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COVID-19 repatriation programs — Classification and optimization models

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A B S T R A C T

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Due to the COVID-19 pandemic and the subsequent measures to control the spread of the virus by border closure and suspension of commercial flights, decision-makers in several countries had to deal with one or more forms of repatriation problems, international and domestic. In addressing an international repatriation problem, a country must schedule flights to return its citizens. Typically, the flight schedules of commercial airlines are announced, and passengers buy their seats accordingly. However, in repatriation, the opposite happens: citizens express their wishes to return to their countries, and flights need to be scheduled. Due to several constraints, decision-makers should repatriate the most vulnerable citizens first. In this work, we offer an overview of repatriation problems from an optimization perspective by visiting real-life cases. We compare the Indian and Jordanian repatriation programs to find similarities and differences between the two. We also develop several mixed-integer linear programs (MILPs) to model different repatriation phases and solve respective illustrative examples to demonstrate the use of the MILPs. Last, we solve two stages of a problem that resembles Jordan’s actual repatriation program. Decision-makers and researchers may use and extend this summary and the optimization models for any future pandemic that might lead to border closures and new repatriation problems.

1. Introduction

The World Health Organization (WHO) declared the COVID-19 pandemic, which is caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), a public health emergency of international concern on 30 January 2020 and a pandemic on 11 March 2020 (WHO, 2020b). To face this invisible menace, the Chinese government imposed a lockdown on Hubei province on 23 January 2020 (Lau et al., 2020), and many other countries followed, creating the largest quarantine in human history (Kharroubi and Saleh, 2020). Many countries restricted all forms of international and domestic travel (e.g., land, air, and sea) (Chinazzi et al., 2020 and Sun et al., 2021). Even in Europe, where countries have nearly achieved a borderless continent, governments needed to revive territorial borders to stop the spread of the virus (Opitowska, 2021).

According to Barua et al. (2020), universal border closure has led to a de-globalization process as the normal flow of people, cash, and products has been affected. Nicola et al. (2020) reviewed the adverse effects of the lockdowns on all economic sectors and showed that all sectors are negatively affected. Consequently, economic growth will slow, and many workers might lose their jobs. According to the BBC (2020), over 200 million people were expected to lose their jobs in April 2020.

In 2017, Finaccord (2017) estimated the number of expatriate workers at 66.2 million, and this number was projected to reach 87.5 million in 2021. The Finaccord (2017) report also showed that the Middle Eastern countries of Saudi Arabia (SA) and the United Arab Emirates (UAE), in addition to Germany in Europe, have the largest percentages of expatriate workers. One million expatriates were expected to lose their jobs in SA due to the sudden lockdown caused by the COVID-19 pandemic in 2020 (Arab News, 2020), and a similar number of expatriates were expected to leave the UAE in 2020 (Hashmi, 2020). Most expatriates who lost their jobs were forced to return to their countries; however, commercial flights were suspended. Consequently, several countries had to schedule emergency repatriation flights (e.g., Al Sherbini, 2020; Lytras et al., 2020). These countries repatriated expatriate workers when borders were closed (Murray, 2020). In addition to expatriate workers, other citizens who were outside their countries due to tourism, education, or business during the lockdowns have also been required to return.

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The repatriation problem was not limited to expatriate workers when borders were closed. In India, 10.55 million internal migrant workers were living and working in cities other than their home towns (Swapnil et al., 2020). Since interstate transportation was suspended in the second quarter of 2020, most domestic migrant workers wanted to return to their home towns, as discussed in Maji et al. (2020).

Governments all over the world had to confront and solve their own problems with repatriation. Despite the importance of these problems, researchers have not sufficiently addressed repatriation from an operational research perspective, except for Maji et al. (2020), who have studied the impact of repatriating domestic migrant workers on SARS-CoV-2 spread. Previous researchers have only considered the needed medical procedures for repatriation and have statistically analyzed the spread of the virus. For example, Lytras et al. (2020) have checked the percentages of repatriated citizens who carried the virus to Greece in March 2020. Similarly, in Içduygu (2020), the SARS-CoV-2's spread was checked among expatriates flying from Wuhan to their countries in the first three months of 2020. Karim et al. (2020) have shown that it is vital to have multi-disciplinary teams understand how the virus might spread in an airplane when repatriating citizens and how to mitigate that spread. Dagens et al. (2020) recommended the use of a hybrid military-civilian model to fly British citizens from Cuba to England, thereby curbing the virus's potential. Finally, Karim et al. (2020) have documented the process of repatriating Malaysian citizens using commercial flights.

