Health Care Optimization by Maximizing the Air-Ambulance Operation Time

Loai Kayed B.Melhim
l.banimelhim@uhb.ed.u.sa
Department of Health Information Management and Technology, College of Applied Medical Sciences
University of Hafr Al Batin, Hafr Al Batin, 39524, Saudi Arabia.

Abstract
Employing the available technologies and utilizing the advanced means to improve the level of health care provided to citizens in their various locations. Citizens have the right to get a proper health care services despite the location of their residency or the distance from the health care delivery centers, a goal that can be achieved by utilizing air ambulance systems. In such systems, aircrafts and their life spans are the essential component, the flight duration of the aircraft during its life span is determined by the maintenance schedule. This research, enhances the air ambulance systems by presenting a proposal that maximizes the aircraft flight duration during its life span. The enhancement will be reached by developing a set of algorithms that handles the aircraft maintenance problem. The objective of these algorithms is to minimize the maximum completion time of all maintenance tasks, thus increasing the aircraft operation time. Practical experiments performed to these algorithms showed the ability of these algorithms to achieve the desired goal. The developed algorithms will manage the maintenance scheduling problem to maximize the uptime of the air ambulance which can be achieved by maximizing the minimum life of spare parts. The developed algorithms showed good performance measures during experimental tests. The 3LSL algorithm showed a higher performance compared to other algorithms during all performed experiments.

Key words:
Air-Ambulance, Maximizing Operation Time, Health Care Optimization.

1. Introduction

In the past, people were gathering close to natural resources, this led to the concentration of services in the centers of these communities, close to these sources [1, 2]. But, with the increase in population and the expansion of geographical areas, large cities appeared with sprawling parties and vast areas. People in these cities, became very far from the various service centers, which makes it so necessary to solve these issues [1, 2]. Various strategies emerged, which focused mainly on two types of strategies. The first strategy was to increase the number of service centers, to reduce the distance between those requesting these services and the service providers [3]. Despite the efficacy of this solution, a new set of issues emerged, namely the difficulty of providing the same level of service in all centers, in addition to the material functional and labor costs. To deal with these challenges, the need for a second strategy arise. Which, instead of distributing resources, tries to take the advantage of available resources by utilizing them to raise the quality of services provided in the existing service centers. For the distance between service seekers and service providers, various available transportation techniques are employed, such as air transportation. One of the most requested services that residents of these cities need is health care services [4, 5], everyone who needs medical care seeks to reach the best providers of that care, and here the need for air ambulance emerged[6]. Recently, most studies point to an increase in the demand for air ambulances, especially in critical cases, distant areas, difficult terrains, valleys, mountains, and during natural disasters such as torrential torrents [5-8].

In the case of air ambulance, especially when transporting critical cases, the aircraft designated to carry out these operations must be with the utmost readiness and effectiveness, as any delay, no matter how small, will disastrously affect the patient's life. Therefore, this reason was the motivation that prompted us to raise this topic, as this research will present a framework that aims to increase the effectiveness and reliability of air ambulance through the development of maintenance work scheduling in order to increase the aircraft work duration within their life span to the maximum extent possible, by reducing the maximum time required to complete the required maintenance operations for these aircrafts. This goal will be reached by developing a set of algorithms that were originally introduced by [9].

The rest of this work is presented as follows: Section 2 describes the previous work, while section 3 will present the definition of the discussed problem in details. The base of the proposed framework are the developed algorithms that will be presented in section 4. Results and discussion are presented in section 5. Finally, the summary of this research, main results and recommendations are presented in section 6.

2. Literature Review

Many researches have discussed the air ambulance transportation. For example, the authors in [10] discussed

Manuscript received February 5, 2022
Manuscript revised February 20, 2022
https://doi.org/10.22937/IJCSNS.2022.22.2.45

the use of air ambulance to transfer for acute myocardial infarction patients. Justifications for adapting air ambulance were presented in [11]. The required specifications necessary for air ambulance to transport patients was presented by [12]. While, the authors in [13] presented the first prototype of an emergency flying air ambulance drone. The challenges and difficulties facing transporting patients through air ambulance was detailed by [14-16].

To reach the maximum performance and the required reliability of aircrafts in the air ambulance system, the companies operating the air ambulances' air crafts must deal with the complex maintenance schedule with high professionalism, as the scheduled maintenance operations include a set of tests, measurements, and periodic and procedural maintenance that is performed periodically to prevent the aircraft from malfunctioning during its working time. Technologies are invested and employed to take the advantage of them in solving the problems facing people's lives in various fields, where the problem scheduling is one of these fields, that's because, systems are available and reliable when their time schedules for the given tasks are achieved and the agreed timings are adhered to [17].

