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Quadratic Assignment Problem (Model, Applications, Solutions): Review Paper

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Abstract

In operations research, Quadratic Assignment Problem (QAP) is a significant combinatorial optimization problem. When the size of the QAP problem increases, it becomes impossible to solve the problem in polynomial time. Several practical problems such as hospital and campus layout, allocation of gates to airplanes in airports and electrical backboard wiring problems can be modeled as QAP. The QAP model seeks to identify the optimal distribution of N facilities to N locations in a way that minimizes the total traveling cost based on the distance between every pair of a location and the amount of traffic between every pair of facilities of organizational units within a building. Against this background, there are two main approaches have been suggested to deal with QAP, and they are, the Exact and Approximate (Heuristic and Metaheuristic) approaches. The exact approach provides a global optimal solution for the small size of QAP, while the approximate approaches can find the optimal or a near-optimal solution at a reasonable time for large-sized QAP. The objectives of this study are as follows: (i) To analysis the QAP model, (ii) To conduct a comprehensive survey of the methods that have been used to solve the QAP model, (iii) To identify the issues and limitations of the methods in (ii), and (iv) to explore the best approach that can be used in enhancing the solutions of QAP model within a reasonable time based on the accuracy of algorithm. The results show that the hybrid metaheuristic approach has the capability of finding the best results within a reasonable time for the large sized problem.

Keywords–-*Metaheuristic algorithms, Combinatorial Optimization Problem, Facility Layout Problem; Quadratic Assignment Problem*

1. Introduction

In the field of combinatorial optimization, one of the most studied problems is the Facility Layout Problem (FLP). As a result many solutions have been proposed for the problem, but most especially, the FLP has been modeled as quadratic assignment problem (QAP) [1]. For the first time in 1957, Koopmans and Beckmann introduced the QAP as a mathematical model related to economic activities by [2]. Service institutions such as hospitals, schools, universities, … etc. have a large number of people to deal with on a daily basis, and as such it is important to urgently find the best design for such institutions. The absence of a good design can have a negative effect on the institutions, as more efforts will be required from people seeking services from the institutions. For this reason, researchers in previous studies have suggested many models that can be used in find the optimal design for the distribution of facilities to locations within buildings. The QAP has been successfully implemented in real-life situations and there are several practical problems such as engineering or economic problems that can be modelled as QAP. One of the primary purposes of QAP is to assign facilities to locations in a way that a particular facility is allocated to an exact location, and vice versa. This way, the total cost which is reflective of the sum of products of flows and distances can be reduced.

Based on review of literature, it has been observed that there are several studies that have focused on addressing the QAP model, with special attention paid to applications, algorithms, comparisons and analysis aimed at providing better solutions that are also able to reduce total cost with optimal distributions for *N* facilities to *N* of locations. With regards to solutions to a QAP, there are two approaches that have been introduced as solutions to the QAP. The first approach can find the optimal

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solution for small sized problem. For instance, Branch and Bound BB has been used by [3], Dynamic Programming used by [4], and the mixed-integer linear programming was used in the study conducted by [5].

The second one is called approximate approach, and it is divided into two categories including the heuristic and metaheuristic. Heuristics methods are useful in finding the best solutions at a relatively affordable computational cost without guaranteeing feasibility and optimality. Metaheuristics refers to the most recent heuristic methods that can be used in a variety of combinatorial optimization. The meta-heuristics are a set of intelligent strategies that can be applied in improving the efficiency of heuristic procedures [6]. Thus, they can be used in solving a wide range of problems. Examples of such meta-heuristics algorithms include Tabu Search algorithm [7], Ant Colony Optimization [8], Ant Colony System [9], and Genetic algorithm [10]. In the same regard, it has been recommended in recent studies [11] that future work should focus using hybrid meta-heuristics approaches in solving QAP with the aim of providing the best solution within the shortest possible computation time. The goal of this study to achieve the following objectives: (i) To analysis the QAP model, (ii) To conduct a comprehensive survey of the methods that have been used to solve the QAP model, (iii) To identify the issues and limitations of the methods in (ii), and (iv) to explore the best approach that can be used in enhancing the solutions of QAP model within a reasonable time based on the accuracy of algorithm. The layout of this paper is presented as follows. Section 2 has presented the Literature Review on the QAP model, Applications of QAP model, and Approaches. In Section 3, Critical Analysis of the Literature Review is presented. Section four has been presented the solutions of the QAP model. Finally, the section 5 includes the conclusions.

