Developing a detection model for a COVID-19 infected person based on a probabilistic dynamical system

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This paper presents a novel model to detect the COVID-19 infected person from a Markovian feedback persons in a limited department capacity. The persons arrive one by one to the department and the balking and the retention of reneged person approaches are considered. There exists one server presents the service to these persons according to first-come, first-served (FCFS) discipline. An efficient and novel algorithm is presented to get the exact value of the probability of \( n \) persons in the department at any time interval. This algorithm depends on the Laplace transform to solve a probabilistic dynamical system of differential equations. By considering the exponential detection function and if the probability of the infected person in the department is equal to the probability of each one, then this algorithm is useful to obtain the detection probability of the infected one. Under steady state, the detection probability of the infected person is described. The usefulness of this model is illustrated for different capacities by using a numerical example to describe the behavior of probabilities of the persons in the department, the detection probabilities of the infected person as functions in time, and the mean time to detection.

KEYWORDS
applications of queueing theory, dynamical systems and their relations with probability theory and stochastic processes, Laplace transformation, probability of detection

MSC CLASSIFICATION
37A50; 60K30; 90B40

1 | INTRODUCTION

COVID-19 is one of the fastest spreading viruses between humans. This disease is spread mainly from person to another through small droplets that a person with Covid-19 secretes from their nose or mouth when they cough, sneeze, or speak. These droplets have a relatively heavy weight, as they do not move to a remote location but rather fall quickly to the ground. A person can contract Covid-19 disease if they breathe in these droplets from a person who has the virus infection. To control this spread, governments took a set of precautions, including social distancing and comprehensive examination. These droplets may land on objects and surfaces surrounding a person, such as tables and doorknobs. At this time, a person can become infected when they come into contact with these objects or surfaces and then touch their eyes, nose, or mouth. Therefore, the rapid detection of possibly infected persons inside the institution helps a key factor in reducing infection among humans.
Mathematicians and statisticians provided a set of mathematical models to predict and estimate the number of infected persons with the COVID-19. Ikizler and Kliger\cite{1} and Griffiths\cite{2} presented some new mathematical models to minimize the risk of COVID-19 among patients. This will reduce the Covid-19 crisis. This crisis had a clear impact on the performance decline of the global economy due to the closure of countries to avoid the virus spread. Habib\cite{3} showed how its mathematical model can use to guide the re-opening of economies during the COVID19 pandemic. Higazy\cite{4} presented a novel fractional order SIDARTHE mathematical model of COVID-19 to understand and control the evolution of the pandemic. Okuonghae and Oame\cite{5} formulated an appropriate mathematical model to discuss the impact of various non-pharmaceutical control measures on the population dynamics of COVID-19. Due to the small number of tests available, Bragazzi et al\cite{6} provided a mathematical model to present the impact of mass influenza vaccination and public health interventions on COVID-19 epidemics with limited detection capability.

Many infected persons with Covid-19 show only very mild symptoms. This is especially true in the early stages of this virus. You can actually catch the infection from a person who has a mild cough and does not feel ill. Some reports indicate that the virus can be transmitted even from people without symptoms. Therefore, the theory of searching for the lost targets is a useful study to discover those infected with this virus to limit its spread. Recently, Teamah et al\cite{7} discussed the importance of this theory to detect the COVID-19 infected Random Walk person. They presented the existence of the optimal search plan which detects this person in minimum time. Also, El Hadidy\cite{8-15} showed the importance of this theory in many real life applications. They presented new models for discovering lost targets (randomly located or moving) with maximum probability and the lowest possible cost. The mathematical model which used here to discover the infected person with Covid-19 in the department is similar to the searching models which used by El-Hadidy,\cite{16} Kassem et al\cite{17} Park et al\cite{18} and Cho et al\cite{19} In these works, the search area is divided into a group of identical cells, and the target moves according to the Markov process. The optimum effort distribution was found to find the target with the maximum probability and minimum cost. Moreover, the searching problem for the lost target has been extensively studied in many search spaces, like the real line, plane, and the space. When the target moves with a knowing stochastic process on one of these search spaces, the main objective is showing the existence of a finite and an optimal search plan. This plan will minimize the expected value of the first meeting time between the searcher and the target. Previous works\cite{20-32} presented more useful search models in many real life situations to detect the lost target with minimum cost and maximum probability. Recently, El-Hadidy and Alfreedi\cite{33} used a novel search model to discover an appropriate pharmaceutical company to get a suitable vaccine against COVID-19 with minimum cost under the quality control policy. The minimum values of the detection cost and the searching effort are obtained from solving an interesting stochastic optimization problem. Furthermore, this model supported the country to choose the suitable company with the highest service rate.