Scheduling problem is a topic that is explored and discussed by many researchers. Various methodologies were utilized by many researchers to minimize maintenance cost and time [18-24]. Researchers in [25] discussed the problem of maximizing the minimum by utilizing the tight lower and upper bounds to derive the first optimal solution. Another methodology based on reordering buffer was implemented in [26] where they discussed the online scheduling with the objective of maximizing the minimum load.

The used approach in the current research was presented by [9], where the researchers provided a mathematical modeling that could be used as an approximate solution to the scheduling problem. Other scheduling algorithms can be adopted for the presented problem [27], [28], [29], and [30].

The current work, presents the problem of air ambulance maintenance scheduling, with an objective of maximizing operation time. To meet this objective, the researchers developed a set of algorithms that are based on three algorithm categories, the utilization of the iterative methods based on the probabilistic method, the randomized lower bounds and the repeating of the resolution of the swapping methods.

3. Problem description

The scheduling problem is used in this paper to ensure the non-disruption of the air ambulance in the maintenance period. The lifespan of spare parts is to be maximized. We denoted by SP the set of spare parts, n_s the number of spare parts. The total number of engines is n_e, the engine index is i and the engine total lifespan is Te_i. The lifespan of each spare part is denoted by ls_j where j is the index of the spare part. At any moment, every spare part is assigned to only one engine. In addition, we suppose that all required spare parts are available when needed.

The studied problem seeking the maximization of the engine that has the minimum operating lifetime which is denoted by Te_{max}. The cumulative lifespan of spare part j is denoted by L_j. The lifespan gap between engines is given by (Eq. 1).

$$ge = \sum_{i=1}^{ne} (Te_i - Te_{min}) \qquad (1)$$

The main objective is to find schedule that minimize ge.

4. Proposed algorithms

4.1 Two-longest-shortest lifespan algorithm (2LSL)

Start by selecting the two spare parts that have the longest lifespan. Then, assign these spare parts to the engines that with the minimum Te_i. Next, select the two spare parts that has the shortest lifespan. Continue scheduling until finishing all spare parts. In this algorithm, let lng(Sp) be the function that returns the two spare parts that with the longest lifespan. While, sht(Sp) be the function that returns the two spare parts with the shortest lifespan.

4.2 Three-longest-shortest lifespan algorithm (3LSL)

The same idea as 2LSL with a difference in selecting three parts instead of two spare parts.

4.3 Two-Shortest-Longest Lifespan Algorithm (2SLL)

The same idea as 2LSL with a difference in selecting three parts instead of two spare parts.

Start by selecting the two spare parts that have the shortest lifespan. After that, schedule these spare parts to the engines that having the minimum Te_i. Finally, select the two spare parts that has the longest lifespan. Continue the scheduling until finishing all spare parts.

4.4 Three-Shortest-Longest Lifespan Algorithm (3SLL)

The same idea as 2SLL, however instead of selecting two spare parts, this algorithm will select three spare parts.

5. Experimental Results

In this section we present the discussion and the analyses of the obtained results. Microsoft Visual C++ (Version 2013) was used to code the proposed algorithms, the codded algorithms were executed on an Intel(R) i5. The developed algorithms were tested by a set of instances, which was generated as described in [24]. The lifespan ls_j was generated according to different probability distributions. In fact, $U[a, b]$ is the uniform distribution between [a, b].

The classes of generated instances are:

- Class A: ls_j in $U[1, 50]$.
- Class B: ls_j in $U[10, 100]$.
- Class C: ls_j in $U[60, 100]$.

The generated instances were given by selecting n_s, n_e and $Class$.
In the practice, we fix $n_s = \{10,15,20\}$ when $n_e = \{2,4,6\}$. However, we fix $n_s = \{100,120,180,220\}$ when $n_e = \{2,4,6,15\}$. For each value of n_s, n_e and $Class$, we generated 10 instances. In total we have 750 instances.

The following will be used as:

- A∗: the best value.
- A: The presented algorithm value.
- $G = \frac{A-A*}{A}$, $G = 0$ if $A = 0$.
- $Time$: running time in seconds.

