Using Ant Colony Optimization to Find the Best Precautionary Measures Framework for Controlling COVID-19 Pandemic in Saudi Arabia

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Abstract

In this paper, we study the relationship between infection rates of covid 19 and the precautionary measures and strict protocols taken by Saudi Arabia to combat the spread of the coronavirus disease and minimize the number of infected people. Based on the infection rates and the timetable of precautionary measures, the best framework of precautionary measures was identified by applying the traveling salesman problem (TSP) that relies on ant colony optimization (ACO) algorithms. The proposed algorithm was applied to daily infected cases data in Saudi Arabia during three periods of precautionary measures: partial curfew, whole curfew, and gatherings penalties. The results showed the partial curfew and the whole curfew for some cities have the minimum total cases over other precautionary measures. The gatherings penalties had no real effect in reducing infected cases as the other two precautionary measures. Therefore, in future similar circumstances, we recommend first applying the partial curfew and the whole curfew for some cities, and not considering the gatherings penalties as an effective precautionary measure. We also recommend re-study the application of the grouping penalty, to identify the reasons behind the lack of its effectiveness in reducing the number of infected cases.

Keywords:

ant colony optimization (ACO), traveling salesman problem (TSP), optimization, algorithms, coronavirus disease 2019 (COVID-19), and precautionary measures.

1. Introduction

When infectious diseases spread, countries, in cooperation with global health organizations, study all ways to find the causes of the disease and search for the best preventive and curative methods to limit its spread. Sometimes countries resort to very strict, difficult but necessary measures for the sake of public health, putting the safety of people first, regardless of material losses. Coronavirus disease 2019 (COVID-19) is a contagious disease that was initially reported 27 cases of unknown etiology at wet markets in Wuhan city, China in November 2019 [1]. It rapidly spread to become a global pandemic on March 11th, 2020 [2]. By the date of conducting this study, March 25th, 2021, the virus has infected more than 124,871,140 confirmed cases and 2,744,543 total deaths [3].

The rapid deterioration of the emerging crisis of the Corona virus, and its expansion in more than 185 countries, has imposed extraordinary global challenges. Some countries lost the opportunity to take decisive precautionary measures to control the health situation on time. Which led to weak mitigation of economic problems accompanying the pandemic. While there were a few countries that were able to precede the virus by one step before its impact escalated. The first confirmed case of infection with the virus appeared in Saudi Arabia on March 2nd, 2020. Since then, strong precautionary and preventive measures that applied to combat the covid-19 outbreak and limit its spread among citizens and residents across the country [4]. These precautionary include suspending the performance of Umrah for citizens and residents on March 4 and then followed by measures such as suspending flights, suspending studies in schools and universities, postponing all sports, mass events, festivals, celebrations, and closing infected areas. on March 17th, 2020, a series of precautionary measures were taken, such as pre-emptive examination procedures, quarantine, social distancing, curfews, closing borders, and closing economic activities completely. Saudi Arabia succeed in being among the best countries that applied these measures at the right time, changing the course of the virus, and decreasing the death rate.

In covid-19 age, Artificial Intelligence (AI) has a significant role in analyzing what happened, leading to how to improve, predicting what may happen, and helping in facing the upcoming. The Ant Colony Optimization algorithm (ACO) is a well-defined heuristic method based on Swarm Intelligence, which is a part of (AI) methodologies. It is a probabilistic technique that stimulated the behavior of the ants, and how the ants communicate (pheromone-based

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communication) to accomplish a task. This algorithm was initially introduced by Marco Dorigo in his Ph.D. thesis [5-6]. The idea was to find out the optimal path in a given graph by imitating the behavior of ants in their trail between a food source and their colony. While ants are searching for food, they release a pheromone on the ground, ants can smell the pheromone and trail the richer amount of pheromones in their path. In case path branches are found; ants tend to choose the path with a higher amount of pheromones.