This paper considers the international repatriation problems that different governments have faced from an operational perspective. We trace repatriation attempts performed by several countries and try to find similarities and differences among these attempts. These models might be necessary if a new global pandemic appears or if humanity faces with a new, more aggressive variant of COVID-19 such as the Delta variant (Rubin, 2021). Since there is a considerable variation in countries in terms of their geography and socioeconomic situations, we first develop a classification scheme that can relate these repatriation problems from an operational perspective. Moreover, researchers can relate other repatriation problems that we do not cover in this work to ones discussed here. Towards this end, we suggest a three-parameter classification scheme, through which we classify two repatriation problems: the Indian and Jordanian problems. Despite their geographical and socioeconomic differences, we found common threads between the two situations — for example, the targeted objective function. On the other hand, Jordan has had to repatriate its citizens to one city, while India had to fly its citizen back to several towns. India had to repatriate 7 million individuals over 11 months (Pande, 2021), whereas Jordan has repatriated around 25,000 citizens in six months (The Jordan Times, 2020).

The essence of the international repatriation problem from an operational perspective is flight scheduling. Decision-makers had to assign and schedule airplanes to repatriate their citizens from foreign countries. Commercial flights are already planned, and passengers buy seats in these flights; however, the opposite happens in repatriation. Passengers, actually citizens, express their desire to fly and the government, in collaboration with the flag-carrying airlines, needs to decide how to schedule the flights. Since optimization models that solve these problems are missing from the literature, we have developed a mixed-integer linear program (MILP) that decision-makers could have used to schedule their repatriation flights or can use in the future in case of a similar global-scale pandemic. Last, we show how our MILP model could have been used in a real-life scenario. To the authors' knowledge, no research paper has analyzed the repatriation problems or developed optimization models for these problems. Hopefully, our contribution to this area will be beneficial to governments, planners, and researchers.

The following section gives a general classification scheme and compares Indian and Jordanian attempts at repatriation. In Section 3, we introduce our MILPs. We start first with a repatriation phase that Jordan had to solve. We then modify and extend the MILP model to allow other cases. We use our MILP model to solve two phases of the Jordanian repatriation problem in Section 4. Finally, we present our conclusions and discuss possible future research in Section 5.

2. Classification

In this section, we suggest a classification scheme for repatriation problems. We then compare two repatriation programs. Classifying related problems makes it easier for researchers and practitioners to understand similarities and differences among the different problems. For example, to classify scheduling problems, researchers have developed a three-parameter classification notation, \(a(b/c)\), (Michael, 2018). In the scheduling notation, \(a\), \(b\), and \(c\) describe the shop configuration, constraints, and objective function, respectively. In this work, we also try to develop a similar notation for international repatriation problems.

The main objective of international repatriation problems is to repatriate the most vulnerable people first. Another objective is to control the spread of the virus, which is handled through dedicated quarantine locations and procedures. Before scheduling their repatriation flights, most countries use platforms in which citizens interested in returning to their countries need to complete return applications, in which they mention their reasons for returning. For example, India's repatriation registration form for returning its citizens from Dubai to India allows users to select one of the following reasons for returning:

1. Medical emergency (self)
2. Medical emergency (family)
3. Death of a family member
4. Stranded tourist/visitor
5. Deportation
6. Loss of employment
7. Expiry of visa
8. Stranded student
9. Pregnancy
10. Other

Decision-makers would choose to return the most vulnerable individuals first, such as people who have lost their jobs or have medical emergencies. Fig. 1 shows the sequence of processes to repatriate citizens from foreign countries. Each circle in Fig. 1 represents a citizen who wants to return. Circles in black represent citizens of the highest priority to return, followed by moderate priority citizens in dashed circles, and low priority citizens in solid circles. Fig. 1 shows that we have two airplanes in stage I, via which we repatriate citizens in countries 3 and 5.

