Experimental Study on an Efficient Dengue Disease Management System

Planning and Optimizing Hospital Staff Allocation

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***Abstract*—Dengue has become a serious health hazard in Sri Lanka with the increasing cases and loss of human lives. It is necessary to develop an efficient dengue disease management system which could predict the dengue out breaks, plan the countermeasures accordingly and allocate resources for the countermeasures. We have proposed a platform for Dengue disease management with following modules: (1) a prediction module to predict the dengue outbreak and (2) an optimization algorithm module to optimize hospital staff according to the predictions made on future dengue patient counts. This paper focuses on the optimization algorithm module. It has been developed based on two approaches: (1) Genetic Algorithm (GA) and (2) Iterated Local Search (ILS). We are presenting the performances of our optimization algorithm module with a comparison of the two approaches. Our results show that the GA approach is much more efficient and faster than the ILS approach.**

***Keywords*—Optimization; genetic algorithm; iterated local search; algorithm comparison; nurse scheduling**

I. Introduction

The number of Dengue fever cases has grown drastically in Asian countries like Sri Lanka, and hospitals are facing challenges when taking care of the patients due to the lack of resources: materials as well as human. Therefore, allocation of available hospital resources and hospital staff to take care of Dengue patients efficiently has become an important requirement.

According to a survey conducted in the context of Sri Lanka, Infectious Disease Hospital (IDH) [6] which is now known as National Institute of Infectious Diseases, faces the same challenges and they require an efficient Dengue Disease Management System that can predict the dengue out breaks, plan the countermeasures accordingly and allocate resources for the countermeasures.

We have proposed a platform for Dengue disease management with following modules: (1) a prediction module to predict the dengue outbreak and (2) an optimization algorithm module to optimize hospital staff according to the predictions made on future dengue patient counts.

This paper mainly focuses on the optimization algorithm module. The optimization algorithm module has been developed based on two approaches: (1) Genetic Algorithm (GA) and (2) Iterated Local Search (ILS). Furthermore, a web-based application was developed named “SmartScheduler”, which generates working schedules of each nurse as part of the optimization algorithm module. “SmartScheduler” tries to generate an optimal work plan for nurses’ staff who take care of the Dengue patients.

Experiments were conducted to measure the performances of the optimization algorithm module (GA based as well as ILS based) using the statistics collected from IDH. With the real data sets, the results show that, GA and ILS can decide the optimal allocations dynamically in the order of seconds. Also, the results show that the GA approach is much efficient and faster than the ILS approach.

The rest of the paper is organized as follows. Section II presents the related work. Section III introduces the optimization algorithm to decide nurse staff allocation. In Section IV, the result and discussions are presented. Under Section V final remarks are mentioned and finally references are mentioned in Section VI.

II. Related Work

To achieve the best utilization of resources, proper optimization is required. In this research, optimization is used to generate working schedules for the nurses of IDH hospital. Optimizing algorithm module is implemented using two approaches: GA and ILS. The GA and ILS approaches are well known methods in the planning and scheduling context [3, 4, 5]. In this section, the limited work on scheduling and planning in the hospital management context will be discussed.

The research work on [1] focused on optimizing healthcare staff in the Pediatric Department of Prince Sultan Military Medical City (PSMMC) using GA with cost bit matrix. The main goal of their optimization was to satisfy doctors scheduling problem as much as possible while fulfilling the employers’ requirements. Their results showed that the suggested method is very useful and able to give reasonable solutions to the problem fast compared to the traditional manual methods.

The authors in [2] worked on Hospital-Residents matching problem using a local search approach and a stable matching approach. The stable matching approach is a method where one finds a stable matching between two equally sized sets of elements. Agents are assigned to another sets of agents which consists of preference lists and capacities under certain constraints. The authors have evaluated both approaches on big artificial instances, that are comparable with practical ones, which involve thousands of agents. Their experimental results show that the algorithm can return a solution in few seconds and with a high quality in terms of the size of the returned matching.

Our research work has been inspired by these works, and we are focusing on an optimization algorithm module to optimize IDH hospital staff according to the predictions made on future dengue patient counts.

III. Optimization Algorithm Module for Staff Scheduling

In this section the optimization algorithm that schedules nurse staff to take care of the dengue patients and generates work plan for each nurse is described.