The higher pheromone indicates that multiple ants are walking on this path, or the path is shorter since the pheromone evaporates as time passing, due to that the amount of the pheromone deposited by an ant walking on the long path will be weaker. So, the final chosen path by all the ants represents the shortest one or the one that leads to a good quality food source. Generally speaking, ACO is a method that combines both artificial ants and local search algorithms. It is an optimization algorithm that is commonly employed for resolving computational problems that involve reduced paths through a given graph e.g., vehicle routing problem (VRP), internet routing, graph coloring, project scheduling, and traveling salesman problem (TSP). In the traveling salesman problem, a salesperson has to visit a group of cities starting from a particular point using the shortest possible distance to visit each only once and back to the starting point. The problem can be modeled using a complete weighted $graph\, G = (N, E)$ where vertices N represents the set of cities (nodes) and edges E represents the set of paths that connect all cities. The weight $W_{i,j}$ on the edge (i, j) represents the distance between cities i and j where edge $(i, j) \in E$ [7-9].

This study aimed to find the best framework of precautionary measures taken by Saudi Arabia on limiting the spread of the virus using traveling salesman problem (TSP) strategies based on ant colony optimization (ACO).

The rest of this paper is organized as follows. Section 2 reviews related work and Section 3 introduces our study area and dataset. In Section 4, we present our proposed methods followed by results and discussion. The conclusion is presented in section 5.

2. Related Work

Since the emergence of COVID-19 cases in China, lots of research studies have been done to study the effectiveness of preventive measures on maintaining the slow down the spread of coronavirus disease. Alkhaldi, G. et al. [10] studied the perception of public and their attitudes towards the pandemic including the levels of public anxiety and adoption of preventive measures, and their sources of information.

They also studied their willingness and ability to self-isolate during and post-lockdown of the coronavirus in Saudi Arabia. The results showed that a majority (74%) were anxious about the COVID-19 pandemic, and they were willing to adopt preventive measures, and perceived the ability to self-isolate. However, the elderly, and the lower wages worker are less adoptive of preventive measures and willingness to self-isolate. Hanawi MK et al. [11] run univariate and multivariable regression analyses on their collected data. An online self-reported questionnaire was used to distinguish the factors related to feelings, understanding, and practices toward COVID-19 from the 3,388 participants. The study showed that women were more familiar with COVID-19 than men, and adults have better awareness and practices than young people. Sundaram B. et al. [12] studied the practicability of applying preventive measures to prevent COVID-19 spread over 105 English primary schools in the summer of 2020. The data were collected in July–August 2020 through questionnaires and interviews, where the topics enclosed the measures being implemented; ease of application, school's guidance; and challenges experienced. The results noticed high rates of applying most recommended measures except requiring a 2-meter space between students, providing enough hand sanitizers, and offering one-way systems in corridors of the school. Ali R et al. [13] worked on a sample among the Egyptians in Upper Egypt to evaluate their awareness and preparation and to identify the obstacles that cause delayed adherence to preventive measures. The data were a non-probability self-nominated sample collected from 21 to 30 August 2020 by online questionnaires and personal interviews. The results showed a high awareness among participants about COVID-19 preventive measures. Yet, not all precautionary measures had the same level of adherence.

Swarm intelligence algorithms have shown great promising solutions to many practical problems. Liu et al. [14] proposed a method namely CLACO-MIS, to refine the diagnoses level of covid-19 on multilevel COVID-19 X-ray image segmentation. CLACO-MIS is a modification of the ant colony optimization (ACO) algorithm with Cauchy mutation to speed up both search and convergence of ACO. They used greedy Levy mutation to avert the local solution. The results showed CLACO-MIS have better performance than some excellent peers in term of the effect of the segmentation and strong adaptability at several threshold levels. The epidemic of Covid-19 in Wuhan highlighted the futility of the process of transporting medical waste. Liu et al. [15] employed the ant colony–tabu hybrid algorithms to model the medical waste transportation between hospital and storage placements. The algorithm establishes several stations, where each station is associated with some hospitals, and optimizes the paths between each station and its associated hospitals. The proposed model showed excellent results in the process of transporting medical waste, and good response to emergencies situations in Wuhan or other big cities.

The main goal of this study is to investigate the relationship between the number of covid-19 cases and the precautionary measures and strict protocols taken by Saudi Arabia to reduce the number of infected cases and the spread of COVID-19. For this reason, ant colony optimization and the traveling salesman problem are used to determine the best framework of precautionary measures.

3. Data Collection

On Monday 2nd March 2020, the Ministry of Health (MOH) announced the first case of coronavirus infection. The data on COVID-19 daily cases in Saudi Arabia were collected from the first case detection until March 25th, 2021, from the official website of the Saudi Ministry of Health, COVID-19 dashboard [16]. To study the effect of preventive measures on the number of infected cases, some preventive measurements were selected along with their corresponding number of daily cases. Table 1, Table 2, and Table 3 show the numbers of daily cases since the partial curfew, the whole curfew, and gatherings penalties started respectively.