Here, according to the Poisson process, the persons arrive at the department to request the service. The service is provided by one server in this department according to the principle of first come, first served as in Kotb and El-Ashkar.\cite{34} Beside applying the feedback concept (used to control the dynamic performance of the department), it has been taken into account that some persons balking from obtaining the service despite their arrival to the institution for reasons of their own, such as slow performance of the server. Also, there are some persons who reneged to enter the department after running out of patience. All these events were taken into account to get a probabilistic dynamical system. At any time $t$, we study the transient behavior of this system by applying the Laplace transformation to get the exponential matrix. We present an efficient algorithm which gives the probability that there are $n$ persons in the department and the probability of empty department. Also, we get these probabilities under steady-state conditions by using the iterative technique as in Kotb and El-Ashkar.\cite{34} These probabilities are used to get the detection probabilities of the infected persons. Hence, we get the mean time to detection, which contributes to limiting of the COVID-19 spread.

This paper is organized as follows: Section 2 presents the basic notations which used to describe our model. In Section 3, we study the transient solution of a probabilistic dynamical system of differential equations that constitute the probability functions in suitable form. In this section, we obtain the exact solution of this system by applying the Laplace transformation to get the corresponding exponential matrix of the coefficient matrix of this system. This solution is used to get the probability of detection and the mean time to detection as a functions of time $t$. Also, an efficient algorithm to detect the infected person has been derived with numerical example. Section 4 gives the probability of detection and the mean time to detection, under steady-state situation. Finally, the concluding remarks and future work are discussed.

**Basic Notations**

$N$  
department capacity

$n$  
number of persons in the department, $0 \leq n \leq N$

$P_n(t)$  
the probability of $n$ persons in the department at time $t$, both waiting is piecewise
2 | MODEL DESCRIPTION

We consider the persons arrive to the department, according to a Poisson process with an interarrival and service times follow an exponential distribution with rates $\lambda > 0$ and $\mu > 0$, respectively, where $0 < \lambda < \mu$. The dynamic performance controlling of the department (feedback concept) done with probability $q$. In addition, the person is no balking with probability $\beta$ ($0 < \beta < 1$) and reneged with probability $\alpha \in (0, 1)$. If the person waited for a long time, then its impatient will be run out. This may be lead the person to leave the department before obtaining the desired service. This is defined as a reneged person; see Thompson et al.\textsuperscript{35} When the person joining the department, he may be wait some time before the service starts with probability $1 - p$. If the patience of the person runs out, then he will renege the department without getting the service with probability $(n - 1)ap$, $2 \leq n \leq N$. In this department, the service is presented to the persons according to the principle first come, first served. The probability that the person performed his (her) service and leave the department is $1 - q$. Thus, the probability that the person does not perform his (her) service and should be feedback and reprocessed again is $q$. Since the department has a limited capacity, then this situation is similar to the model which has been studied in Kotb and El-Ashkar.\textsuperscript{34} Consequently, we have the following probabilistic dynamical model:

$$
\begin{align*}
\dot{P}_0(t) &= -\lambda P_0(t) + \mu q P_1(t), \quad n = 0, \\
\dot{P}_1(t) &= \lambda P_0(t) - (\beta \lambda + \mu q) P_1(t) + (ap \zeta + \mu q) P_2(t), \quad n = 1, \\
\dot{P}_n(t) &= \beta \lambda P_{n-1}(t) - (\beta \lambda + \mu q + (n-1)ap \zeta) P_n(t) + (nap \zeta + \mu q) P_{n+1}(t), \quad 2 \leq n < N, \\
\dot{P}_N(t) &= \beta \lambda P_{N-1}(t) - (\mu q + (N-1)ap \zeta) P_N(t), \quad n = N.
\end{align*}
$$

The main objective is to obtain $P_n(t)$ (used to get the probability of the infected person which equals $P_n(t)/n$). This probability is used to find $P_D(t)$ by using the conditional probability of detection function $1 - \exp(-\omega)$ where $\omega$ is the amount of effort (it is considered as a random variable); see Park et al.\textsuperscript{18} and Cho et al.\textsuperscript{19} Thus, as in El-Hadidy,\textsuperscript{16} we found

$$P_D(t) = (P_n(t)/n)(1 - \exp(-\omega)).$$

3 | TRANSIENT ANALYSIS

As in Chaparro and Akan,\textsuperscript{36} and for a given vector of functions, $\mathbf{Y}(t)$, the Laplace transform is defined by

$$y(s) = \mathcal{L}\{\mathbf{Y}(t)\} = \int_0^\infty e^{-st}\mathbf{Y}(t)dt, \quad s > 0,$$

and the inverse Laplace of $y(s)$ is given by

$$\mathbf{Y}(t) = \mathcal{L}^{-1}\{y(s)\} = \frac{1}{2\pi i} \lim_{c-i\gamma \rightarrow c+i\gamma} \int_c^{c+i\gamma} e^{st}y(s)ds.$$

Dyke\textsuperscript{37} evaluated the complex integration part in Equation 4 by calculating the residues of poles lying inside the Bromwich contour. Now, to study the transient solution of (1), we rewrite the equations in this probabilistic dynamical system in a matrix form such that

$$\dot{\mathbf{P}} = \mathbf{MP},$$
Detection algorithm for an infected person

Example

We use Maple 13 to get our computations by the execution on Intel Core i5 CPU with Microprocessor 1.8 GHz and with 8 GB RAM. Let the inter-arrival and service times of persons have two exponential distributions with \( \lambda = 2.3 \) and \( \mu = 4.72 \) and reneging time \( \zeta = 1 \). The probability of \( n \) customers in systems when \( N = 4, 5, 6, 7 \) as functions in time \( t \). Table 1 presents the rest parameters to obtain the exact solutions. For \( t \in [0, 5] \), Figure 1A–D shows the exact vector solutions \( P(t) \) for \( N = 4, 5, 6, 7 \), respectively. The solution of the above system (5) appears in Figure 1 where the matrices of the coefficients are given by

\[
M = \begin{bmatrix}
-2.3 & 0.9116199334 & 0 & 0 \\
2.3 & -0.9631955255 & 1.230909726 & 0 \\
0 & 0.05157559206 & -1.2824835318 & 1.550199518 \\
0 & 0 & 0.05157559206 & -1.550199518 \\
\end{bmatrix}, \quad N = 4,
\]

\[
M = \begin{bmatrix}
-2.3 & 1.945991269 & 0 & 0 & 0 \\
2.3 & -4.237750862 & 2.441212176 & 0 & 0 \\
0 & 2.291759593 & -4.732971770 & 2.936433084 & 0 \\
0 & 0 & 2.291759593 & -5.228192677 & 3.431653991 \\
0 & 0 & 0 & 2.291759593 & -3.431653991 \\
\end{bmatrix}, \quad N = 5,
\]

where (5) is a linear probabilistic dynamical system of homogenous differential equations with random constant coefficients. The analytical solution for this system is given as a closed form based on exponential matrix,

\[
P(t) = \exp(Mt)P(0).
\]