The obtained results of the percentage (Perc) of each algorithm and the running time for all algorithms are shown in Table 1. Both of the algorithms 2LSL and 3LSL returned a near result as shown in Table 1.

Table 1: The percentage (Perc) of each algorithm and the running time

	2LSL	3LSL	2SLL	3SLL
Perc	47.3%	49.1%	11.5%	11.6%
Time	-	-	-	-

The average gap results according to n_s for all algorithms are shown in Table 2. The best obtained gap results were obtained at $n_s = 10$ for the algorithm 3LSL with the value of 0.16. While the algorithm 2LSL obtained the best gap results of 0.15 and 0.17 at $n_s = 20{,}220$. The worst gap results were obtained by 2SLL and 3SLL at $n_s = 180$.

Table 2 :The average gap results according to n_s

n_s	2LSL	3LSL	2SLL	3SLL
10	0.28	0.16	0.47	0.44
15	0.31	0.30	0.28	0.27
20	0.15	0.39	0.58	0.54
100	0.18	0.36	0.56	0.58
120	0.41	0.25	0.72	0.73
180	0.39	0.25	0.78	0.77
220	0.17	0.37	0.59	0.60

Table 3: The average gap results according to n_e

n_e	2LSL	3LSL	2SLL	3SLL
2	0.47	0.19	0.74	0.73
4	0.11	0.66	0.74	0.74
6	0.33	0.20	0.48	0.47
15	0.10	0.03	0.22	0.23

The average gap results according to n_e for all algorithms are shown in Table 3. The best obtained gap results were obtained at $n_e = 15$ for the algorithm 3LSL with the value of 0.03. While the algorithm 2LSL obtained the best gap results of 0.11 and 0.10 at $n_e = 4{,}15$. The worst gap results were obtained by 2SLL and 3SLL at $n_e = 2{,}4$.

6. Conclusion

The distance between health care seekers and health care providers is no longer the main concern, due to the development of the transport sector and the tendency to rely on air ambulance, especially in the cases of, critical cases, disasters or in the case of difficult terrain such as high mountains or deep valleys. In the air ambulance transport system, air planes are bone of this system, availability and reliability are a must. To achieve this, a firm maintenance schedule, with a predefined maintenance tasks, should be applied. Applying the maintenance schedule, requires a valuable time in which, air planes are off duty during all that time. The proposed approach, developed a set of algorithms to minimize the off duty time. The developed algorithms applied different scheduling categories, the utilization of the iterative methods based on the probabilistic method, the randomized lower bounds and the repeating of the resolution of the swapping methods. Experimental tests were performed on the developed algorithms to derive their performance metrics, obtained results showed that many algorithms have reached the desired goal. Some algorithms have better performance results than others.

Acknowledgments

The authors would like to thank the Deanship of Scientific Research, University of Hafr Al-Batin for funding this work under Project Number No. G-114-2020.

