Sudoku grids technique for the drugs assignment in an automated dispensing cabinets

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Abstract— **In this article we propose to study one of the real problems of combinatorial optimization in healthcare public; the assignment of drugs to different compartments of drawers. It is a matter of placing a set of drugs in the compartments of a drawer, making sure not to place two similar drugs (drugs with packaging or similar sounds but with different contents) in neighboring compartments. During this research, we were able to establish analogies between the drug assignment problem and the SUDOKU grid filling problem. We will show the interest and effectiveness of this approach through a concrete example.**

Keywords— Automated dispensing cabinets ADCs, dispensing errors, patient safety, QAP quadratic assignment problem, Sudoku

I. Introduction

In order to improve the quality of the drug dispensing system, it is important to work on the analysis of errors and the possibilities for improvement. Indeed, some points require further study, such as frequency analysis and sources of errors as well as latent errors. By analyzing the causes of errors and trying to reduce the risk of errors, an improvement of the system is possible. To do this, it is essential to implement major changes in the processes governing the drug circuit. This being the case, for effective prevention, high security technologies, such as computerized prescription; automated dispensing; automated preparation and automatic final checks can significantly reduce the error rate. However, these techniques are not yet a widespread practice within hospitals. Before introducing these measures, many strategies can be implemented to reduce the risk of error and improve the quality of the system. Therefore, improvement requires the implementation of these measures.

They are intended to replace conventional cabinet storage in a care unit. The ADCs (Automated Dispensing Cabinets) (Fig.1) allows secure storage and restricted access to medicines for authorized staff: pharmacists and doctors. By facilitating, among other things, the selection of medications by nurses through rapid access and the signaling of the drug to be taken by a light signal, they must make it possible to reduce medication errors (EM) [1].

Fig. 1. automated dispensing cabinets, Pyxis MedStation 4000.

the article is composed of several sections. In Section 2, we will present a review of the literature on medication dispensing systems, including Automated Dispensing Cabinets (ADCs). In section 3 we will first discuss the issue of assignment in drawers of the dispensing cabinet. We will propose in section 4 the similarity between the drug assignment problem and the SUDOKU puzzle, and we will explore the application of SUDOKU's solving techniques to our problem. Finally, we end in section 5, with a conclusion with future perspectives.

II. Literature Review

Improving patient safety is still a priority in the hospital environment, and pharmacists have studied various strategies and technologies to achieve this goal. Automated dispensing decentralized drug delivery systems that store, distribute and monitor drugs by computer have been recommended as a potential mechanism to improve patient efficiency and safety. They are currently widely used in many hospitals [2]. The fact that these systems can improve the efficiency of drug distribution, as well as their ability to reduce medication errors, is controversial and depends on many factors, including how users design and implement systems [3].

Nevertheless, several studies have shown a positive impact on the reduction of dispensing errors after the introduction of Automated Dispensing Systems (ADSs) in care units [4]; [5]; [6]; [7]; [8]; [9].

The dispensing machines provide secure storage of medicines in the care units, as well as electronic monitoring of the use of controlled drugs. Automated dispensing cabinets improve the availability of different doses and facilitate the timely delivery of drugs by increasing their accessibility in patient care units [10].

On the other hand, since the first introduction of dispensing cabinets by hospitals, there has been an increasing number of reports of medication errors created by these systems [11]; [12]. According to a safety bulletin from the Institute for Safe Medication Practices Canada (ISMP Canada) that reviewed these technologies, it is noted that the nature of the risks associated with these systems are attributed to the abuse and random placement of drugs in the compartments. The ISMP Canada report made 24 recommendations to ensure that automated dispensing systems are used to minimize the risk of medication errors.

In ADCs and other dispensing systems, there is always the problem of confusion of drug names and their packaging, which can lead to potentially dangerous dispensing errors. These drugs are called look-alike, sound-alike [13]; [14]. Each stage of the "medication circuit" (from the prescription of the drug to the administration to the patient) can cause confusion between products of similar appearance or names.