See Hasselblatt and Katok,\(^{38}\) where \( P(0) \in \mathbb{R}^{(N+1) \times 1} \) is the initial condition vector; \( P(0) = [100 \ldots 0]^T \). To get the exponential matrix, we use the Laplace transform (3) on (5) and (8), and solving for this transform of the exponential matrix yields

\[
\mathcal{L}\{\exp(Mt)\} = (sI - M)^{-1},
\]

where \( I \in \mathbb{R}^{(N+1) \times (N+1)} \) is the identity matrix. Now, by applying the inverse Laplace (4) on (9), we get the exponential matrix \( \exp(Mt) \). Hence, the exact solution of the system (5) will be obtained.

### 3.1 Detection algorithm for an infected person

We construct an algorithm to obtain the exponential matrix \( \exp(Mt) \) and then obtain \( P_{a}(t) \) which used to obtain \( P_{D}(t) \) from (2). The algorithm steps can be summarized as follows:

**Step 1.** Input the values of \( \lambda, \mu \).

**Step 2.** Generate the real random values between 0 and 1 for the parameters; \( \alpha, \beta, p, \omega \) and \( q \), by using the command \( \text{rand}(0.0..1.0) \), except the values of \( \omega \) is greater than or equal to one.

**Step 3.** Generate a tridiagonal matrix \( M \) that contains the coefficients \( m_{ij} \) given by (6) and (7).

**Step 4.** Compute the inverse matrix of \( B \), where \( B = sI - M \).

**Step 5.** Compute the inverse Laplace transform of each term of \( B^{-1} \), and put the results into a new matrix (\( S \)).

**Step 6.** Generate a column of initial conditions (\( Ic \)) to get the exact solution as given in Equation 8.

**Step 7.** Find the product of \( S \) and \( Ic \) (to get the exact solution of (5)).

**Step 8.** Use (2) to get \( P_{D}(t) \).

**Step 9.** Compute the mean time of detection \( E_{D}(t) = \sum_{n=1}^{N} nP_{D}(t) \).

### 3.2 Example

We use Maple 13 to get our computations by the execution on Intel Core i5 CPU with Microprocessor 1.8 GHz and with 8 GB RAM. Let the inter-arrival and service times of persons have two exponential distributions with \( \lambda = 2.3 \) and \( \mu = 4.72 \) and reneging time \( \zeta = 1 \). The probability of \( n \) customers in systems when \( N = 4, 5, 6, 7 \) as functions in time \( t \). Table 1 presents the rest parameters to obtain the exact solutions. For \( t \in [0, 5] \), Figure 1A–D shows the exact vector solutions \( P(t) \) for \( N = 4, 5, 6, 7 \), respectively. The solution of the above system (5) appears in Figure 1 where the matrices of the coefficients are given by

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\end{bmatrix}, \quad N = 4,
\]

\[
M = \begin{bmatrix}
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2.3 & -4.237750862 & 2.441212176 & 0 & 0 \\
0 & 2.291759593 & -4.732971770 & 2.936433084 & 0 \\
0 & 0 & 2.291759593 & -5.228192677 & 3.431653991 \\
0 & 0 & 0 & 2.291759593 & -3.431653991 \\
\end{bmatrix}, \quad N = 5,
\]
| $N$ | $\alpha$ | $p$ | $\beta$ | $\omega$ |
|-----|----------|-----|---------|---------|
| 4   | 0.3957188605 | 0.8068601836 | 0.02242417046 | 8.001874845 |
| 5   | 0.8426226844  | 0.5877137142  | 0.9964172142  | 3.864083074  |
| 6   | 0.6946071893  | 0.2269870200  | 0.7306162929  | 1.065070537  |
| 7   | 0.4501449181  | 0.6147166333  | 0.7301565454  | 7.847364978  |

