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I. INTRODUCTION

This paper serves as a bridge between Science and environmental management and elucidates the OR algorithms as a solution to establish equilibrium between development and ecological wellbeing.

A large share of the global disease burden is due to environmental degradation. Environmental diseases are caused by polluted air, water, soil, chemical exposures, ultraviolet radiations, inadequate waste management, etc. These factors are responsible for over 12.6 million in nearly 1/4 of the deaths in the world.

Operations research has been around for close to 50 years and is concerned with the study of how to apply different scientific models into the decision-making process, making the decision-making process more logical. This paper aims to compare three types of algorithms namely, particle swarm optimization (PSO) and genetic algorithm (GA), and ant colony optimization

Particle swarm optimization - This algorithm has a wide area of usage, in environmental management, it is used in wastewater management, heating load forecasting, and wireless sensor network.

Genetic algorithm- This revolves around Ozone layer depletion, Land use in different agricultural activities, improving agricultural supply, and Vehicle routing problems.

Ant colony optimization - This algorithm is about traffic control, water resource management, and forest transportation planning problems.

Previous OR Models -

Ma-Lin Song- came up with a model namely fuzzy slacks-based measure (F-SBM) model For reducing an undesirable output, controlling the quantities of pollutants discharged, and improving the environment,

Jie Wu - came up with a model to evaluate the regional total-factor energy and environmental efficiency of China

Jiasen Sun - came up with a model namely the allocation of emission permits (AEP) model for controlling the total emission level of the manufacturing companies.

VítězslavMáša - worked on the analysis of gas microturbine integration in a commercial laundry.

Fugui Dong, Wen Zhanf - evaluated and compared power network plans including distributed photovoltaic generations. They used the improved Entropy-Matter-Element extension model to work on the network plan.

Raja Jayaraman - on employee allocation to satisfy the conflict related to economic development, energy consumption, workforce allocation, and greenhouse gas emission (GHG) emissions by using a stochastic goal programming model.

II. LITERATURE REVIEW

Jacqueline Ruwaard (1996) This one paper which establishes a link between operations research and environmental management through a variety of examples. For the most part the discussion of its use remains highly generic and does not explain how various algorithms, which form an essential part of OR, are put to work to generate the optimal solution.

Marco Dorrigo et al (2006) The focus of most research papers has been on the highly technical nature of the algorithms themselves, i.e. the generation of actual objective function, fitness function to solve the problem at hand. Although the context is relevant, it goes deep into the mathematical aspect of how the algorithms generate the optimal solution.

Finding the application of algorithms for environmental management proves to be difficult. There are multiple applications of the same algorithm in a wide variety of fields, whereas there is very little information about the application in environmental management.

QuingquingQiao et al (2020) Within the 3 algorithms discussed in this paper, the area that is very well known is solid waste management. When analysing the relationship between PSO, ACO and environmental management for example, there is an abundance of research available for studies conducted on solid waste management or municipal waste management, but not other areas. It is so much so that the information seems repeated, and there is not much scope for further research within this area.

SonerHaldenbilen (2013) Many research papers mention very briefly about the advantages and disadvantages of the algorithm in a particular context, at most they are one to two lines. The main focus of the research papers has been to conduct the experiments, run the algorithms, obtain the data, analyse the data, and reach a conclusion to solve a particular real world problem, with a lot of emphasis on the technical nature of the process. Therefore, in order to recommend a particular algorithm, more than conducting the experiment, it is necessary to compare the effectiveness of multiple algorithms.

Research objectives

On the basis of the literature review, the research objectives are outlined as follows:

a. Finding and analysing different algorithms, with their use highlighted in environmental management specifically
b. Briefly explaining the technical aspect of the algorithms, and the inspiration behind them, with little focus on the steps and process behind implementing the algorithm.
c. Narrowing the focus to just environmental management and it's related applications.
d. Widening the scope of research to other fields within environmental management apart from solid waste management, although solid waste management would be discussed in the paper.
e. Highlighting the benefits and disadvantages of use of the algorithms in the context of environmental management, weather mentioned in the research paper or not

Analysis and Findings

Particle Swarm Optimisation

Particle swarm optimization algorithm revolves around the concept of animal behaviour, particularly a flock of birds, and derives a mathematical framework that can be used in complex problems existing in the fields of science and technology, as well as operations research.

A flock of birds needs a centre point or a commonplace to land. In analysing this centre point, they need to take into consideration issues that may threaten to kill them, such as availability of food, water, enough vegetation as a place of shelter and shield away from predators. For this, appropriate communication between the birds, called swarms, would need to occur to ensure that all the birds land at the same spot, which is collectively decided. Every member of the flock individually analyses and communicates different spots (called particles) to each other before a common particle is decided, to maximize their chance of survival within the given environmental constraints.