2. Literature Review (QAP model, Applications of QAP model, Approaches solved QAP model)

In this section, a comprehensive survey of studies that focused on Quadratic Assignment Problem (QAP) are highlighted. These studies include two scenarios; a review of the literature on QAP is presented in the first one, while the second scenario presents the review of literature on the previous studies reviewed in this study were searched for in the following databases, Science Direct Scopus database, Web of Science, and IEEE Xplore. For the review of literature, different categories of reports were excluded while conferences papers and journal articles were used because it most likely that they contain more appropriate and advanced scientific researches that are related and relevant to the current survey. A total article of 195 articles were used for the survey, and Figure 1 shows the search process.

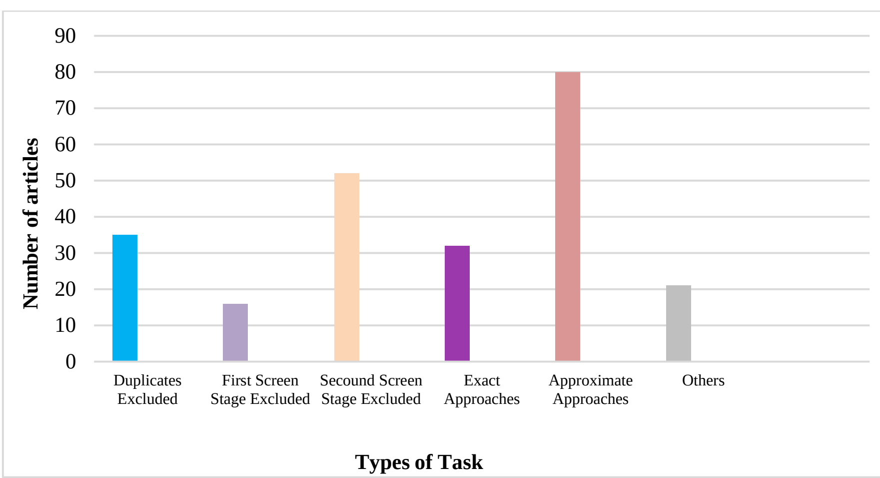

Figure 1 Process of Screech

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2.1 QAP model

The QAP as an NP-hard problem, is one of the most difficult combinatorial optimizations in the area of operation research. This problem cannot be solved in polynomial time if the size is large [12]. This section contains three subsections, and the first subsection presents an analysis of the QAP model, the second subsection presents the processing of QAP model, while the third subsection outlines the applications of QAP model.

2.1.1 Analysis of QAP Model

In this subsection, the QAP model is analysed based on the three stages associated with the QAP model. Figure 2 shows the analysis of QAP model, and the three stages of QAP model have been presented as follows:

2.1.1.1 Input Stage

The characteristics of the QAP model are critical to finding the most suitable solution for QAP. The characteristics include: **Problem Size:** N = facilities, location. **Distance Matrix (D):** Distance between every pair of locations. **Flow Matrix (F):** Amount of traffic between every pair of facilities.

2.1.1.2 Processing Stage

This stage involves solving the **Permutations (π):** A permutation or one-to-one mapping between all facilities to location; this stage is responsible for the layout through the distribution of N facilities to N locations. There are $N!$ (N size of the problem) permutations to assign all facilities to locations based on determining the flow matrix and the distance matrix. And solve the **Objective Function:** find total cost or flow * distance between all assigned pairs ($\sum_{i=1}^{n}\sum_{j=1}^{n} F_{ij} D_{\pi(i),\, \pi(j)}$).

2.1.1.3 Outcomes Stage

The results of QAP model solutions can be summarized as follows: find the best layout depending on the distribution permutations of N facilities to an N of locations regarding the distance between any two locations and the flows between any two facilities to minimize total cost. Based on the above, there are two issues in QAP model that are worth highlighting, and are highlighted as follows:

- Huge distances are created due to the absence of the locations' layout for some. So, there is an urgent need to find the best layout of distributions of N facilities to N locations to reduce the total cost based on determining the flow matrix and the distance matrix.
- Whenever the size of the problem increases, it becomes more difficult to find the best solution within a reasonable time frame.