**TABLE 1** The random values of $\alpha$, $p$, $\beta$, and $\omega$

**FIGURE 1** The probability functions $P_n(t)$ of $n$ persons in the department at time $t$, for $0 \leq n \leq N$, (A) $N = 4$, (B) $N = 5$, (C) $N = 6$, and (D) $N = 7$ [Colour figure can be viewed at wileyonlinelibrary.com]

\[
M = \begin{bmatrix}
-2.3 & 3.648621266 & 0 & 0 & 0 & 0 \\
2.3 & -5.329038740 & 3.806288082 & 0 & 0 & 0 \\
0 & 1.680417474 & -5.486705556 & 3.963954898 & 0 & 0 \\
0 & 0 & 1.680417474 & -5.644372372 & 4.121621714 & 0 \\
0 & 0 & 0 & 1.680417474 & -5.802039188 & 4.279288530 \\
0 & 0 & 0 & 0 & 1.680417474 & -4.279288530 \\
\end{bmatrix}, \quad N = 6,
\]

and finally for $N = 7$,

\[
M = \begin{bmatrix}
-2.3 & 1.818537491 & 0 & 0 & 0 & 0 & 0 \\
2.3 & -3.497897545 & 2.095249060 & 0 & 0 & 0 & 0 \\
0 & 1.679360054 & -3.774609114 & 2.371960628 & 0 & 0 & 0 \\
0 & 0 & 1.679360054 & -4.051320682 & 2.648672196 & 0 & 0 \\
0 & 0 & 0 & 1.679360054 & -4.328032250 & 2.925383765 & 0 \\
0 & 0 & 0 & 0 & 1.679360054 & -4.604743819 & 3.202095333 \\
0 & 0 & 0 & 0 & 0 & 1.679360054 & -3.202095333 \\
\end{bmatrix}.
\]
For the probability of detection (2) and the mean time to detection $E_D(t)$ for different department capacities $N = 3, 4, 5, 6$, see Figures 2 and 3, respectively.

4 | STEADY STATE SOLUTION

In the steady state, the above system (1) becomes

\[
\begin{align*}
-\lambda P_0 + \mu q P_1 &= 0, \quad n = 0, \\
\lambda P_0 - (\beta \lambda + \mu q) P_1 + (ap\zeta + \mu q) P_2 &= 0, \quad n = 1, \\
\beta \lambda P_{n-1} - (\beta \lambda + \mu q + (n - 1)ap\zeta) P_n + (nap\zeta + \mu q) P_{n+1} &= 0, \quad 2 \leq n < N, \\
\beta \lambda P_{N-1} - (\mu q + (N - 1)ap\zeta) P_N &= 0, \quad n = N.
\end{align*}
\]

(10)

By using the iterative method as in Kotb and El-Ashkar,\textsuperscript{34} then the probability of $n$ persons in the department is given by

\[
P_n = \begin{cases} 
P_0, & n = 0, \\
\delta^n \prod_{i=0}^{n-1} \left( \gamma + i \right) P_0, & 1 \leq n \leq N,
\end{cases}
\]

(11)

where $\delta = \frac{\beta \lambda}{ap}$ and $\gamma = \frac{\mu q}{ap}$.

By using the boundary condition $\sum_{n=0}^{N} P_n = 1$, we get the probability of no persons in the department $P_0$ as follows:

\[
P_0^{-1} = 1 + \frac{1}{\delta} \sum_{n=1}^{N} \prod_{i=0}^{n-1} \left( \gamma + i \right).
\]

(12)

As in Section 2, the probability of detection $P_D$ is given by

\[
P_D = \left( P_n/n \right) \left( 1 - \exp(-\omega) \right).
\]

(13)