Table 1: Partial Curfew

Date	*Infected cases*
3-23-20	51
3-24-20	205
3-25-20	133
3-26-20	112
3-27-20	92
3-28-20	99
3-29-20	96
3-30-20	154
3-31-20	110
4-01-20	157

Table 2: Whole Curfew

Date	*Infected cases*
4-2-20	165
4-3-20	154
4-4-20	140
4-5-20	191
4-6-20	93
4-7-20	289
4-8-20	43
4-9-20	137
4-10-20	355
4-11-20	364
4-12-20	382
4-13-20	429
4-14-20	472
4-15-20	435
4-16-20	493
4-17-20	518
4-18	762
4-19	1132
4-20	1088

Table 3: Gatherings Penalties

Date	*Infected cases*
5-17-20	2840
5-18-20	2736
5-19-20	2593
5-20-20	2509
5-21-20	2691
5-22-20	2532
5-23-20	2642
5-24-20	2442
5-25-20	2399
5-26-20	2235
5-27-20	1931
5-28-20	1815
5-29-20	1644

To investigate the impact of each measurement individually and determine the best precautionary measures framework that helps better reduce the number of cases infected with Covid-19, we have determined the periods in which the precautionary measures do not overlap with each other. In specific, the period of each precautionary measure begins after the end of the preceding one. However, some precautionary measures may still be applied in the background of other precautionary measures such as a partial curfew [17]. The partial curfew was imposed on March 23rd, from 7 pm to 6 am for 21 days, while the total curfew was imposed on some major cities Makkah and Madinah around the clock on April 2nd, and in Riyadh, Tabuk, and Dammam on April 6th until April 20th. On April 21st, the partial curfew has been resumed by adjusting the times during which movement is permitted in Ramadan to 9 am until 5 pm. On April 26th, curfew partial was lifted in all regions of the Kingdom from 9 am to 5 pm until May 13th and banning social gatherings of more than 5 people, including weddings and funerals. On May 17th, the gatherings penalty for a family was determined to prevent gatherings inside homes, rest houses, chalets, or farms for more than one family who does not share housing.

4. Methodology

4.1. Ant Colony Optimization Method on Traveling salesman problem

The proposed algorithm simulates the Ant Colony Optimization (ACO) algorithm applied to the traveling salesman problem (TSP) by Marcodorigo et al [7]. At the first tour (path traversal), each artificial ant was distributed in randomly selected cities (nodes/ vertices). An ant k might move from current city x to city y on a TSP graph where it can select the neighbor cities (vertices linked by edges) with a lot of pheromone trails based on a random variable q homogeneously distributed on [0, 1], and a pre-defined parameter $q_0 = 0 \le q_0 \le 1$. This can be done by applying the probabilistic formula both of trail stored on edges and of a heuristic value (e.g., see Eq. 1), which was chosen here to be a function of the edge's length.

$$y = \begin{cases} \arg max_{y \in visit_k}(x) \left\{ \left[\tau_{xy}(t)\right]^{\alpha} \left[\eta_{xy}\right]^{\beta} \right\} & if\ q \le q_0 \\ Y & Otherwise \end{cases} \quad (1)$$

Where:

- τ_{xy} is the pheromone trail level on edge (x, y) that connects city x with city y.
- η_{xy} is a heuristic function, which was selected to be $\frac{1}{dist_{xy}}$ where $dist_{xy}$ the distance between cities x and y
- α and β are both positive parameters that weigh the relative importance of pheromone trail and heuristic function (ant visibility). This probability is important and represents a trade-off between edge length (visibility) and pheromone trail intensity, where $\alpha = 0$, which means the closed vertex x is more probable to be picked– a promising solution. $\beta = 0$, means only pheromone increase (that will lead the system to a stagnation situation where all ants generate a sub-optimal path- feasible solution).
- $visit_k$ unlike natural ants, artificial ants can memorize the cities (nodes) that have already been visited, where buffer $visit_k = 0$ for each new tour and is updated by adding the newly visited city after each step.
- Y is a random variable calculated using the probability distribution (e.g., see Eq. 2) that helps to select shorter edges (move from city x to city y) that have a higher level of pheromone trail:

$$p_{x,y}^{k}(t) = \begin{cases} \frac{[\tau_{xy}(t)]^{\alpha}[\eta_{xy}]^{\beta}}{\sum_{k \epsilon visit_k}[\tau_{xk}(t)]^{\alpha}[\eta_{xk}]^{\beta}} & if\ y \in visit_k \\ 0 & Otherwise \end{cases} \quad (2)$$