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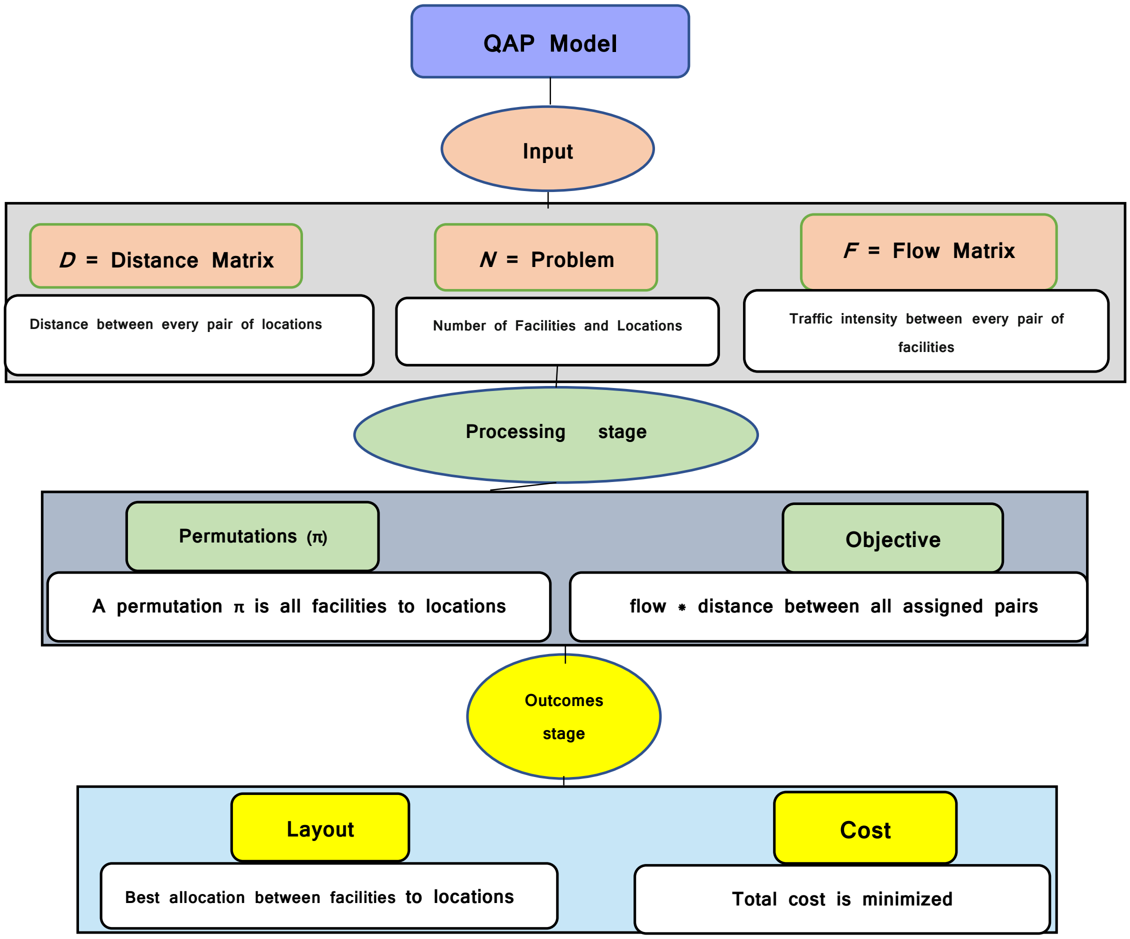

Figure 2 Analysis of QAP Model

2.1.2 Computational Complexity of QAP Model

QAP, which falls under the category of NP-hard problem, can only be solved in polynomial time for small problems through the use of exact algorithms like branch and bound, cutting the plane, branch and cut, as well as dynamic programming approaches. With the use of such approaches, the best solutions can be achieved. However, it is difficult to enumerate all the solutions in large instances due to the presence of *N!* permutations (solutions). In other words, it is challenging to enumerate and determine the best solutions for large instances. Examples of some permutations (QAP solutions) are presented in the table 1. The QAP is one of the most difficult issues, and as such, has attracted the attention of many researchers globally due to its theoretical and practical relevance, as well as its complexity problems [13], [14], [15], [16], and [17]. QAP it is highly challengeable and attractive [18].

Table 1 Example of permutation

Problem Size	Permutations (solutions)
$N = 3$	$3! = 6$
$N = 4$	$4! = 24$
$N = 10$	$10! = 3,628,800$

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$N = 20$	20! = 2,432,902,008,176,640,000

2.1.3 Applications of QAP model

The QAP model was applied in several applications in real life, table 2 shows some of these applications.

References	Subjects
[19]	Assignment of buildings in a University campus
[20]	In a hospital planning
[21]	Forest management
[22]	In facilities layout for minimizing work-in process (WIP)
[23]	Placement of electronic components
[24]	Keyboard Layout Problem
[25]	An applied case of quadratic assignment problem in hospital department layout

Table 2 Application of QAP model

2.2 Approaches

In this study, the method used to survey the literature review included two classifications, the first of them includes surveying all the methods that solved the model for a period of 2005-2019. While the second classification included approaches that were used as (Improvement, Hybrid, and Parallel). On the other hand, the aim of both classifications was to identify the issues that methods suffer from, in addition to revealing the best approach that can be used to deal with the QAP model for large size and within a reasonable time. The QAP model has been solved by two approaches the first of them is the exact approach while the second involved the approximate approach. The exact approach capable to find the optimal solution just with the small size of the problem when the increases size problem the exact approach becomes unable to find the optimal solution with reasonable time [26].