Genetic Algorithm – GA

Genetic algorithm has its basis in evolutionary biology, particularly Charles Darwin's theory of survival of the fittest in the process of natural selection. Through processes such as selection, mutation, and crossovers, which generate different variations of possible solutions within the solution space, the best solution at each stage of mutation is selected based on how well it can give an optimal answer given the constraints of the problem. Mutations are random processes, therefore, as the number of mutations increases, it may or may not lead to the best possible solution, depending on its feasibility in the current environment.

Ant colony optimization

Ant colony optimization, like particle swarm optimization, revolves around the concept of analysing animal behaviour and formulating that into a mathematical model that can accurately solve complex problems. The biological concept behind this problem is that ants try to find the most optimal (shortest) route from the ant hole to a food source through depositing pheromones, a chemical made by ants that follow the path that they take. This chemical is detectable by other ants, and as the frequency of using that path increases, the concentration of pheromone builds along that path, making it easier for other ants within the same colony to detect, and thus making the path the most optimal for the rest of the colony.

Application of PSO: CVRP

PSO is a well-regarded application for capacitated vehicle routing problems or CVRP. It is a variation of the well-known vehicle routing problem, commonly used in waste management. CVRP describes a problem for a number of vehicles with limited carrying capacity, which can be of the same fixed capacity along each route or each vehicle of varying capacity, the optimal routes must be found such that all the collection points along those routes are catered to without exceeding the vehicle capacity, coming back to the same starting point (depot) at the least possible cost after completing a full trip.

Certain factors need to be considered when designing the CVRP model, and so, the constraints of those variables need to be defined.

It is not just the carrying capacity the algorithm considers. It is possible to integrate other factors also such as the amount of GHG produced, amount of fuel consumed with relation to time and distance, amount of waste collected at each bin along the set predefined route, amongst others.

Applications of GA: Ozone layer depletion control

Ozone layer depletion is the least investigated out of all the areas because it has not been of much concern to individuals until recent years. Countries and cities find it increasingly difficult to comply with emission standards, and so GA is applied to find the most cost-effective way one can meet the set emission standards of tropospheric ozone emission. The complex chemical basis of ozone layer breakdown is appropriately

modelled using GA, as it can support such complexity, and multiple constraints of cost, pollution control, amongst other things can be considered.

Application of GA: Land Use in different agricultural activities

GA can be used in studying the productivity of certain land areas in a city or country. This application specifically looked at how GA could be used to improve cultivation yields, and the value of the produce, the richness (number of different species in a given area), and how to decrease the effect of natural disasters in a given area. All these factors are combined to determine their impact on the pressing issue of climate change. Multiple objective genetic algorithms were used to analyse various criteria, as they can solve for different constraints in one single algorithm. GA was able to bring out the contradicting nature of the data, or the trade-off that resulted when comparing the different variables with each other. The data from GA was then used to design environmental policies that could optimally reduce disaster, and increase the productivity of the land, while subsequently minimizing the effect on climate change.

Application of GA: Green production modelling to improve agricultural supply

An interesting application of GA can be seen when environmental management and economics go hand in hand. More specifically, GA was used to achieve the goals of economic, environmental, and social benefits, in such a way that the productive yield of the farmers on the given piece of land increases, and that they can profit more from their produce. The constraint functions were natural resources, social demand for the crops, environment, given production conditions, amongst others. GA was used in analysing the scheduling optimality of various crops in each industry of animal husbandry, fisheries, agriculture amongst other things.

Applications of ACO: Area Traffic Control

As countries and cities become populated, as more people move into higher income levels and private transport becomes popular, there is an increasing need to control urban road traffic effectively, due to cost, time, pollution, fuel consumption, and other such related factors. It, therefore, becomes important to regulate the timings of signals in such a way that all of these factors are at their minimum. In one such literature, the ACO is used in combination with another model known as TRANSYT, where ACO tries to optimize the traffic signal timing fluctuations and the TRANSYT model puts this into action in the already existing road signal network.

Applications of ACO: Water Resource Management

ACO has been applied in watershed management, which is, the flow of rainfall and snow from a particular land area into a larger water body. Using ACO in this particular context has been especially helpful because it helps to evaluate the total solids that dissolve into the larger water bodies, and as a result how feasible it is to generate a cost-effective way to treat water so that it is safe for consumption. As the waste that is generated by individuals is dumped into water bodies, waste management companies need to work with each other to determine the acceptable level of waste that can be dumped and that still meets environmental regulations, for which ACO is needed to determine optimality.