III. Problem Position

In a first work, (Pazour and Meller, 2012) [15] treated the problem of allocation of drugs in the drawers of a medicine cabinet subdivided into compartments of the same size (matrix form), avoiding placing the pairs that have a great similarity rate between them side by side. Two compartments are considered neighbors when they share one side in common. The assignment problem that we are considering here is to determine the compartments that will receive the drugs by knowing the similarity matrix of the drugs and avoiding placing two similar drugs in two neighboring compartments. This problem is considered an FLP "Facility Layout Problem" [35] [36] whose mathematical formulation is given in the form of QAP "Quadratic Assignment Problem". [16] [17] [18] [37] [38]. Pazour and Meller (2012) [15] tried to solve this problem, using CEPLEX 10.1, but could not find a solution because of PC memory limitations. Then they proposed to work with a heuristic approach. They developed a heuristic approach called (a steepest-descent-pairwise-exchange algorithm).

The effectiveness of the approach used by Pazour and Meller was tested on real data from the use of ADCs. For the same assignment problem of Pazour and Meller (2012), (Hachemi and Alla, 2013) [19] developed an approach based on controller synthesis by petri nets. The goal was to add control places to prohibit placement of two similar drugs side by side. To do this, they used the invariant method.

The following notation is used in the formulation of the QAP [20]; [21]:

$$\min \sum_{i}\sum_{j}\sum_{k}\sum_{l} Fik\, Djl\, Xik\, Xjl \qquad (1)$$

Parameters:

n: the total number of installations and locations

Fik: the flow of installations from location i to location k.

Djl: the distance from location j to location l.

Variables :

$$Xij = \begin{cases} 1 \ \textit{if the material i is placed in location j}. \\ 0 \ \textit{otherwise}. \end{cases}$$

$$\sum_i Xij = 1 \ \forall i \qquad (2)$$

$$\sum_j Xij = 1 \ \forall j \qquad (3)$$

Xij is binary. (4)

The objective function (1) minimizes total distances and flows between installations. Constraints (2) and (4) make it possible to ensure that each installation i is assigned to a single location. Constraints (3) and (4) ensure that each location has exactly one installation delivered to it.

IV. The Similarity of The Drug Assignment and Sudoku Puzzle

In the first time, our contribution was to approach the assignment of drugs in a set of drawers to fill a SUDOKU puzzle. We presented the concept of Sudoku (chaker and Hachemi,2018) [22]. The famous Sudoku numerical enigma represents a constraint problem, the classic Sudoku consists of filling a grid of (9 × 9), divided into nine blocks (3×3), so that each column, row and block contain different numbers of 1-9[23] [24] [25].

Sudoku problem attracts much attention from mathematicians and computer scientists, it is classified as NP-complete problems. Several methods of solving Sudoku have been proposed, such as recursive backtracking, simulated annealing, integer programming, balancing algorithms Sinkhorn, the projection method [26] [27] [28] [29] [30]

We have shown the similarity between the drug assignment and the Sudoku puzzle, see the Table 1. And we have presented a numerical example according to the similarity matrix that represents the similarity rate between all the drug pairs that we want to allocate in drawers of an automated ADCs cabinet. Such as When the element is equal to 1 it means that the two drugs are similar and therefore, they should not be placed side by side. On the other hand, if the element is equal to 0, this means that the two drugs are not similar and can therefore be placed side by side.

Table. 1. The comparison between the drug assignment and the Sudoku problem

Drugs assignment problem	**Sudoku**
Avoid placing two similar drugs in the neighborhood	Place the numbers from 1 to 9 only once in the row, column, and block
Drawers	Blocks, Sudoku grid
Compartments	Cells
Modeling (QAP)	Modeling (ILP) Integer Linear Programming
NP-hard problem	NP-complete problem