This issue motivated researchers to more efforts to develop approximate algorithms that can find the optimal or a near-optimal solution at a reasonable time and for large problem instances. Approximate approach has been divided into two types, i.e. the first called the Heuristics algorithms, while the second type is namely Metaheuristics algorithms. In same the context, the gaps in the metaheuristics as follows: methods have been mostly performed based on a simple mean of objective function values, standard deviation, and some basic statistical tests on certain test functions. More well-established and commonly agreed performance validation criteria are required in order to establish firm conclusions about the efficiency of any method being introduced. Theoretical and mathematical foundations are required for different components of metaheuristics; such as exploration versus exploitation, local optimum versus global optimum searchability, convergence, …, etc. [27], [28], and [29].

Based on the previous studies, each algorithm has advantages and disadvantages, and for this reason researchers are motivated to focus on the hybrid approach. The aim of using the hybrid is to leverage the advantages of two algorithms to address and improve the disadvantages, which in turn yields better results as compared to using one approach. In this literature review, the recent algorithms used in improving the solutions of QAP model have been reviewed and are highlighted in Table 3.

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References	Title	Algorithms
[30]	A Biogeography-Based Optimization Algorithm Hybridized with Tabu Search for the Quadratic Assignment Problem	A Biogeography-Based Optimization Algorithm Hybridized with Tabu Search (BBOTS)
[31]	Hybrid Algorithm for Solving the Quadratic Assignment Problem	Hybrid Golden Ball algorithm with Simulated Annealing (GBSA)
[32]	Integrating the whale algorithm with Tabu search for quadratic assignment problem: A new approach for locating hospital departments	Integrating the whale algorithm with Tabu search (WAITS)
[33]	A hybrid algorithm combining lexisearch and genetic algorithms for the quadratic assignment problem	Hybrid lexisearch algorithm with genetic algorithm (LSGA)
[34]	A new hybrid approach based on discrete differential evolution algorithm to enhancement solutions of quadratic assignment problem	Discrete Differential Evolution Algorithm Hybridized with Tabu Search Algorithm (HDDETS)

Table 3 Hybrid metaheuristic approaches

3. Critical Analysis of the Literature Review

Constructive criticism aims to analyse the studies by finding the strengths and weaknesses of the works related to the studied topic. On the other hand, there are many methods and frameworks that have been proposed for this purpose and for identifying the author's studies (articles or thesis) and statements of the topics and purpose of it. Constructive criticism of the literature review in this paper is summarized as follows:

1- Facility Layout Problem (FLP) seeks to improve a travelled path of the people when they move among the departments in the service sector.
2- Particularly, when the FLP is modelled as a Quadratic Assignment Problem (QAP) the efficiency of the facilities involved is increased as a set of the facilities are efficiently assigned to a set of sites.
3- A large and growing body of literature has investigated the QAP and proven impossible to be solved in polynomial time as the size of the problem increases.
4- Exact approaches and approximate approaches are currently the most popular methods for investigating to solving the QAP.
5- The exact approaches are one of the more practical ways to obtain the optimal solution to the QAP but with the small size of QAP.
6- Previous studies have demonstrated the ability of approximate approaches to find the optimum or near optimum solution within a reasonable time and for large size of QAP.
7- The literature review has highlighted the issues of metaheuristics algorithms that still suffering from them such as premature convergence, stagnation and the lack in the exploitation mechanism.
8- The metaheuristics algorithms are considered to be the best approximate approaches because they possess two intelligence strategies called diversification and intensification.
9- More recent attention has recommended that a hybrid approach is the best suitable method for solving a QAP, especially if it uses a local research algorithm.
10- There is a relatively small body of literature that focused on solving the QAP by using the Discrete Differential Evolution algorithm (DDE).

4. Solutions of QAP Model

This section addresses the studies mentioned in Table 3 of the literature review section of this study. More so, there are two subsections contained in this section; the first subsection includes the analysis while the second subsection presents the comparison and discussion. On the other hand, their outcomes were

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discussed and analysed, then a comparison was done based on the accuracy (best gap) with the aim of determining the best approach.