2.1. Classification notation

shows that we have two airplanes in stage I, via which we repatriate citizens in countries 3 and 5. Our suggested classification considers three inputs, \(a(b/c)\). The meaning, description, and possible values to be used with each input are:

- \(a\) represents the departure location.
- \(b\) represents the arrival location.
- \(c\) represents the type of passenger.
1. Number of phases ($\alpha$). The Indian government commenced the Vande Bharat Mission (VBM) to repatriate its citizens from around the world.\footnote{https://www.civilaviation.gov.in/en/covid-19-vbm} The VBM is a repatriation program that consists of several phases as shown in \url{https://mea.gov.in/vande-bharat-mission-list-of-flights.htm}. Similarly, Lebanon has had to schedule its repatriation flights over several phases \cite{Youssef2021}. The Australian government, on the other hand, has scheduled 20 flights to repatriate its citizens at once \cite{Haydar2020}, or in one phase. We use $S$ and $P$ to indicate a single repatriation phase and a repatriation program, respectively. There is no need to repatriate all citizens in a phase; however, for a repatriation program, all individuals interested in returning need to be repatriated. Lastly, a repatriation program can be divided into several phases due to the dynamic nature of the problem. More individuals might show their interest in returning or cancel their repatriation applications. Moreover, countries might increase the number of quarantine locations by dedicating more quarantine locations or flights.

2. Number of locations from which we repatriate citizens to the number of places they are moved ($\beta$). On the one hand, the VBM has repatriated Indian citizens to the capitals of several Indian states from several world cities. On the other hand, Jordan has launched a repatriation program to return its citizens from several countries to one location, Amman, Jordan’s capital. For $\beta$, we use $m^2m$, $s^2m$, $s^2s$, and $m^2s$, where $m$ and $s$ stand for many countries and a single country, respectively. For example, the VBM can be described as $m^2m$, whereas Jordan’s repatriation program is $m^2s$.

3. Limitations due to quarantine and flight arrangements ($\gamma$). Most countries followed the WHO recommendations for a quarantine duration \cite{WHO2020b} of two weeks at the start of the pandemic. Later, different policies were implemented, such as wearing wristbands instead of quarantining \cite{Nasajpour2021}, quarantining based on the severity of the spread of COVID-19 in the country from which a repatriated citizen flew, and providing a negative polymerase chain reaction (PCR) test. Countries hosting expatriate workers and other stranded citizens might also limit the number of flights. Thus, we use $F$ and $Q$ to show whether flights or quarantine locations were limiting the number of repatriated citizens. Not only do airplanes’ capacities limit the number of flights but also the acceptance of host countries for all repatriating countries to fly their citizens.

2.2. Real repatriation programs

This section briefly compares the Indian and Jordanian repatriation programs and applies the suggested classification notation for these programs. India is a large country, a subcontinent whose population exceeds 1.3 billion. On the other hand, Jordan is a small country with around 10 million citizens. Despite these big differences, both countries had more expatriate workers than countries of similar populations.

2.2.1. VBM repatriation program

According to \cite{Today2021}, the “Vande Bharat Mission” is a program by the Indian government to repatriate Indian nationals from around the world amidst the crisis caused by the coronavirus pandemic. Till March 2021, over 67.5 lakh Indians were brought back from abroad. India’s flag-carrying airline and its subsidiaries were responsible for flying Indian citizens back to their country for the first repatriation phases; however, they allowed commercial flights later by creating air bubbles with 27 countries \cite{Pande2021}. India had to differentiate between its citizens based on the reason to return, as discussed earlier, to repatriate its citizens. We only consider the first phases of the VBM before creating any of the air bubbles, which resembles the situation prior to 2020. A good summary about VBM can be found in \cite{Pande2021}.

In addition to the return reason, the decision-makers who needed to schedule the repatriation flights had information about the starting city and ending city. Moreover, since the flag-carrying airline was the only carrier, the airplanes’ fleet capacity was also known by the decision-makers. Returned citizens had to stay for 2 weeks in quarantine; however, quarantine location did not limit the number of flights. Based on this description, we can classify the VBM program as $P|m^2m|F$.