A. Requirement Gathering

Before proposing an optimization model for scheduling the nurse staff, it was very important to understand the current context of dengue patients and their treatment process in Sri Lanka. Therefore, personal interviews and discussions with the IDH hospital staff were carried out to gather the monthly patient's data, nurse staff data, ward details etc. of IDH hospital [6]. Additionally, personal discussions and interviews with doctors and nurses outside of the IDH hospital were held to analyze the collected data for scheduling purposes [6].

B. Fitness Function

The optimization algorithm was developed using two approaches: (1) GA and (2) ILS. The goal of the algorithm is to find a solution that schedules nurse staff optimally. We have consulted IDH staff and general hospital administration bodies to identify the factors effecting staff scheduling [6]. They are as follows:

- Number of patients in a ward
- Number of wards and its priority
- Total number of patients
- Nurses requested to work overtime (OT)
- Maximum number of patients that could be allocated to a nurse

It is important to note that, according to the discussion and interviews, in the best case, the maximum number of patients that could be allocated to a nurse is 8 [6].

Therefore, considering these factors affecting staff scheduling, a fitness function was derived (a minimization function) to measure the quality of the solutions provided by the optimization algorithm as follows:

Patients per nurse as allocated by the algorithm > 8

fitness = fitness + x

else if Patients per nurse as allocated by the algorithm = 8

fitness = fitness + 0

else if Patients per nurse as allocated by the algorithm < 8

fitness = fitness + y

If the nurse already has worked (overtime)

fitness = fitness + x

C. Genetic Algorithm (GA) based Approach

Genetic algorithm is a search heuristic that is based on Charles Darwin's theory of natural evolution [9]. This algorithm reflects the procedure of natural selection where the fittest individuals are selected for reproduction to produce offspring of the next generation. Simply, it chooses individuals from the current population and uses them as parents to produce the children for the next generation. Over succeeding generations, the population evolves towards an optimal solution.

GA can be described by the following five key steps [9]:

1) Generate an initial population F (0) with n solutions

2) Compute the fitness value u(f) for each individual solution f in the current population F(t)

3) Generate the next population F(t+1), by selecting i best solutions from F(t)

4) Produce offspring by applying the genetic operators to population F(t+1)

5) Repeat from Step 2 until a satisfying solution is achieved.

In the research work, GA was used as one of the approaches to achieve optimization in nurse scheduling and the process is briefly explained below

The GA process begins with an initial population with n number of solutions, where in each solution, the nurses are scheduled to wards randomly, without considering any factors. Random initialization method is selected because it drives the population to optimality.

The encoding of a Solution (optimal number of nurses for wards) is demonstrated in Figure 1. S symbolizes the solution in a population. In a solution, each gene supplies two pieces of information: (i) the gene index number represents the ward index number; and (ii) the value in the gene signifies the optimum number of nurses for that ward. For example, the value of the first gene is 6, indicating ward number 1 has been allocated total of 6 nurses.

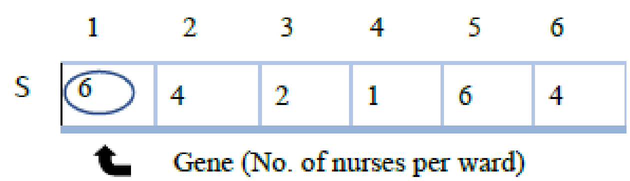

Fig. 1. Encoding of a Solution.

Two types of genetic operators to produce offspring were considered: (1) mutation and (2) crossover. The crossover is a convergence operation which is intended to pull the population towards a local min or max. The mutation is a divergence operation which is intended to occasionally break one or more members of a population out of a local min/max space and potentially discover a better space. Each generation of the GA approach goes through mutations and crossovers.

For the crossover operator, as shown in figure 2, the "One-Point crossover" approach was used. A random point of two solutions are selected as the crossover points and two new solutions are generated by exchanging the elements of parents among themselves up until the crossover point is reached.

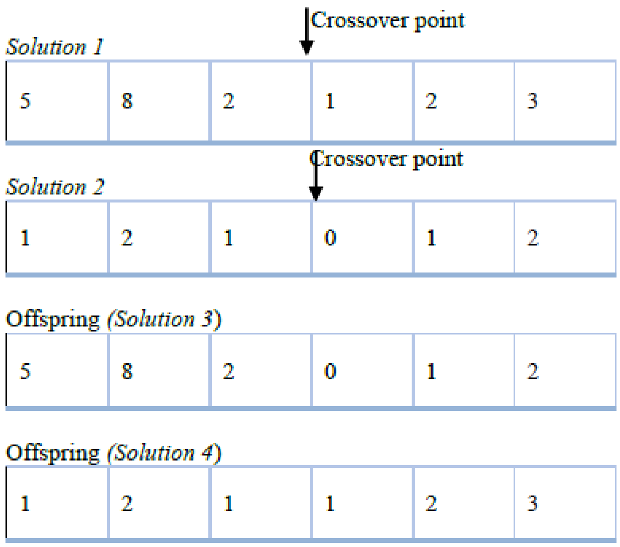

Fig. 2. One-Point Crossover.