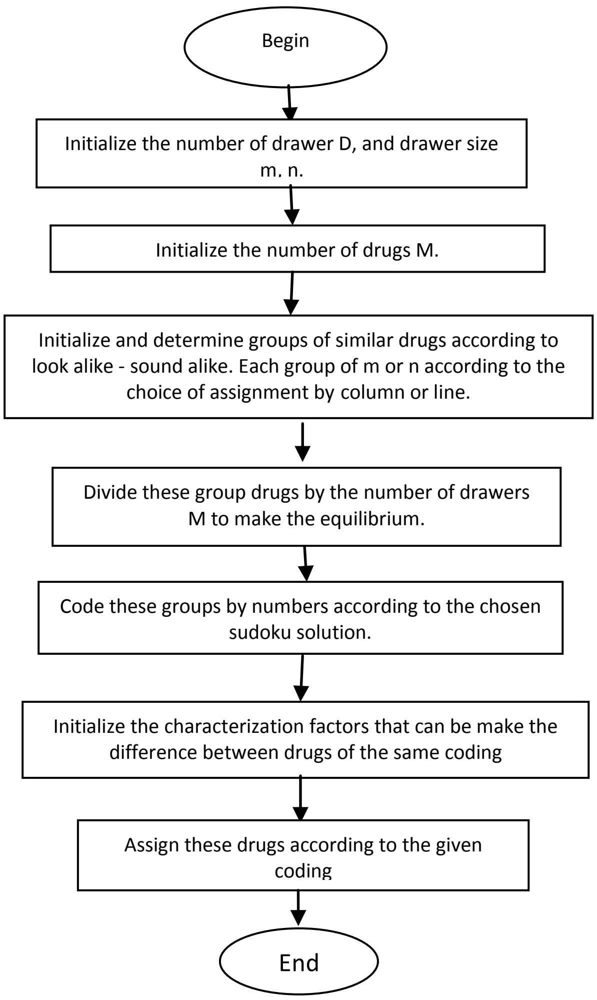
Our contribution in this study is to generalize the assignments by the Sudoku puzzle with the different seizes (4×4), (5×5), (6×6) and (9×9). We can consider the both like drawer either the block or all the grid of Sudoku, because the contain blocks e.g. the grid of (9×9) contain 9 blocks.

We use these standards sizes of Sudoku to develop other sizes like (5×6), (6×7), (7×8) …etc.

We work to optimize the Sudoku coding to minimize the coding just using 1 and 2 for maximize the number of similar medications.

This flow chart below (Fig.2) summary all steps are followed to solve this drugs assignment problem and the filling an ADCs for avoiding confused similar medications when dispensing drugs step, and reduce the rate of errors in the both steps dispensing and administration.

Fig. 2. Flow chart of Sudoku approach



1. Sudoku grid applications

a) Development of drawer (5×6) by the Sudoku of (4×4)

The columns 5 and 6 take the same coding of the columns 1 and 2 respectively, and the row 5 takes the same coding of first row, as shown in Fig.3.

Fig. 3. Coding by sudoku (4×4) development

1	2	3	4	1	2
3	4	1	2	3	4
2	1	4	3	2	1
4	3	2	1	4	3
1	2	3	4	1	2

b) Development of drawer (5×6) by the Sudoku of (5×5) The column 6 takes the same coding of the first column.

Fig. 4. Coding by sudoku (5×5) development

1	5	4	3	2	1
3	2	1	5	4	3
5	4	3	2	1	5
2	1	5	4	3	2
4	3	2	1	5	4

c) Development of drawer (5×6) by the Sudoku of (6×6)

In this case, we need to delete the last coding row.

Fig. 5. coding by Sudoku (6×6) development

5	6	3	2	1	4
2	1	4	6	3	5
6	3	1	4	5	2
4	2	5	3	6	1
3	5	2	1	4	6
1	4	6	5	2	3

d) Development of drawer (5×6) by the square magic (3×3)

We applique the same method to place the coding from magic square coding to the cases empty, as shown in Fig.6.