Where $p_{x,y}^{k}$ is the likelihood with which ant k chooses to move from city x to city y. At each step, ant k moves from current city x to city y, and modifies the pheromone trail on the visited edges (local trail update), giving $(1 - \rho)$, where it represents the parameter of pheromone decay, and $\rho = (0 < \rho < 1)$ that signifies the trail evaporation after ant visit another city. In the end, after all the ants finished their tours (path/visited edge), the ant that outputs the shortest path modifies visited edges (the edges belonging to its path (global trail update) by adding more pheromone trail that is inversely proportional to the path length. The pheromone will be updated using Eq. 3:

$$\tau_{xy}(t+1) = (1-\rho)\,\tau_{xy}(t) + \Delta\,\tau_{xy}(t) \quad (3)$$

Where $\Delta\ \tau_{xy}(t)$ represents the shortest path (e.g., see Eq. 4), and n represents the number of artificial ants.

$$shortest\ path = \sum_{k=1}^{n} \Delta\,\tau_{xy}^{k}(t) \quad (4).$$

Here $\Delta\,\tau_{xy}^{k}(t)$ represents the path length (e.g., see Eq. 5)

$$\Delta\,\tau_{xy}^{k}(t) = \begin{cases} \frac{Q}{L_k} & if\ (x,y)\ \epsilon\ \ path_k \\ 0 & Otherwise \end{cases} \quad (5).$$

Where Q is an arbitrary constant, and L_k represents the path length performed by ant k and. Marcodorigo et al [7] concluded three ideas from natural ant behavior to their artificial ant colony as follows: ants prefer the paths that have a high level of pheromone, shorter paths have a higher amount of pheromone, ants communicate through a chemically mediated namely pheromone trail.

4.2. Proposed Algorithm

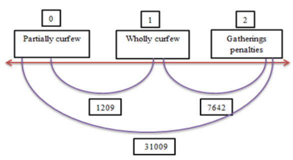
To investigate the impact of preventive measurements on the number of Covid-19 infected cases, and determine the best precautionary measures framework, we simulate Ant Colony Optimization (ACO) that is applied to a symmetric traveling salesman problem (TSP) for three preventive measurements; partially curfew the wholly curfew, and gatherings penalties as follows:

- We consider the cities in the traveling salesman problem as the preventive measurements.

- The distances between the cities as the total number of infected cases in the period of each preventive measure, and
- Ants represent the agent that investigates the preventive measurements to find the shortest path (minimum, number of infected cases).

The input matrix shows the number of infected cases in each preventive measure given in figure 1, their visibility for each edge ($1/dist_{xy}$) is shown in Table 4, and randomly select first preventive measurements by each ant are shown in Table 5.

Programing codes are developed in Python. The algorithm was provided by the input matrix that represents the preventive measures and the total cases in their period, and some input parameters such as: α, β, Q, number of ants, pheromone distribution for each edge, and number of iterations. The algorithm might stop early (less than the number of iterations) when there is no further improvement in the score. The returned output is the best preventive measures framework that minimizes the number of infected cases. In specific, our proposed algorithm determined the minimum total confirmed cases resulting from some preventive measures out of the rest candidates of preventive measures. Thus, it excludes the worst preventive measures that did not affect decreasing the number of infected cases compared to the other measures. When having more than 3 preventive measures, the way of constructing the matrix will be a little bit different, so figure 2 shows a matrix with four preventive measures. The preventive measures are ordered based on their timeline, then each one is connected to its successor by its total cases, while the last one is connected to the first one. Regarding the rest indexes in the matrix, it does not matter to the desired output, so it is filled by the total cases of all the preventive measures to ensure that they are not going to be considered by the algorithm.



	partially curfew	wholly curfew	gatherings penalties
partially curfew	0	1209	31009
wholly curfew	1209	0	7642
gatherings penalties	31009	7642	0

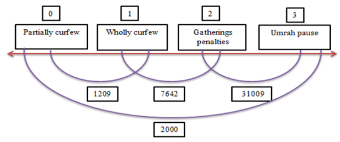
Fig. 1 Input Matrix.