2.2.2. Jordan’s repatriation program

Jordan’s repatriation program between March and August 2020 was similar to VBM in asking citizens wishing to return to Jordan to complete a form showing the reason behind their return request, as discussed earlier. More than 24,799 citizens expressed their interests in the Jordanian repatriation platform to return to Jordan \cite{Jordanian2020}. Unlike subcontinent India, citizens repatriated to Jordan were returned to one city, Amman, Jordan’s capital. To control the spread of SARS-CoV-2, the Jordanian government had to rent 5,000 hotel rooms at the start of the pandemic to isolate repatriated people \cite{GARDA WORLD2020}. Thus, repatriation flights would have to stop if quarantine locations are full. Jordan had scheduled five repatriation phases as shown in \cite{Jordanian2020}. The full Jordanian repatriation program can be described as $P|m^2s|Q$.

2.2.3. Comparing the repatriation programs of India and Jordan

The large size and population of India compared to Jordan and the policies taken to control the COVID-19 pandemic, have affected the repatriation arrangements of both countries. Jordan closed its borders and has enforced a strict lockdown to prevent the spread of COVID-19 \cite{GARDA WORLD2020}. Fig. 2 shows the number of new COVID-19 cases per day in Jordan. Through complete border closure in the first six
months of the pandemic, Jordan succeeded in having very few infection cases per day from March to September 2020. However, COVID-19 infiltrated Jordan in September 2020 through truck drivers. Even if India officially closes all its borders, it is impossible to stop people from moving in and out of India. Moreover, the repatriation program of Jordan has returned around 25,000 citizens to Jordan; however, India has repatriated approximately 7 million citizens. Due to this large number of citizens, India was asked to allow commercial flights to make more than one flight, then this constraint can be modified by changing the right-hand side of Eq. (3) to the number of allowed trips. Lastly, Eq. (4) gives an upper limit to the number of citizens that can return back such that this number does not exceed QC.

$$\text{max } Z = \sum_{i \in R} \sum_{k \in U} \sum_{m \in M} a_{ij} \times y_{im}$$ (1)

subject to

$$\sum_{i \in R} y_{im} \leq C_k \times x_{ik}, \forall k \in U, \forall i \in M$$ (2)

$$\sum_{i \in R} x_{ik} \leq 1, \forall k \in U$$ (3)

$$\sum_{i \in R} \sum_{m \in M} y_{im} \leq QC$$ (4)

$$x_{ik} = \begin{cases} 1 & \text{if airplane } k \text{ is assigned to city } i \\ 0 & \text{otherwise} \end{cases}$$ (5)

$$y_{ik} = \begin{cases} 1 & \text{if airplane } k \text{ is assigned to fly citizen } l \text{ from city } i \\ 0 & \text{otherwise} \end{cases}$$ (6)

3.1. MILP model for the single-phase repatriation problem

We start by defining the different sets used in developing the MILP models. Set $R = \{1, 2, \ldots, r\}$ represents the set of citizens that have registered in the repatriation platform, whereas, set $N = \{1, 2, \ldots, n\}$ is the set of priority groups. Set $M = \{1, 2, \ldots, m\}$ represents the set of cities from which citizens are repatriated.

Each citizen $l \in R$ is assigned to priority group $j \in N$, which we denote by $f_{lj}, l \in R \text{ and } j \in N$, and reside in city $i \in M$, which we denote by $f_{ij}, l \in R \text{ and } j \in N$. The decision-makers try to return all the citizens stranded out of the city; however, they are constrained by the airplane fleet capacity, or air bubble arrangements with other countries, and quarantine location availability. Due to these limiting constraints, it is crucial to return citizens having high priorities first, i.e., repatriate as much as possible from group 1, followed by group 2, 3, until groups $n$. For group $j \in N$, decision-makers assign weight $a_j$ to show the importance of returning this group, i.e., $a_j$ is the importance measure of group $j \in N$. This parameter, $a_j$, can also be interpreted as the cost of keeping a citizen of this group out of the citizen’s home city. The higher the group priority is, the higher the value of $a_j$ is.

In addition to sets $R$, $M$ and $N$, we also have set $U = \{1, 2, \ldots, u\}$ that represents the set of flag-carrying airplanes, and each airplane $k \in U$, has capacity $C_k$. Lastly, $QC$ denotes the available quarantine locations. In summary, we have $u$ airplanes that would repatriate citizens who reside in $m$ different cities and first return the most vulnerable citizens.