Fig. 6. coding by magic square (3×3)

8	1	6	8	1	6
3	5	7	3	5	7
4	9	2	4	9	2
8	1	6	8	1	6
3	5	7	3	5	7

e) Optimization of the coding for using just 1 and 2

We use this coding to maximize the number of similar medications and facilitate the coding of medications.

We consider the benchmark size of drawer (5×6), the coding become like Fig. 7.

Fig. 7. coding only by 1 and 2

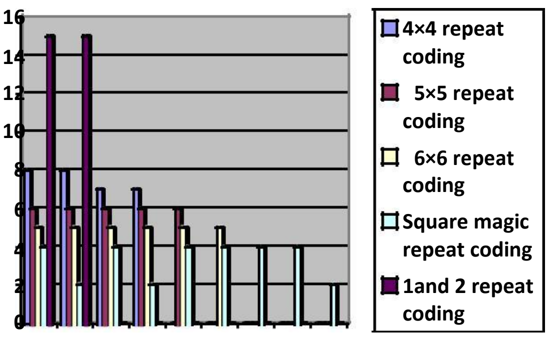
1	2	1	2	1	2
2	1	2	1	2	1
1	2	1	2	1	2
2	1	2	1	2	1
1	2	1	2	1	2

The Table 2 and the bar chart (Fig.8) present the various coding and repetition for every code.

Table. 2. Repetition of codes for different possible solutions

Coding	1	2	3	4	5	6	7	8	9
4×4 repeat Coding	8	8	7	7	0	0	0	0	0
5×5 repeat coding	6	6	6	6	6	0	0	0	0
6×6 repeat coding	5	5	5	5	5	5	0	0	0
Square magic repeat coding	4	2	4	2	4	4	4	4	2
1 and 2 repeat coding	15	15	0	0	0	0	0	0	0

Fig. 8. bar chart present different coding



This bar chart shows the comparison between different coding, such as the coding by 1 and 2 accept more similar medications. We can also conclude which coding help us during the drugs assignment according the number of similar medications is equal the repetition code.

2. Performance assessment

There are many factors, we can take its by consideration for more precision and more performance like: concentration, dosage form (solid, liquid, injection…), demand (high, medium, low), usage (pediatric, adult ...), allergic cause

In the study of Pazour and meller (2012), they calculated the similarity rating with all these factors with same impact. By this method you have to know the similarity rating between all drugs you want to assign. This method is difficult and longer to find solution either exact or heuristic.

We suggest to put the priority to avoid firstly the confused drugs names because the drug names have important impact to make confused errors according some studies [31] [32][33], then we assign the drugs by Sudoku technique [30], and next we take other factor by consideration for put the medication which have more common factors more far then medication don't have common factors; as shown in Table 3.

Table. 3. Factors effect and similarity degree

Medication	**Concentration**	**Dosage form**	**Demand**	**Similarity degree**
ceFAZolin	+	+	+	+++
cefoTEtan	+	-	+	++
cefOXitin	-	-	+	+
cefTAZidime	-	+	+	++
cefTRIAXone	+	+	+	+++

- \+ have the same value.
- \- have different value.

According this information factors, the medications still having the same coding, but we put the medications which have the same similarity degree far than other medication have the same coding.

In this part, we have proved that we can use different size of sudoku for different size of drawer. Then how to apply the priority in assignment when we take into account many factors of similarity. Next, by sudoku technique we can know the capacity of confused drugs could be assigned for any drawer size in different cases as shown in sudoku grid application. Finally, sudoku technique give us an opportunity to minimize medication errors when we maximize the number of confused drugs.

Example: in this example, we assign 30 medications to a drawer of 30 compartments. All these medications from ISMP's list of confused drug names.

We give all similar medication groups the same coding according the drawer capacity. We never put the different coding for the similar medication e.g. we have three similar medication, so we give the same coding for them.

In this case of our example, we can use three different coding, see the Table. 4 and the medication assignment in the Table 5.