Consequently, the mean time to detection is given by $E_D = \sum_{n=1}^{N} nP_D$. Figure 4 shows the values of $P_n$ for different values of the parameters $\lambda, \mu, \zeta$ and the generated random values of $\alpha, \beta, p, o, q$ (see the above algorithm). Consequently, we get the values of $P_D$ and $E_D$ as in Figures 5 and 6.
FIGURE 3  $E_D(t)$ for several values of (A) $N = 4$, (B) $N = 5$, (C) $N = 6$, and (D) $N = 7$ [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 4  $P_n$ for different values of $\lambda, \mu, \xi$, and $N = 10$ [Colour figure can be viewed at wileyonlinelibrary.com]
5 | CONCLUSION AND FUTURE WORK

A probabilistic dynamical model to detect the COVID-19 infected person has been presented. The Markovian feedback persons arrive one by one to a limited department capacity (with capacity $N$) according to a Poisson process. This model depends on a system of differential equations that constitute the probability functions in suitable form. Laplace transformation is used to get the exponential matrix of this system, and then we get the exact probability of $n$ persons in the department. More than deriving an algorithm to get this probability, we obtained the detection probability of the infected one and the mean time of detection. In addition, the steady-state situation has been discussed to get the probability and the mean time of detection for the infected person. In the future work, it is doable to consider a multi-server setting for our providing numerical method. This could be a natural extension to explore this model. In addition, we can consider the amount of effort $\omega$ is a random variable with a known distribution. Also, we can study the optimal value of $\omega$ to get the maximum probability of detection for the infected person.
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CONFLICT OF INTEREST

The author declares that he has no conflict of interest.