The decision-makers need to decide which airplane to send to one of the $n$ cities. Consequently, for decision variables, we use $x_{ik}$ that has a value of 1 if airplane $k$ is assigned to city $i$, 0 otherwise, as shown in Eq. (5). We also use $y_{ik}$ that has a value of 1 if airplane $k$ is flying citizen $l$ from city $i$, 0 otherwise, as shown in Eq. (6). Since we know $l_i$, all $y_{ilk}$, for which $i \neq l_i$ should have a value of 0, i.e., there is no need to add them to the model.

The objective function, as shown in Eq. (1), maximizes the sum of priority measures $a_j$. The first constraint, as shown in Eq. (2), guarantees that the sum of citizens leaving city $i \in M$ via airplane $k \in U$ is less than the capacity of airplane $k \in U$. Eq. (3) guarantees that an airplane can be assigned to one city. If an airplane is allowed to make more than one flight, then this constraint can be modified by changing the right-hand side of Eq. (3) to the number of allowed trips. Lastly, Eq. (4) gives an upper limit to the number of citizens that can return back such that this number does not exceed QC.

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3.2. Extension I: limiting the number of flights to hosting countries

As discussed earlier, there might be some limitations imposed by countries concerning the number of flights. In this case, we need new input parameters $F_i$ to show the maximum number of flights to city $i \in M$. For example, saying $F_i = 5$ means that we cannot assign more than five flights to city 1. For this condition, we need to add the constraint shown in Eq. (7). This constraint prevents the number of flights assigned to city $i \in M$ to exceed $F_i$.

$$\sum_{k \in U} x_{ik} \leq F_i, \forall i \in M.$$  

(7)

3.2.1. Illustrative example II

Considering the illustrative example that was discussed earlier, and taking the case of $u = 8$ and $QC = 2,500$. The solution of this case as shown in Table 2 is to fly two airplanes to cities 1, 2, and 5 and one airplane to cities 3 and 4. Now, assume that city 2 would not allow more than one airplane to fly from this city, then we need to add this constraint to $x_{21} + x_{22} + x_{31} + x_{32} + x_{41} + x_{42} \leq 1$ to the MILP model. Thus, solving this problem results in a new solution that assigns two airplanes to cities 1, 3, and 5, while cities 2 and 4 are assigned one airplane only, and the objective function value remains the same.

3.3. Extension II: having different destinations

For this case, we need to define a new set $P = \{1,2,\ldots,p\}$ to show the set of destination cities. Moreover, the decision variables, $x_{ik}$ and $y_{ikh}$, needs to be redefined as shown in Definitions 12 and 13 to account for destination city $h \in P$. Any $y_{ikh}$ that does not correspond to the starting and ending cities that a citizen ask for should have a value of 0, as discussed earlier. The rest of the optimization model needs to take into account these new decision variable definitions as shown in Eqs. (8)-(11).

$$\begin{align*}
\max Z &= \sum_{i \in R} \sum_{k \in U} \sum_{m \in M} \sum_{h \in P} a_{ij} \times y_{ikh} \\
\text{subject to} \quad &\sum_{i \in R} y_{ikh} \leq C_k \times x_{ihk}, \quad \forall k \in U, \quad \forall i \in M, \quad \forall h \in P \\
&\sum_{i \in M} x_{ikh} \leq 1, \quad \forall h \in U \\
&\sum_{i \in R} \sum_{k \in U} \sum_{h \in P} y_{ikh} \leq QC \\
x_{ikh} &= \begin{cases} 
1 & \text{if airplane } k \text{ is assigned to fly from city } i \text{ to city } h \\
0 & \text{otherwise}
\end{cases} \\
y_{ikh} &= \begin{cases} 
1 & \text{if airplane } k \text{ is assigned to fly from city } i \text{ to city } j \\
0 & \text{otherwise}
\end{cases}
\end{align*}$$

(8)–(11)

3.3.1. Illustrative example III

For the illustrative example that we have used previously, assume that we have two cities with international airports to which the repatriated citizens need to return, 1 and 2. Table 3 shows the number of citizens per group who wants to return from cities 1, 2, 3, 4, and 5 out of the country to cities 1 and 2 in the country. Note that we use the same number of passengers residing in each city; however, we randomly divide this number into two groups. One group is flying to city 1, while the other is flying to city II. Solving the suggest MILP model for $QC = 2,500$ and 8 possible flights, we have the assign a single airplane to the following destinations (1,I), (2,I), (4,I), (5,I), (1,II), (2,II), (4,II) and (5,II). The resulting objective function value is 17,600, which is less than the objective function value of 18,500 as shown in Table 2.