For the mutation operator, as shown in figure 3, the "swap mutations" approach was used, where the over allocations and less allocation of nurses for a ward are swapped accordingly (added and removed within a solution).

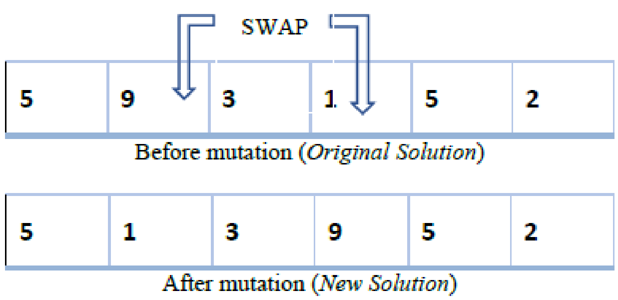

Fig. 3. Mutation.

The newly generated solutions are evaluated according to the fitness function derived in Section B. The process is continued until x number of generations are explored and the best solution (the solution with minimum fitness value) is selected as the optimal number of nurses for wards.

D. Iterated Local Search (ILS) based Approach

ILS is more effective and quickly explores the optimal solution. It can find a highly accurate optimum by using a few numbers of iterations [10]. This algorithm keeps track on its current state (current solution) and moves to neighboring states (neighborhood) with the results of current state. Then it repeats the same process if the neighboring states get better than the current state, until it gets the best solution.

ILS process can be described by the following key steps [10]:

1) Generate an initial solution f

2) Produce a new solution f' by applying local search and perturbation to the solution f

3) Compute the fitness value for the new solution f'

4) If the fitness value of new solution f' is better than fitness value of original solution f,

Accept the new solution f'

else accept the original solution f

5) Repeat from Step 2 until a satisfying solution is achieved.

The ILS starts with an initial solution. Two approaches to generate the initial solution are as follows: (1) best fit and (2) random fit. In the best fit approach, the nurses are allocated to wards according to the requirement of each ward (number of nurses required by each ward). Wards are considered sequentially (by the ward number), and nurses are allocated starting from first wards, second ward etc. Therefore, the last wards might not get nurses allocated at all. On the other hand, with the random fit approach, the nurses are allocated to wards randomly, without considering any factors.

Next, the initial solution goes through a perturbation process to generate a new solution. In the perturbation process, each nurse is selected sequentially and moved from the allocated ward to another ward. Each of this move generates a new solution. Each new solution will be evaluated using the heurist function. The previously mentioned fitness function under section B was used as the heuristic function for ILS. If the new solution gives a better fitness value, then the old solution is discarded, and new solution is considered as the current solution.

The process is continued until x number of iterations are explored and the best Solution (the solution with minimum fitness value) is selected as the number of tourists that can be accommodated for each location.

IV. Results And Discussion

A. Experimental Setup

The optimization algorithms were implemented using Spyder application under Anaconda Navigator which is a free and open source distribution of the python programming language. Experiments were performed on a laptop with the following specifications;

- CPU: Intel Core i7 (2.40GHz)
- RAM: 4GB
- OS: Windows 10 (64-bit Operating System)

The statistics collected from the IDH were used (number of dengue patients, number of specialized wards, number of nurses etc.) for the experiments [6].

B. GA based Approach for Nurse Allocation

In this section, the results of the GA approach are presented, which was one of the approaches used to allocate nurses optimally.

The solutions are generated assuming there are 25 nurses and 3 wards. There are 30 patients in Ward 1, 30 patients in Ward 2 and only 10 patients in Ward 3.

Experiment 1: As explained earlier, the GA process tries to improve the given initial solution by applying genetic operations over the generations. To explore how GA process improves the initial solution, 30 rounds of experiments were conducted [7]. First, find the initial solutions, and then improve the solution using GA process. As shown in the figure 4, the important observation was that most of the improvements in the fitness function happens early on (during first 250 generations) and after that improvements decrease significantly. In fact, there were very few improvements after 300 generations.