4.1 Analysis Process

All the algorithms in Table 3 were tested on QAP database cases in QAPLIB (http://anjos.mgi.polymtl.ca/qaplib/), and there are two types of solutions mentioned in the database of QAP the first type called Optimal Solution (OPT) while the second type called Best-Known Solution (BKS). On the other hand, there are two sets of problems in QAPLIB that represent a challenge for any proposed algorithm. More so, until now, these problems are regarded as open research. These problems were introduced by [35] and [36]. In this paper, the number of OPT is 79 instances, whilst the number of BKS is 29 instances. The equation below has been included to find the accuracy of the algorithms as follows:

$$Gap = (c_{Best} - C^*) / C^* \times 100 \qquad (1)$$

Where, C_{Best} is the best solution value found by the proposed algorithm, while C* is the best-known value taken from QAPLIB. On the other hand, the quality of the solutions obtained using the algorithms can be influenced by the set algorithm parameters. To identify the most suitable set of parameter values that produce desirable outcomes, there is need to conduct more experiments.

4.2 Comparison and Discussion

In this scenario, the results obtained through the use of the algorithms in Table 3 are presented and discussed. There are two stages in this scenario; in the first stage the optimal solutions (OPT) are presented, while at the second stage the Best-Known Solution (BKS) is discussed. The algorithms proposed in the literature were applied to 79 cases (which have an optimal solution OPT) of the database of QAP as shown in Table 4. The BBOTS approach, which is a hybrid obtained by combining BBO algorithm and the TS algorithm was able to obtain 29 OPT out of 79 OPT. The results obtained by the GBSA approach which is a hybrid obtained by combining the GB algorithm with the SA algorithm, obtained 40 OPT out of 79 OPT. One the other hand, the WAITS approach is a hybrid of whale algorithm and tabu search algorithm achieved 73 OPT out of 77 OPT. Finally, the HDDETS approach being a hybrid derived from a discrete differential evolution algorithm with the tabu search algorithm, obtained 75 OPT out of 77 OPT.

Table 4 Optimal Solutions (OPT) obtained by studies in Table 3

Category	Name of Problem	Number of OPT	BBOTS [30]	GBSA [31]	WAITS [32]	LSGA [33]	HDDETS [34]
1	Nug	15	12	8	14	1	15
2	Chr	14	6	4	12	2	14
3	Esc	19	4	18	19	1	19
4	Lipa	16	-	-	14	-	12
5	Had	5	5	5	5	1	5
6	Tai	10	2	5	9	2	10
Sum		**79**	**29**	**40**	**73**	**7**	**75**

Figure 3 shows the outcomes of the comparison from Table 4 as follows:

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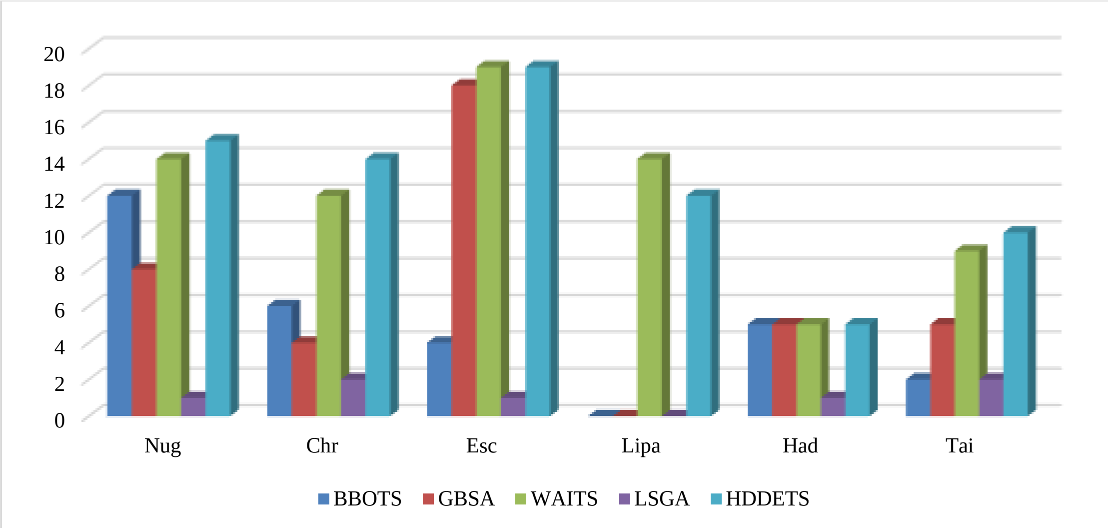

Figure 3 Graphical representation of Table 6

The second stage is included the results of 29 instances of a database of QAP that solved by BBOTS, GBSA, WAITS, LSGA, and HDDETS approaches, these instances have BKS in the standard. Table 5 has been presented the results as follows: the BBOTS and GBSA approaches were unable to yield any results in section BKS, while the WAITS approach achieved 3 BKS out of 29 BKS. Another approach called LSGA obtained 3 BKS out of 29 BKS, while the last approach in Table 3 obtained 12 BKS out of 29 BKS recorded in the QAPLIB database.

