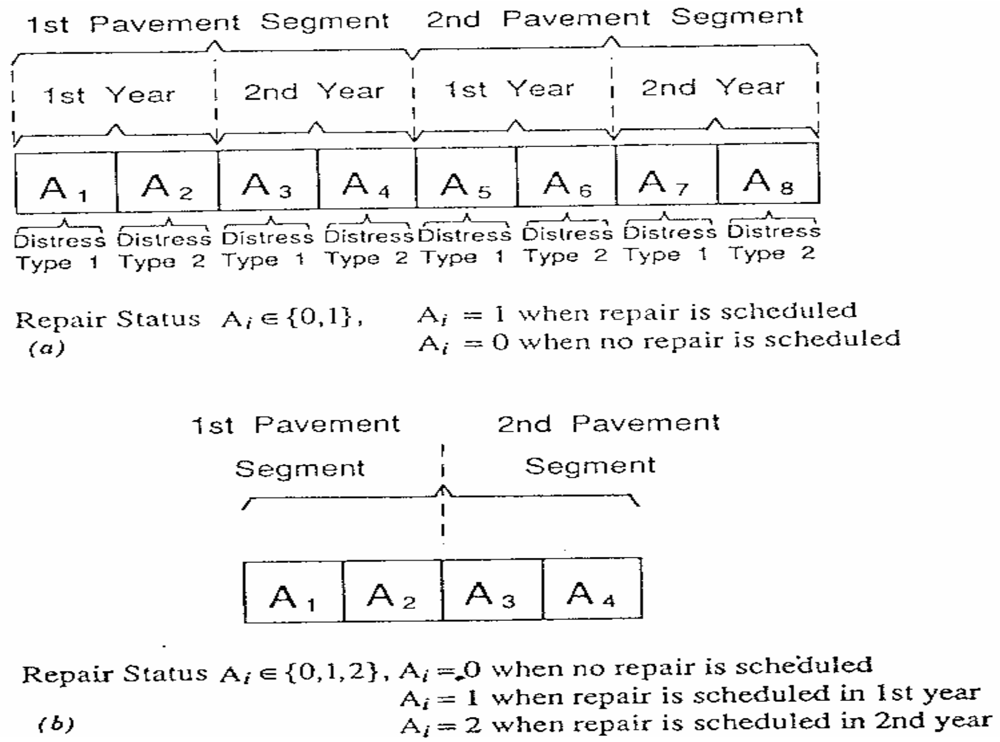
Bosurgi et al. [51] developed optimization model whose problem was opportunely programming a genetic algorithm that manages the decisional process on the bases of pavement's condition defined using present serviceability index (PS1). In the genetic representation created, each year of the programming period was mapped to a gene for each homogenous section. The value for each gene represents a possible maintenance invention. It was possible to associate the PS1 of the pavements after the intervention by inserting the developed model into the genetic algorithms.

Chan et al. [43] developed a computer model, known as PAVENET that involves the application of optimization technique to the problem of maintenance-budget planning and maintenance planning activity programming. Two coding (methods) were used in the PAVENET. The first is a binary coding and the second is a non-binary coding. For the

purpose of illustration, a network of two pavement segments, each with two distress types

and their planning period of two years was assumed (figure 2).

Figure 2: This figure shows coding problem parameters: (a) Binary coding in PAVENET; (b) Non-binary coding in PAVENET [43]

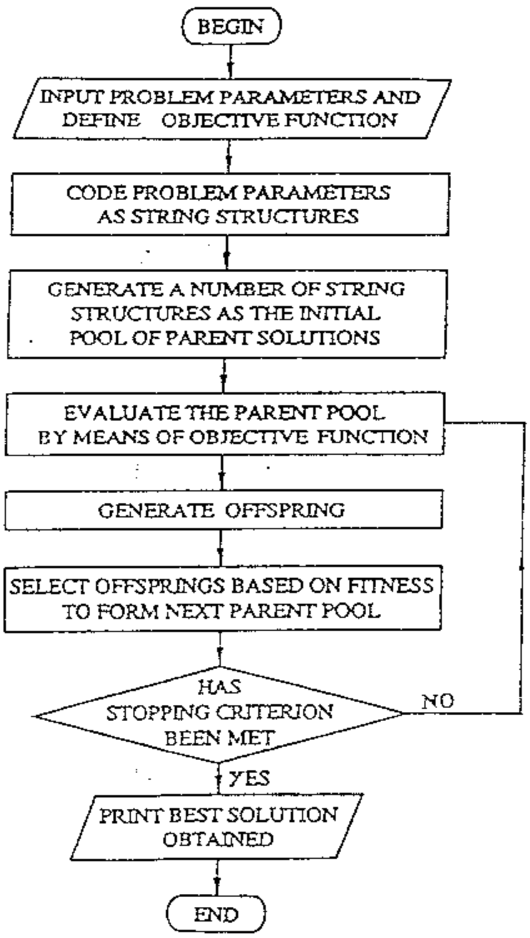


Fwa et al [47] presented the formulation and solution of a genetic algorithms programme, known as PAVENET-R, developed for the programming of pavement maintenance and rehabilitation activities of a road network over a multi-period planning horizon. It considers three main pavement distress types.