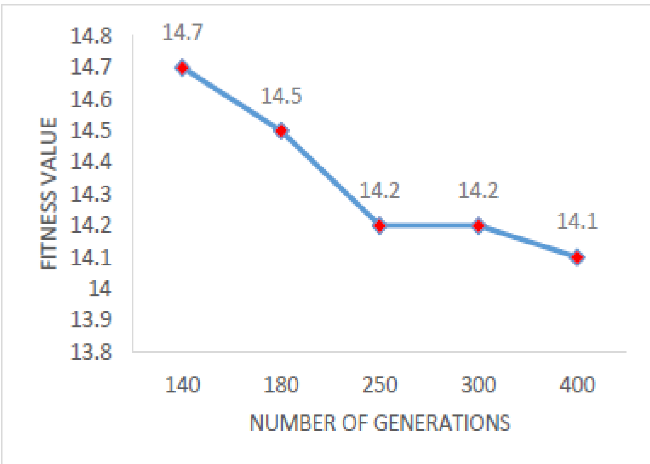

Fig. 4. Effect of Number of Generations on the Fitness Score.

Experiment 2: GA process begins with a set of solutions known as the initial population. To evaluate how GA process is affected by the size of the population (number of initial solutions), experiments were carried out for different population sizes (30 rounds of experiments for each population size) [7]. As shown in figure 5, the results showed that a better solution can be achieved when the population size is greater than 10.

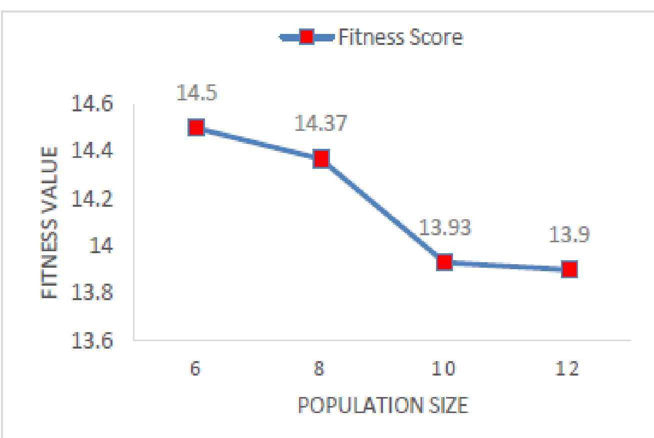

Fig. 5. Effect of Population Size on the Fitness Score.

C. ILS based Approach for Nurse Allocation

The same data set and same fitness function were used (as the heuristic function) for ILS approach, to compare ILS approach with GA approach.

Experiment 3: As explained in Section III, the ILS process generates the initial solution using two approaches: (1) best fit and (2) random fit. Two sets of experiments were conducted separately for the two approaches (30 rounds of experiments for each approach) [8].

In each experiment, revealed how the ILS tries to improve the given initial solution by applying perturbation and hill climbing over the iterations. First, find the initial solution (by best fit or random fit), and then improve the solution using ILS process.

As shown in the figure 6, the first observation was, starting with an initial solution generated by best fit approach was better than starting with an initial solution generated by random fit approach. As the best fit approach already provided an initial solution which was much better, the ILS process did not have to do much work to improve the solution in its iterations. Therefore, if started with an initial solution from the best fit approach, one can find a better solution fast.

The next observation is, in general, that most of the improvements in the heuristic function happens early on (during first 20 iterations) and after that improvements decrease significantly.

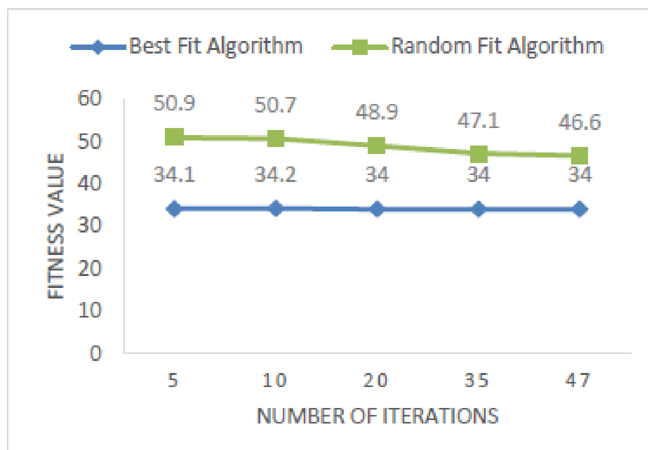

Fig. 6. Effect of Number of iterations on the Fitness Score.