Table 5 Best Known Solutions (BKS) obtained by studies in Table 3

Category	Name of Problem	Number of BKS	BBOTS	GBSA	WAITS	LSGA	HDDETS
1	Sko	13	0	0	1	1	4
2	Tai	16	0	0	2	2	8
Sum		**29**	**0**	**0**	**3**	**3**	**12**

Figure 4 shows the outcomes of the comparison from Table 5 as follows:

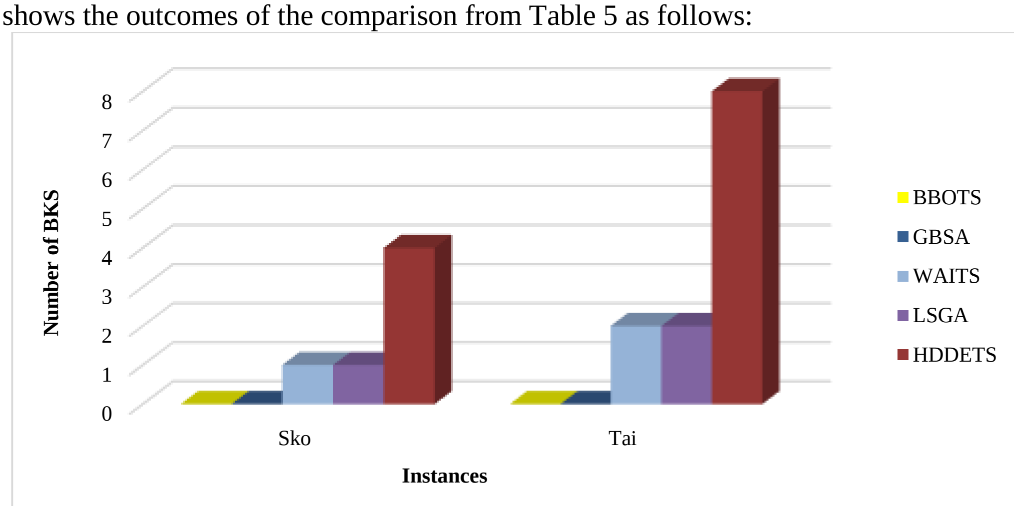

Figure 4 Graphical representation of Table 8

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5. Conclusion

This study has been introduced a survey of Quadratic Assignment Problem (QAP) which included analysis of QAP model and presented some of the applications of the QAP model, and finally, given picture comprehensive for the approaches which have been solved the QAP model. Because of the importance of QAP in real-life, researchers in many previous studies have conducted a survey of the QAP. On the other hand, this study was proposed in a different way for the purpose of achieving comprehensive objectives, as well as to highlight the gaps and determinants of all approaches used to solve the QAP model.

On the other hand, the best hybrid approaches HDDETS were explored to improve the model's solutions within a reasonable time. This was achieved through a comparison of the results obtained by the recent studies in the literature. In the same of context, the previous studies employed the use of the hybrid approach, and the comparison is done based on the accuracy of the performance of the algorithms in many cases from the database of QAP. For future work, it is suggested that researchers should focus on developing a good framework for hospital layout problem through a link between the QAP model and the approach HDDETS which can find the best layout at a minimized total cost.