Table. 4.Real example of confused drug names and its coding

Medication	FluvoxaMINE	Altocor	ePHEDrine	ALPRAZolm	CARBOplatin	CeFAZolin	ClonazePAM
Confused with	LuPHENAZie flavoxATE	Advicor	EPINEPHrine	LORazepam clonazePAM	CISplatin	CefoTEtan cefOXitin cefTAZidime cefTRIAXone	CloNIDine cloZAPine cloBAZam LORazepam
Medication number	3	2	2	3	2	5	5
Coding 1	1	3	3	2	4	1	2
Coding 2	1	1	1	1	2	1	2
Coding 3	1	1	2	2	6	3	4

Table.5. medications assignment for drawer (5×6) benchmark

2 LORazepam	1 fluPHENAZine	4 CARBOplatin	3 Altocor	2 ALPRAZolam	1 fluvoxaMINE
4 hydrOXYzine	3 Advicor	2 clonazePAM	1 flavoxATE	4 CISplatin	3 ePHEDrine
1 ceFAZolin	2 clonazePAM	3 EPINEPHrine	4 DACTINomycin	1 cefoTEtan	2 cloNIDine
3 FLUoxetine	4 hydrALAZINE	1 cefOXitin	2 cloZAPine	3 DULoxetine	4 DAPTOmycin
2 LORazepam	1 cefTRIAXone	4 hydroCHLOROthiazide	3 PARoxetine	2 cloBAZam	1 cefTAZidime

The current study found that:

- We can see no similar couple medication put it on adjacency
- When the staff of hospital and pharmacy understand this operating principle of our assignment method can be reduce significantly the human selection error.
- This benchmark can be support 15 similar medication
- We can use this technique manually or programed.
- One interesting finding is how to extract the utility and advantage sudoku problem solutions without pass to other algorithms execute (search a heuristic or metaheuristics).
- The time execution to solve sudoku one of NP-Complete by approach solution (heuristic or metaheuristic problem) is less than the time to solve of NP- Hard [21] [34], See the Tables 6 and 7.

Tableau. 6. algorithms execution time to solve Sudoku puzzle

Algorithm	Brute force	SA	GRA	GA	HS
Shortest time (s)	0.002	0.09	0.002	0.9	3
Longer time (s)	0.25	1.3	0.07	11.4	100.6

Tableau. 7. Algorithms execution time to solve QAP

Algorithms	GA	TS	SA
Shortest time (s)	8.6	0.1	2.3
Longer time (s)	33.6	17.8	13.7

v. Conclusion

In this article, we proposed to study the problem of assigning a batch of drugs to a set of drawers composing an ADC. The mean idea is based on the exploitation of a similarity between the problem of drug assignment and Sudoku grids of corresponding sizes. The approach developed consists in coding the different drugs to be affected according to several groups. Then from the solution of the Sudoku grid of the same size, a drug is placed according to its code in the grid. This provides an assignment that separates drugs from the same group preventing them from being side by side. The application of the approach remains valid for different drawer sizes, and how to optimize this application like coding only by two codes. As a perspective, on the one hand we work to draw a well-structured organigram in order to program these steps of coding the drugs according to look-alike sound -alike, then we consider other characterization factors as a step to raise the performances in different cases and several drawers. And on the other hand, we will evaluate the performance against the use of other techniques and heuristics for solve this problem.

References

[1] Chapuis, C. (2009). Impact d'une armoire à pharmacie sécurisée en réanimation médicale sur l'iatrogénèse médicamenteuse, la gestion des médicaments et la perception des utilisateurs (Doctoral dissertation).

[2] Pedersen, C. A., Schneider, P. J., & Scheckelhoff, D. J. (2006). ASHP national survey of pharmacy practice in hospital settings: dispensing and administration—2005. American Journal of Health-System Pharmacy, 63(4).

[3] Fung, E.Y., Leung, B., Hamilton, D. and Hope, J. (2009). Do automated dispensing machines improve patient safety? The Canadian journal of hospital pharmacy, 62(6).

[4] Helmons, P.J., Dalton, A.J. and Daniels, C.E. (2012). Effects of a direct refill program for automated dispensing cabinets on medication-refill errors. American Journal of Health-System Pharmacy, 69(19), pp.1659-1664.