GENETIC ALGORITHMS FORMULATION IN PAVENET-R

The overall procedure in the genetic algorithm in the computer program in PAVENET-R is shown by the flow chart in figure 3. It starts with coding representation of the problem parameters and selection of an initial pool of parent genotypes. The subsequent genetic process includes the evaluation of parent genotypes, generation of offspring genotypes and formation of the next parent pool. The process is repeated until a pre-selected stopping criterion is satisfied.

Figure 3: This figure shows Genetic Algorithm in PAVENET-R [47]



Selection of Optimization Model to Guide the Development of Program-R

Four different Optimization models were reviewed and their merits and demerits observed.

Herabat and Tangphaisankun [50] considered International Roughnesss Index (IRI) in their model but did not include rehabilitation in the program.

Bosurgi *et al.* [51] considered Pavement Serviceability Index (PSI) in their model but also lacks rehabilitation and pothole moles in the program.

Chan *et al.* [43] considered the pavement distress deterioration model actually, but did not go beyond maintenance level. This renders the model unfit for the proposed work. Fwa *et al.* [47] considered pavement distress deterioration models and especially rehabilitation program which makes it considerable. The Fwa *et al.* [47] model was considered and adopted to guide the development of Nigerian optimization model. The model stands a better chance than the other models considered alongside and therefore, selected as a guide for optimization model for Nigeria with slight modification.

Genetic Algorithms Formulation in Program-R

A flowchart showing the overall scheme of the Genetic Algorithms formulation is given in figure 4. The modification made to Fwa *et al.* [47] model is the introduction of pothole models, incorporation in the Pavement Serviceability Index (PSI) prediction model as depicted in figure 4. This serves as a contribution to the proposed work.

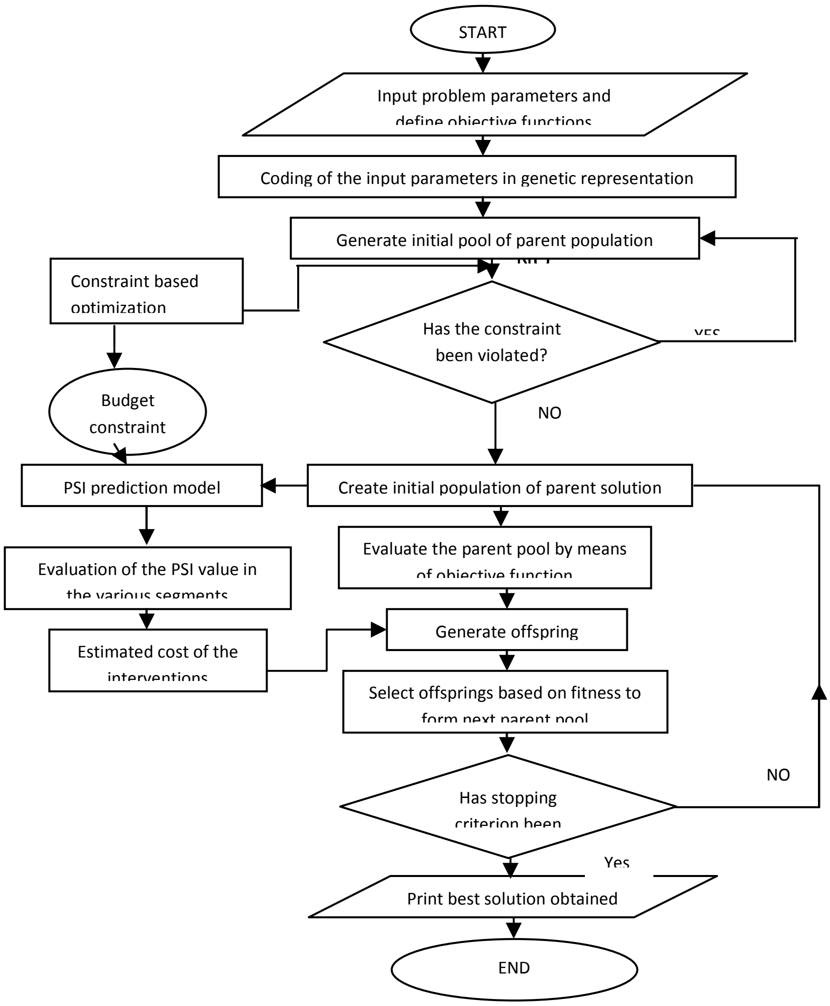
First, the problem is defined including the objective function and constraints that control the solution. The objective considered is to maximize the average Pavement Serviceability Index (PSI) value of the highway considering a limited budget.

It starts with input problem parameters and defining objective functions, coding representation of the problem parameter, selection of an initial pool of parent genotypes, checking the constraint violation, evaluation of parent genotype generation of offspring genotypes and formation of the next parent pool. The process will be repeated until a preselected criterion is satisfied.

CONCLUSION

This study reviewed the application of Genetic Algorithm Optimization computer model for pavement management. The techniques of genetic algorithms from first principles; the application of genetic algorithms to science and engineering and also application to highway and transportation engineering were reviewed. A candidate model was selected to guide the development of optimization model for road maintenance and rehabilitation in Nigeria.

Figure 4: This figure shows genetic Algorithms in Program-R



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ACKNOWLEDGEMENT / SOURCE OF SUPPORT

Nil

CONFLICT OF INTEREST

No conflict of interests was declared by the authors.