Applications of ACO: Forest Transportation Planning Problem

The context in which this algorithm is used is the transportation of forest-sourced timber from the forest to where it is needed. Timber transportation is regarded as one of the most costly forest activities, therefore, the main objective is to use ACO to minimize the cost of transporting timber, while also considering the environmental cost of selecting a particular road network. They took into consideration both existing and hypothetical road networks to arrive at the most optimal solution. The cost factor takes into consideration both fixed and variable costs: fixed cost of road construction and maintenance, and the variable cost of the proportion of the amount of timber transported to the length of the road.

Advantages and Disadvantages of PSO, GA and ACO

Advantages: PSO

a. Highly flexible in nature as the number of consumer increase, the waste also increases, which means the model needs to be changed and optimized each time
b. A lot of variables can be incorporated into one algorithm, not just in terms of minimizing cost and optimizing vehicle capacity, but also in terms of minimizing travel time, GHGs, fuel consumption amongst others, which initially

might seem unrelated, but all contribute to the optimal usage of the vehicle space and size, and give us a holistic view of the entire scenario

c. In PSO, there are a wide variety of applications, so much so that they can be applied in niche areas within waste management, and along with different variations of a single problem

Advantages: GA

a. Since both PSO and GA are automatic algorithms, the solution can be found within seconds
b. GA focuses on solving the problem at hand rather than taking in multiple variables and generating what may be an overall ineffective model for cost minimization if too many variables are considered.
c. One thing highlighted in both the papers analysed was that for waste management, it would make more sense if the waste was collected in a segregated manner than having one single waste bin for all kinds of waste. It would be much easier to define the constraints and the functions for each waste type than to mix everything.
d. GA can range in complexity of modelling a particular problem, and software can aid in solving the problem as it gets more complex

Advantages: ACO

a. A variation of ACO, which is multi-objective ant colony optimization, was that it was able to take into consideration multiple constraints while trying to solve for the optimal solution, in the context of watershed management. This made the model more whole (holistic) and applicable in various areas
b. An objective highlighted in the literature is that at each stage of trying to find and update the optimal solution to reach the best optimal solution, the solution space is narrowed so that it takes less time to find the optimal solution at each stage, making the algorithm more efficient.
c. It is an automatic algorithm, therefore it can be computed quickly like PSO and GA

Disadvantages: PSO

a. PSO requires the use of sophisticated technology as the data needs to be constantly monitored, and the analysis needs to be carried out in real-time, especially in this scenario because there are a lot of qualitative factors that might influence the data collection
b. PSO focuses too much on the data collection aspect than actually finding a solution to the problem. Although the calculations can be done within seconds, the work and process that goes into collecting that data would present an overall higher cost than just using an algorithm like GA to find the most optimal solution

Disadvantages: GA

a. The genetic algorithm focuses more on the most optimum combinations within the given set of constraints and is very limited in the kind of variables that can be altered to achieve a particular solution as only the related variables need to be altered to get the optimum solution for a particular problem (ie only cost-related variables need to be altered to reduce the overall operating cost of the vehicle)
b. For both PSO and GA, the user needs to know about coding and computer systems like Python and C++ to draft the code for each change in the mutations or to understand the collected variables
c. Although it is automated, it needs to be run multiple times in order to reach the solution, and there is a certain level of complexity in building the model because the numbers are encoded for the GA to work.

Disadvantages: ACO

- ACO on its own, even considering the different variations of the optimization model, works best when combined with other models to reach the optimal solution. This has been noted in most of the research papers that have been analysed for this project.
- Analysing the biological basis of the algorithm, there needs to be a mapping of the possible solutions first using a graph instead of directly being able to solve for the optimal solution- it has to follow a particular fixed path

III. CONCLUSION AND RECOMMENDATIONS

Operational research models have been applied to environmental problems since the late 1960s. Technological advancement has allowed for OR models to become increasingly sophisticated.

A wide spectrum of environmental problems will solve with optimization methods, such as the environmental process synthesis and design, waste management and minimization, water resources management, energy management with environmental considerations.

This paper sheds light on how Operational research has been and further can be a huge contributor to prevent and control the existing epidemic of environmental degradation.

It explains in brief 3 algorithms that have been put to use in the environment sector namely - Particle Swarm Optimisation (PSO), Genetic Algorithm (GA), and Ant Colony Optimisation.

It talks about the advantages and disadvantages and later compares the 3 algorithms.

Environmental degradation is an increasingly relevant issue that has and can have severe impacts on the economic and business front, therefore it is critical that people embrace and accept the requirements of operational research in environment protection. This has implications for decisions and processes associated with all aspects of operations. It also is responsible for serving as an economic advantage, promising cost efficiency and effectiveness.

It is recommended that there should be an increased focus on analysing the advantages and disadvantages of the algorithms, which provides a true and fair picture of actual costs incurred and the extent to which a wide variety of problems are solved. It is hoped that, through this, the best algorithm is chosen.

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