Table 4: Visibility of edge $= 1/dist_{xy}$

	partially curfew	***wholly curfew***	***gatherings penalties***
partially curfew	0	0.00082713	0.0000323
wholly curfew	0.00082713	0	0.000131
gatherings penalties	0.0000323	0.000131	0

Table 5: Randomly select first Preventive measurements by each ant

Ant	***0***	***1***	***2***
Preventive measurements	partially curfew	wholly curfew	gathering penalties



	partially curfew	wholly curfew	gatherings penalties	Umrah Pause
partially curfew	0	1209	**41860**	2000
wholly curfew	1209	0	7642	**41860**
gatherings penalties	**41860**	7642	0	31009
Umrah Pause	2000	**41860**	31009	0

Figure 2: matrix with 4 preventive measures

This approach includes the following steps:

Input:

- *Total number of infected cases during preventive measures (partially curfew, wholly curfew, and gatherings penalties)*
- *No of preventive measures=3,*
- *Ant =3*
- *α =1, β=1, Q=2,*
- *Number of iterations=100*
- *pheromone distribution for each edge=1*

Output: *The best precautionary measures framework that minimizes the number of infected cases.*

Method:

- *initialize t =0; and randomly set ants on n nodes (preventive measures)*
- *Select the next node (preventive measurement) based on the following probabilistic formula:**

$$p_{x,y}^{k}(t) = \begin{cases} \dfrac{[\tau_{xy}(t)]^{\alpha}\,[\eta_{xy}]^{\beta}}{\sum_{k\epsilon visit_k}[\tau_{xk}(t)]^{\alpha}\,[\eta_{xk}]^{\beta}} & if\ y\epsilon\ visit_k \\ 0 & Otherwise \end{cases}$$

- *For each artificial ant, compute the path length L_k (daily infected cases associated with each preventive measurement), and update the shortest path found (the path that has minimum infected cases- high amount of pheromone) using the following:*

- *For every edge (x,y), where (x,y) are two preventive measurements, compute :*
  - $\Delta\ \tau_{xy}(t) = \sum_{k=1}^{n} \Delta\, \tau_{xy}^{k}(t)$
  - $\tau_{xy}\ (t+1) = (1-\rho)\ \tau_{xy}(t) + \Delta\ \tau_{xy}(t).$
- *For each ant k =1 to n do*

$$\Delta\, \tau_{xy}^{k}(t) = \begin{cases} \frac{Q}{L_k} & if\ (x,y)\ \epsilon\ path_k \\ 0 & Otherwise \end{cases}$$

$\Delta\, \tau_{xy}^{k}(t) {+}{=}\ \Delta\, \tau_{xy}(t)$

- $t++$
- $\Delta\, \tau_{xy}^{k}(t) = 0$
- *If there are no more preventive measurements stop, otherwise select the next node (preventive measurement) and repeat the same process**

5. Results and Discussion

This method follows the traveling salesman problem and works correctly to provide the expected output except it does not go back to the starting point and there is no specific starting point. Tables 6-9 present the selection method of the preferred precautionary measures according to the ant colony optimization algorithm where (0,1,2) stands for, partial curfew, whole curfew for some cities, and gatherings penalties respectively. At the first iteration, ants move randomly. Thus, we set the pheromone (τ) =1 for all edges (equal level of pheromone, see Table 6). For each ant, we compute the path (visibility of edge, see Table 7) and compute the amount of pheromone that helps to identify the shortest path. Ant can select the next node (precautionary measures) simply by using the probability matrix (see Table 8). At the end of iteration one, we compute the best score (minimum cost) that represents the best precautionary measures (shortest path) that minimized the number of infection cases. We repeat the steps at each iteration for each ant. The next pheromone matrix updated the pheromone level (see Table 9) by using $\tau_{xy}\ (t+1) = (1-\rho)\ \tau_{xy}(t) + \sum_{k=1}^{n} \Delta\, \tau_{xy}^{k}(t)$. Figure 3 shows the best precautionary measures framework that is obtained by the proposed algorithm where (2,1,0) stands for gatherings penalties, whole curfew for some cities, and partial curfew respectively. The partial curfew and the whole curfew for some cities have the minimum total cases over the other combinations. This conclusion was extracted from the best path as follows; The number of infected cases between "2" and "1" in the matrix is the total infected cases for the whole curfew, while the number of infected cases between "1" and "0" in the matrix is the total cases for the partial curfew. Therefore, a partially curfew and a wholly curfew for some cities give the minimum number of total cases. However, we should consider the following observations: coronavirus symptoms start after 2-14 days of the infection day, thus, there is a probability that an infected case shows during the period of another preventive measure. Also, the fact that the number of cases infected with Covid-19 was small at the beginning of the pandemic and then increased over time, may indicate that the competition between preventive measures between the early onset phase and several months after the onset of the pandemic is unfair. Figure 4 performance of the proposed algorithm.