4. Jordan’s repatriation problem

This example resembles the real scenario that Jordan has faced in repatriating its citizens. However, per the request of authorities in Jordan, we do not use real numbers. The decision-makers did not provide priority numbers; instead, they have used linguistic descriptors to show citizens’ vulnerability. After a brainstorming session, the decision-makers have identified four categories, very urgent, very important, important, and not urgent. These classifications were assigned the values of 10, 6, 4, and 2, respectively, in the MILP model.

More than 24,799 citizens expressed interest in the Jordanian repatriation platform (Jordanian, 2020) in April 2020. We randomly distribute this number of citizens into 10 cities and four groups. The government had to rent 5,000 hotel rooms at the start of the pandemic to isolate repatriated people (GARDA WORLD, 2020). We use this number in our example. We also assume that the flag-carrying airline decided to use 20 planes. These 20 airplanes are divided into four groups based on capacity. Each group has five airplanes. The airplanes’ capacities are 300, 250, 200, and 150 passengers.

In our example, we assume that citizens reside in ten cities, as shown in column 1 of Table 4. We divide the stranded citizens into four groups, A–D, and we give weights to each group, as shown in the last row of Table 4. The number of citizens in each country and each group at day 0, $P_{ci}$, are shown in columns 2–5 of Table 4. Columns 6–9 of Table 4 show the number of citizens that wanted to return in phase II of the repatriation program. The numbers in columns 6–9 of Table 4 are found by subtracting the number of repatriated citizens after solving the phase I problem.

The solutions to phase I and phase II are shown in Table 5. Since the total capacity of the airplanes is 4,500, the number of repatriated citizens did not exceed this number in either phase. Columns 2 and 4 of Table 5 show the airplanes that were assigned to each city, whereas columns 3 and 5 show how much these assignments contributed to the objective function value. The objective function values of phase I and phase II are 45,000 and 31,180, respectively, as shown in the last row of Table 5. In phase I, the solution shows that all repatriated citizens were from the highest priority group, which can be asserted by comparing column 2 and column 6 of Table 4 with capacities of the assigned airplanes to each city in the phase I solution. The solution of phase II shows that airplanes were assigned to repatriate the first citizens in group A then those in group B.

5. Conclusions and future research

The COVID-19 pandemic has forced many countries to deal with one or more repatriation problems. Research has focused on the medical aspects of repatriation or the spread of the virus during repatriation. However, there is a vital operational aspect to this problem. As a first step in analyzing and understanding these newly emerging problems, we need to classify them. Thus, a repatriation classification scheme is introduced in this work. Using the suggested classification scheme, we have compared the repatriation programs of Jordan and India.
Returning the most vulnerable citizens has been the objective of several international repatriation programs. Based on this objective, we develop an MILP model for a hypothetical single-phase problem that we expect to extend to other situations faced by different countries. The first extension considers limitations imposed by other countries with respect to the number of accepted flights per day, whereas, the second extension considers the case of returning citizens to different cities in their country. We also solve three examples to explain the MILP models. As a general observation about these three examples, the more constraints the MILP model accounts for, the lower the objective function value. Lastly, we solve a problem that resembles the Jordanian repatriation problem.

This research is limited to repatriation problems in which transportation modes other than air were used. We hope that researchers may extend the proposed model to other real-life repatriation problems that other countries have solved. For mathematical models, several real-life constraints were not considered — for example, forcing airplanes to carry the maximum number of passengers. Another example is the scheduling of pilots and flight crews. If pilots need to stay in quarantines as do passengers, this might be a major constraint on flight crews. We hope that governments can use these models for repatriation or evacuation problems.

CRediT authorship contribution statement

Sameh Al-Shihabi: Conceptualization, Methodology, Software, Writing – original draft. Mohammed M. AlDurgham: Methodology, Writing – review & editing. Mazen Arafeh: Methodology, Writing – review & editing.

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