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References

[1] J. Liu, H. Zhang, K. He, and S. Jiang, “Multi-objective particle swarm optimization algorithm based on objective space division for the unequal-area facility layout problem,” Expert Syst. With Appl. Receiv., pp. 3–27, 2018, doi: 10.1016/j.eswa.2018.02.035.
[2] T. C. Koopmans and M. J. Beckmann, “Assignment Problems and the Location of Economic Activities Author (s): Tjalling C . Koopmans and Martin Beckmann,” Econometrica, vol. 25, no. 1, pp. 53–76, 1957.
[3] Z. Drezner, “Finding a cluster of points and the grey pattern quadratic assignment problem,” OR Spectr., vol. 28, pp. 417–436, 2006, doi: 10.1007/s00291-005-0010-7.
[4] G. G. Zabudskii and A. Y. Lagzdin, “Dynamic programming for the quadratic assignment problem on trees,” Autom. Remote Control, vol. 73, no. 2, pp. 336–348, 2012, doi: 10.1134/S0005117912020117.
[5] H. Zhang, C. Beltran-Royo, and L. Ma, “Solving the quadratic assignment problem by means of general purpose mixed integer linear programming solvers,” Ann. Oper. Res., vol. 207, no. 1, pp. 261–278, 2012, doi: 10.1007/s10479-012-1079-4.
[6] Z. Beheshti and S. M. H. Shamsuddin, “A review of population-based meta-heuristic algorithm,” Int. J. Adv. Soft Comput. its Appl., vol. 5, no. 1, pp. 1–35, 2013.
[7] A. Misevicius, “A tabu search algorithm for the quadratic assignment problem,” Comput. Optim. Appl., vol. 30, no. 1, pp. 95–111, 2005, doi: 10.3233/INF-1992-3405.
[8] N. Ç. Demirel and M. D. Toksari, “Optimization of the quadratic assignment problem using an ant colony algorithm,” Appl. Math. Comput., vol. 183, no. 1, pp. 427–435, 2006, doi: 10.1016/j.amc.2006.05.073.
[9] Mutar, Modhi Lafta, Burhanuddin Mohd Aboobaider, Asaad Shakir Hameed and Norzihani Yusof, “Enhancing Solutions of Capacity Vehicle Routing Problem based on an Improvement Ant Colony System Algorithm,” vol. 11, pp. 1362–1374, 2019.

ISSN: 2005-4238 IJAST

[10] B. Rostami and F. Malucelli, "A revised reformulation-linearization technique for the quadratic assignment problem," Discret. Optim., vol. 14, pp. 97–103, 2014, doi: 10.1016/j.disopt.2014.08.003.
[11] M. Abdel-Basset, G. Manogaran, H. Rashad, and A. N. H. Zaied, "A comprehensive review of quadratic assignment problem: variants, hybrids and applications," J. Ambient Intell. Humaniz. Comput., vol. 0, no. 0, pp. 1–24, 2018, doi: 10.1007/s12652-018-0917-x.
[12] M. E. Riffi, Y. Saji, and M. Barkatou, "Incorporating a modified uniform crossover and 2-exchange neighborhood mechanism in a discrete bat algorithm to solve the quadratic assignment problem Incorporating a modified uniform crossover and 2-exchange neighborhood mechanism," Egypt. Informatics J., vol. 18, no. 3, pp. 221–232, 2017, doi: 10.1016/j.eij.2017.02.003.
[13] S. Sahni and T. Gonzalez, "P-Complete Approximation Problems," J. ACM, vol. 23, no. 3, pp. 555–565, 1976, doi: 10.1145/321958.321975.
[14] E. Duman, M. Uysal, and A. F. Alkaya, "Migrating Birds Optimization: A new metaheuristic approach and its performance on quadratic assignment problem," Inf. Sci. (Ny)., vol. 217, pp. 65–77, 2012, doi: 10.1016/j.ins.2012.06.032.
[15] U. Benlic and J. K. Hao, "Breakout local search for the quadratic assignment problem," Appl. Math. Comput., vol. 219, no. 9, pp. 4800–4815, 2013, doi: 10.1016/j.amc.2012.10.106.
[16] B. R. M. M. Y. Mohamad Amin Kaviani, Mehdi Abbasi, "A hybrid Tabu search-simulated annealing method to solve quadratic assignment problem," Decis. Sci. Lett., vol. 3, no. 3, pp. 391–396, 2014, doi: 10.5267/j.dsl.2014.2.004.
[17] A. R. Montero and A. S. Lopez, "Ant Colony Optimization for Solving the Quadratic Assignment Problem," 2015 Fourteenth Mex. Int. Conf. Artif. Intell., no. 3, pp. 182–187, 2015, doi: 10.1109/MICAI.2015.34.
[18] E. Lalla-Ruiz, C. Expósito-Izquierdo, B. Melián-Batista, and J. M. Moreno-Vega, "A Hybrid Biased Random Key Genetic Algorithm for the Quadratic Assignment Problem," Inf. Process. Lett., vol. 116, no. 8, pp. 513–520, 2016, doi: 10.1016/j.ipl.2016.03.002.
[19] J. W. Dickey and J. W. Hopkins, "Campus building arrangement using topaz," Transp. Res., vol. 6, no. 1, pp. 59–68, 1972, doi: 10.1016/0041-1647(72)90111-6.
[20] A. N. Elshafei, "Hospital Layout as a Quadratic Assignment Problem," Oper. Res. Q., vol. 28, no. 1, p. 167, 1977, doi: 10.2307/3008789.
[21] J. Bos, "Zoning in forest management: A quadratic assignment problem solved by simulated annealing," Journal of Environmental Management, vol. 37, no. 2. pp. 127–145, 1993, doi: 10.1006/jema.1993.1010.
[22] S. Benjaafar, "Modeling and Analysis of Congestion in the Design of Facility Layouts," Manage. Sci., vol. 48, no. 5, pp. 679–704, 2002, doi: 10.1287/mnsc.48.5.679.7800.
[23] G. Miranda, H. P. L. Luna, G. R. Mateus, and R. P. M. Ferreira, "A performance guarantee heuristic for electronic components placement problems including thermal effects," Comput. Oper. Res., vol. 32, no. 11, pp. 2937–2957, 2005, doi: 10.1016/j.cor.2004.04.014.
[24] M. Dell'Amico, J. C. D. Díaz, M. Iori, and R. Montanari, "The single-finger keyboard layout problem," Comput. Oper. Res., vol. 36, no. 11, pp. 3002–3012, 2009, doi: 10.1016/j.cor.2009.01.018.
[25] X. Feng and Q. Su, "An applied case of quadratic assignment problem in hospital department layout," 2015 12th Int. Conf. Serv. Syst. Serv. Manag. ICSSSM 2015, 2015, doi: 10.1109/ICSSSM.2015.7170278.
[26] A. S. Hameed, B. M. Aboobaider, N. H. Choon, and M. L. Mutar, "Review on the Methods to Solve Combinatorial Optimization Problems Particularly : Quadratic Assignment Model," Int. J. Eng. Technol., vol. 7, pp. 15–20, 2018.
[27] K. Hussain, M. N. Mohd Salleh, S. Cheng, and Y. Shi, "Metaheuristic research: a comprehensive survey," Artif. Intell. Rev., pp. 1–43, 2018, doi: 10.1007/s10462-017-9605-z.