D. Genetic Algorithm Approach vs Iterated Local Search Approach

This section presents the results of GA approach vs ILS approach comparison. For both approaches, the same initial solution was used and carried out GA process and ILS process separately.

Experiment 4: To evaluate the performances of GA and ILS, in terms of the fitness value, four scenarios were considered where the number of nurses were varied for each scenario. 30 rounds of experiments were conducted for each scenario, with GA and ILS separately. As shown in table 1 and figure 7 (averages of 30 experiment rounds), GA was able to find better solutions than ILS, in all four scenarios.

TABLE I. FITNESS VALUES COMPARISON (GA VS ILS)

Number of nurses	Best Fitness Score	
	Genetic Algorithm	**Iterated Local Search**
15	49	67
20	22	25
25	12	16
30	9	10

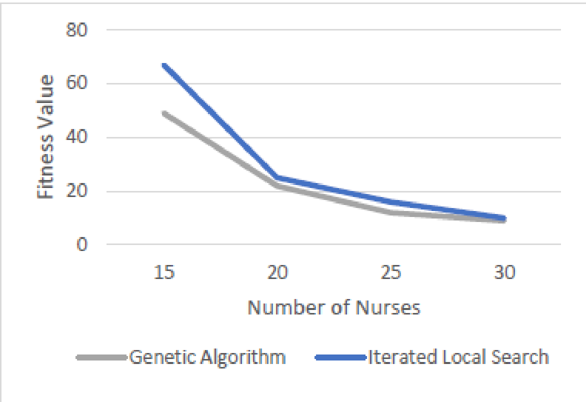

Fig. 7. Fitness Values Comparison (GA vs ILS).

TABLE II. TIME COMPARISON (GA VS ILS)

Number of nurses	Time Taken (seconds)	
	Genetic Algorithm	**Iterated Local Search**
15	0.025986	0.027986
20	0.048973	0.049971
25	0.037977	0.051970
30	0.059965	0.070957

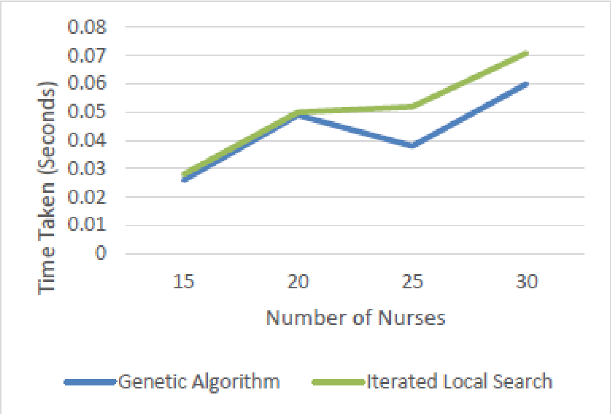

Fig. 8. Time Comparison (GA vs ILS).

Experiment 5: To evaluate the performances of GA and ILS, in terms of the time, once again, four scenarios were considered where the number of nurses were varied for each scenario. 30 rounds of experiments were conducted for each scenario, with GA and ILS separately. As shown in table 2 and figure 8 (averages of 30 experiment rounds), GA was able to find solutions faster than ILS, in all four scenarios.

V. FINAL REMARKS

We have proposed a platform for Dengue disease management with following modules: (1) a prediction module to predict the dengue outbreak and (2) an optimization algorithm module to optimize hospital staff according to the predictions made on future dengue patient counts.

This paper focuses on the optimization algorithm module to generate the hospital staff schedule, specially the nurse staff allocation, based on two approaches: (1) GA and (2) ILS. Experiments were conducted to measure the performances of the optimization algorithms using the statistics collected from IDH. With the real data sets, the results show that, GA and ILS can decide the optimal allocations dynamically in the order of seconds. Also, the results show that the GA approach is much efficient and faster than the ILS approach when considering the fitness value and the performance.

Comparing to similar surveys, this study depicts that the proposed optimization algorithm (GA) is not only fast but is also efficient and the same solution which we have developed using GA can be used to solve similar optimizing problems. As mentioned previously the experiments were conducted considering a limited dataset taking into consideration the situation of the IDH hospital. For further analysis, a larger dataset is essential to achieve improved results.

As the future work, we are planning to work on the prediction module to complete our proposed platform for Dengue disease management

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