References

1. Allchin, F.R. and G. Erdosy, *The archaeology of early historic South Asia: the emergence of cities and states*. 1995: Cambridge University Press.
2. Page, S.E., *On the emergence of cities.* Journal of Urban Economics, 1999. **45**(1): p. 184-208.
3. Ur, J., *Households and the emergence of cities in ancient Mesopotamia.* Cambridge Archaeological Journal, 2014. **24**(2): p. 249-268.
4. Rosenstock, I.M., *Why people use health services.* The Milbank Quarterly, 2005. **83**(4).
5. Clim, A., et al., *Health services in smart cities: Choosing the big data mining based decision support.* International Journal of Healthcare Management, 2020. **13**(1): p. 79-87.
6. Albrecht, R., et al., *Transport of COVID-19 and other highly contagious patients by helicopter and fixed-wing air ambulance: a narrative review and experience of the Swiss air rescue Rega.* Scandinavian journal of trauma, resuscitation and emergency medicine, 2020. **28**: p. 1-6.
7. Røislien, J., et al., *Exploring optimal air ambulance base locations in Norway using advanced mathematical modelling.* Injury prevention, 2017. **23**(1): p. 10-15.
8. Duchateau, F.-X., et al., *Coronavirus Disease 2019: The Impact of Coronavirus Disease 2019 on the Use of Air Ambulances for International Medical Assistance.* Air Medical Journal, 2021.
9. Jemmali, M., *Budgets balancing algorithms for the projects assignment.* International Journal of Advanced Computer Science and Applications (IJACSA), 2019. **10**(11): p. 574-578.
10. Kaplan, L., D. Walsh, and R.E. Burney, *Emergency aeromedical transport of patients with acute myocardial infarction.* Annals of emergency medicine, 1987. **16**(1): p. 55-57.
11. Rosenberg, B.L., et al., *Aeromedical service: how does it actually contribute to the mission?* Journal of Trauma and Acute Care Surgery, 2003. **54**(4): p. 681-688.
12. Delorenzo, A.J., et al., *Characteristics of fixed wing air ambulance transports in Victoria, Australia.* Air medical journal, 2017. **36**(4): p. 173-178.
13. Anand, P., et al., *Drone Ambulance Support System.* International Journal of Engineering and Techniques, 2018. **4**(2).
14. Schwabe, D., et al., *Long− Distance Aeromedical Transport of Patients with COVID− 19 in Fixed− Wing Air Ambulance Using a Portable Isolation Unit: Opportunities, Limitations and Mitigation Strategies.* Open Access Emergency Medicine: OAEM, 2020. **12**: p. 411.
15. Veldman, A., et al., *Long-distance transport of ventilated patients: advantages and limitations of air medical repatriation on commercial airlines.* Air medical journal, 2004. **23**(2): p. 24-28.
16. Plant, J.R., D.B. MacLeod, and J. Kortbeek, *Limitations of the prehospital index in identifying patients in need of a major trauma center.* Annals of emergency medicine, 1995. **26**(2): p. 133-137.
17. Bazargan, M., *Airline operations and scheduling*. 2016: Routledge.
18. Jemmali, M., *Projects Distribution Algorithms for Regional Development.* 2021.
19. Jemmali, M., *Intelligent algorithms and complex system for a smart parking for vaccine delivery center of COVID-19.* Complex & Intelligent Systems, 2021: p. 1-13.
20. Jemmali, M., *An optimal solution for the budgets assignment problem.* RAIRO: Recherche Opérationnelle, 2021. **55**: p. 873.
21. Alquhayz, H. and M. Jemmali, *Max-Min Processors Scheduling.* Information Technology and Control, 2021. **50**(1): p. 5-12.
22. Jemmali, M., *Approximate solutions for the projects revenues assignment problem.* Communications in Mathematics and Applications, 2019. **10**(3): p. 653-658.
23. al Fayez, F., L.K.B. Melhim, and M. Jemmali. *Heuristics to Optimize the Reading of Railway Sensors Data*. in *2019 6th International Conference on Control, Decision and Information Technologies (CoDIT)*. 2019. IEEE.
24. Jemmali, M., L.K.B. Melhim, and M. Alharbi. *Randomized-variants lower bounds for gas turbines aircraft engines*. in *World Congress on Global Optimization*. 2019. Springer.
25. Haouari, M. and M. Jemmali, *Maximizing the minimum completion time on parallel machines.* 4OR, 2008. **6**(4): p. 375-392.
26. Epstein, L. and R. van Stee, *Maximizing the minimum load for selfish agents.* Theoretical Computer Science, 2010. **411**(1): p. 44-57.
27. Jemmali, M., M.M. Otoom, and F. al Fayez. *Max-Min Probabilistic Algorithms for Parallel Machines*. in *Proceedings of the 2020 International Conference on Industrial Engineering and Industrial Management*. 2020.
28. Alquhayz, H., M. Jemmali, and M.M. Otoom, *Dispatching-rule variants algorithms for used spaces of storage supports.* Discrete Dynamics in Nature and Society, 2020. **2020**.
29. Alharbi, M. and M. Jemmali, *Algorithms for investment project distribution on regions.* Computational Intelligence and Neuroscience, 2020. **2020**.

30. Jemmali, M., et al., *Lower bounds for gas turbines aircraft engines.* Communications in Mathematics and Applications, 2019. **10**(3): p. 637-642.

Loai Bani Melhim. was born in Irbed, Jordan, in 1974. He received his Bachelor degree in Computer Engineering and Master degree in Computer Information Systems in 2005 from Arab Academy / Faculty of Information Systems & Technology, Amman – Jordan. He received the Ph.D. degree in Advanced Internet Security and Monitoring from Universiti Sains Malaysia (USM), Malaysia in 2013. Currently he is an Assistant professor at Department of Health Information Management and Technology in University of Hafr Al Batin. His interests include Intrusion Detection System (IDS), Intrusion Prevention System (IPS), Botnet and Malware Protection and Detection. Computing Security, Smart Cities and Systems Optimizations.