ISSN: 2005-4238 IJAST

[28] S. Jain, S. Kumar, V. K. Sharma, and H. Sharma, “Improved differential evolution algorithm,” 2017 Int. Conf. Infocom Technol. Unmanned Syst. Trends Futur. Dir. ICTUS 2017, pp. 627–632, 2017, doi: 10.1109/ICTUS.2017.8286085.

[29] A. W. Mohamed, “RDEL: Restart differential evolution algorithm with local search mutation for global numerical optimization,” Egypt. Informatics J., vol. 15, no. 3, pp. 175–188, 2014, doi: 10.1016/j.eij.2014.07.001.

[30] W. L. Lim, A. Wibowo, M. I. Desa, and H. Haron, “A biogeography-based optimization algorithm hybridized with tabu search for the quadratic assignment problem,” Comput. Intell. Neurosci., vol. 2016, 2016, doi: 10.1155/2016/5803893.

[31] M. E. Riffi and F. Sayoti, “Hybrid Algorithm for Solving the Quadratic Assignment Problem,” Int. J. Interact. Multimed. Artif. Intell., vol. 5, no. 4, p. 68, 2017, doi: 10.9781/ijimai.2017.10.003.

[32] M. Abdel-Basset, G. Manogaran, D. El-Shahat, and S. Mirjalili, “Integrating the whale algorithm with Tabu search for quadratic assignment problem: A new approach for locating hospital departments,” Appl. Soft Comput. J., vol. 73, pp. 530–546, 2018, doi: 10.1016/j.asoc.2018.08.047.

[33] Z. H. Ahmed, “A hybrid algorithm combining lexisearch and genetic algorithms for the quadratic assignment problem,” Cogent Eng., vol. 5, no. 1, pp. 1–15, 2018, doi: 10.1080/23311916.2018.1423743.

[34] A. S. Hameed, B. M. Aboobaider, M. L. Mutar, and N. H. Choon, “A new hybrid approach based on discrete differential evolution algorithm to enhancement solutions of quadratic assignment problem,” Int. J. Ind. Eng. Comput., vol. 11, no. 1, pp. 51–72, 2020.

[35] J. Skorin-Kapov, “Tabu Search Applied to the Quadratic Assignment Problem,” ORSA Journal on Computing, vol. 2, no. 1. pp. 33–45, 1990, doi: 10.1287/ijoc.2.1.33.

[36] E.Taillard, “Robust Taboo search for quadratic assignment problem,” Parallel Comput., vol. 17, pp. 443–455, 1991.

[37] Asaad Shakir Hameed, Burhanuddin Mohd Aboobaider, Modhi Lafta Mutar, and Ngo Hea Choon: An Efficient Crossover Operator for Quadratic Assignment Problem Based on Discrete Differential Evolution Algorithm. International Journal of Advanced Science and Technology. Vol. 28, No. 8, (2019), pp. 591-601.

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