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REFERENCES

1. Alp Ikizler TA, Kliger AS. Minimizing the risk of Covid-19 among patients on dialysis. Nat Rev Nephrol. 2020;16(6):311-313.
2. Griffiths JP. Can mathematical modeling solve the current Covid-19 crisis? BMC Publ Health. 2020;20:551-555.
3. Habib N. A mathematical model to guide the re-opening of economies during the Covid19 pandemic. Ann Med Surg. 2020;57:5-6.
4. Higazy M. Novel fractional order SIDARTHE mathematical model of Covid-19 pandemic. Chaos, Solitons Fractals. 2020;138:11007.
5. Okuonghae D, Oname A. Analysis of a mathematical model for Covid-19 population dynamics in Lagos, Nigeria. Chaos, Solitons Fractals. 2020;139:110032.
6. Bragazzi N, Xiao Y, Li Q, Tang B, Wu J. Modeling the impact of mass influenza vaccination and public health interventions on Covid-19 epidemics with limited detection capability. Math Biosci. 2020;325:108378.
7. Teamah AAM, Afifi WA, Dar JG, El-Bagoury AAH, Al-Aziz SN. Optimal discrete search for a randomly moving COVID19. J Stat Appl Probab. 2020;9(3):473-481.
8. El-Hadidy M. The searching algorithm for detecting a Markovian target based on maximizing the discounted effort reward search. J Egypt Math Soc. 2020;28(37):1-18.
9. El-Hadidy M. Quality control for a detected an appropriate queue from K-independent M/M/C/N queueing models. Qual Reliab Eng Int. 2021;37(1):165-175.
10. El-Hadidy M. Existence of cooperative search technique to find a Brownian target. J Egypt Math Soc. 2020;28(1):1-12.
11. El-Hadidy M. On the existence of a finite linear search plan with random distances and velocities for a one-dimensional Brownian target. Int J Oper Res. 2020;37(2):245-258.
12. El-Hadidy M, Alfreedi A. Minimizing the expected search time of finding the hidden object by maximizing the discount effort reward search. J Taibah Univ Sci. 2020;14(1):479-487.
13. El-Hadidy M, Alzulaibani A. A mathematical model for preventing HIV virus from proliferating inside CD4 T Brownian cell using Gaussian jump nanorobot. Int J Biomath. 2019;12(7):1950076.
14. El-Hadidy M, Abou-Gabal H. Searching for the random walking microorganism cells. Int J Biomath. 2019;12(6):1950064.
15. El-Hadidy M, Alfreedi A. On optimal coordinated search technique to find a randomly located target. Stat Optim Inf Comput. 2019;7(4):854-863.
16. El-Hadidy M. On maximum discounted effort reward search problem. Asia-Pac J Oper Res. 2016;33(3):1650019.
17. Kassem M, Mohamed A, El-Hadidy M. M-states search problem for a lost target with multiple sensors. Int J Math Oper Res. 2016;10(1):104-135.
18. Park M, Hong C, Lee M. Optimal search-relocation trade-off in Markovian-target searching. Comput Oper Res. 2020;36:2097-2104.
19. Cho S, Hong C, Park M. A pseudo-polynomial heuristic for path-constrained discrete-time Markovian-target search. Eur J Oper Res. 2009;193:351-364.
20. El-Hadidy M, Abou-Gabal H. Coordinated search for a random walk target motion. Fluctuation Noise Lett. 2018;17(1):1850002.
21. El-Hadidy M, Alzulaibani A. Cooperative search model for finding a Brownian target on the real line. J Taibah Univ Sci. 2019;13(1):177-183.
22. El-Hadidy M. Searching for a d-dimensional Brownian target with multiple sensors. Int J Math Oper Res. 2018;9(3):279-301.
23. M. El-Hadidy AT, El-Bagoury A. 3-dimensional coordinated search technique for a randomly located target. Int J Comput Sci Math. 2018;9(3):258-272.
24. Mohamed A, El-Hadidy M. On probabilistic modeling and feasibility of collision between a randomly moving meteor and satellite. Afrika Matematika. 2021;32(1-2):1-15.
25. El-Hadidy M. Existence of finite parabolic spiral search plan for a Brownian target. Int J Oper Res. 2018;31(3):368-383.
26. El-Hadidy M. Study on the three players linear rendezvous search problem. Int J Oper Res. 2018;33(3):297-314.
27. Kassem M, El-Hadidy M. Optimal multiplicative Bayesian search for a lost target. Appl Math Comput. 2014;247:795-802.
28. El-Hadidy M. Fuzzy optimal search plan for n-dimensional randomly moving target. Int J Comput Methods. 2016;13(6):1650038.
29. El-Hadidy M, Alzulaibani A. Existence of a finite multiplicative search plan with random distances and velocities to find a d-dimensional brownian target. J Taibah Univ Sci. 2019;13(1):1035-1043.
30. El-Hadidy M. Generalised linear search plan for a d-dimensional random walk target. Int J Math Oper Res. 2019;15(2):211-241.
31. El-Hadidyand M, Fakhharany M. Optimal 3-dimensional search model to find the underwater randomly hidden target. Int J Math Oper Res. 2021;18(2):210-235.
32. El-Hadidy M. Spiral with line segment directory for a helix search path to find a randomly located target in the space. *Int J Oper Res*. 2021;40(2):185-199.

33. El-Hadidy M, Alfreedi A. Detection of an appropriate pharmaceutical company to get a suitable vaccine against Covid-19 with minimum cost under the quality control process. *Qual Reliab Eng Int*. 2021; In Press. https://doi.org/10.1002/qre.2881

34. Kotb K, El-Ashkar HA. Quality control for the feedback M/M/1/N queue with balking and retention of reneged customers. *FILOMAT*. 2020;34(1):167-174.

35. Thompson JM, Shortle JF, Gross D., Harris CM. *Fundamentals of Queueing Theory*. Second: John Wiley and Sons; 2018.

36. Chaparro LF, Akan A. *Signals and Systems Using MATLAB*. Third: Academic Press; 2019.

37. Dyke P. *An Introduction to Laplace Transforms and Fourier Series*. Second: Springer; 2001.

38. Hasselblatt B, Katok A. *A First Course in Dynamics With a Panorama of Recent Developments*. Cambridge: Cambridge University Press; 2003.

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