6. Conclusion

Saudi Arabia achieved remarkable success in flattening the epidemic curve by applying early strict preventive and precautionary measures. In this paper, we presented the ant colony optimization algorithm for the traveling salesmen problem to study the impact of preventive measurements on the number of Covid-19 infected cases. Some preventive measurements were selected along with their corresponding number of daily cases. We investigated the effect of each measure individually and determined the best precautionary measures framework that helps better reduce the number of cases infected with Covid-19. We have determined the periods in which the measures do not overlap with each other. The results indicated that the partial curfew and the whole curfew for some cities have the minimum total cases over the gatherings penalties measures.

Table 6: Pheromone Matrix

	0: partial	*1: whole*	*2: gather. Pen.*
0: partial	0	1	1
1: whole	1	0	1
2: gather. Pen.	1	1	0

Table 7: Heuristic Matrix = Visibility of edge = $1/dist_{xy}$

	0	***1***	***2***
0	0	0.00082713	0.0000323
1	0.00082713	0	0.000131
2	0.0000323	0.000131	0

Table 8: Probability Matrix = $[\tau_{xy}(t)]^{\alpha}\,[\eta_{xy}]^{\beta}$

	0	***1***	***2***
0	0	0.00082713	0.0000323
1	0.00082713	0	0.000131
2	0.0000323	0.000131	0

Table 9: Pheromone Matrix at iteration 2

	0	***1***	***2***
0	0	2.9	0.9
1	0.9	0	2.9
2	0.9	0.9	0

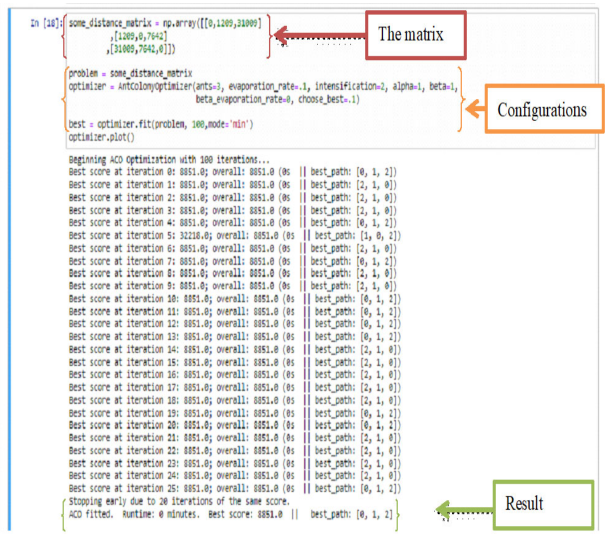


Fig. 3 Results.

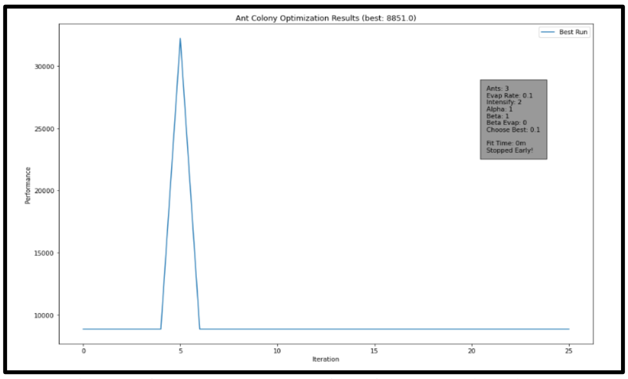


Fig. 4 performance (score -number of cases) Vs. iterations.

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