[5] Cousein, E., Mareville, J., Lerooy, A., Caillau, A., Labreuche, J., Dambre, D., Odou, P., Bonte, J.P., Puisieux, F., Decaudin, B. and Coupé, P. (2014). Effect of automated drug distribution systems on medication error rates in a short-stay geriatric unit. Journal of evaluation in clinical practice, 20(5), pp.678-684.

[6] Oswald, S., & Caldwell, R. (2007). Dispensing error rate after implementation of an automated pharmacy carousel system. American Journal of Health-System Pharmacy, 64(13).

[7] Rochais, É., Atkinson, S., Guilbeault, M., & Bussières, J. F. (2014). Nursing perception of the impact of automated dispensing cabinets on patient safety and ergonomics in a teaching health care center. Journal of pharmacy practice, 27(2), 150-.

[8] Tsao, N. W., Lo, C., Babich, M., Shah, K., & Bansback, N. J. (2014). Decentralized automated dispensing devices: systematic review of clinical and economic impacts in hospitals. The Canadian journal of hospital pharmacy, 67(2), 138.

[9] Grissinger, M. (2012). Safeguards for using and designing automated dispensing cabinets. Pharmacy and Therapeutics, 37(9), p.490.

[10] Gaunt, M.J., Johnston, J. and Davis, M.M. (2007). Automated dispensing cabinets. AJN The American Journal of Nursing, 107(8), pp.27-28.

[11] Agrawal, A. (2009). Medication errors: prevention using information technology systems. British journal of clinical pharmacology, 67(6), pp.681-686.

[12] Flynn, E.A. and Barker, K.N. (2006). Effect of an automated dispensing system on errors in two pharmacies. Journal of the American Pharmacists Association, 46(5), pp.613-615.

[13] Kundig, F. (2011). Médicaments look-alike, sound-alike : un enjeu important dans le domaine de l'infectiologie. Revue médicale suisse, 7(312).

[14] Basco, W.T., Ebeling, M., Hulsey, T.C. and Simpson, K. (2010). Using pharmacy data to screen for look-alike, sound-alike substitution errors in pediatric prescriptions. Academic pediatrics, 10(4), pp.233-237.

[15] Pazour, J. A., & Meller, R. D. (2012). A multiple-drawer medication layout problem in automated dispensing cabinets. Health care management science, 15(4), 339-354.

[16] Yew Wong, K., &Chiak See, P. (2010). A hybrid ant colony optimization algorithm for solving facility layout problems formulated as quadratic assignment problems. Engineering Computations, 27(1), 117-128.

[17] Chiang, W. C., & Chiang, C (1998). Intelligent local search strategies for solving facility layout problems with the quadratic assignment problem formulation. European Journal of Operational Research.

[18] Meller, R. D., Narayanan, V., & Vance, P. H. (1998). Optimal facility layout design. Operations Research Letters, 23(3), 117-127.

[19] Hachemi, K., & Alla, H. (2013). Affectation de médicaments dans un système automatisée de dispensation de médicaments : approche basée sur la synthèse de contrôleur par réseau de petri.

[20] Rupasinghe, T. D., & Kurz, M. E. (2009). January. Metaheuristics for Quadratic Assignment Problem (QAP). In IIE Annual Conference. Proceedings (p. 48). Institute of Industrial and Systems Engineers (IISE).

[21] Said, G. A. E. N. A., Mahmoud, A. M., & El-Horbaty, E. S. M. (2014). A comparative study of meta-heuristic algorithms for solving quadratic assignment problem. arXiv preprint arXiv:1407.4863

[22] Abderrahmen, C. Khalid, H. (2018). Affectation des médicaments dans une armoire automatisée de dispensation : Approche inspirée des grilles de Sudoku. Conference GISEH 2018 GENEVA.

[23] Chi, E.C. and Lange, K. (2012). Techniques for solving sudoku puzzles. arXiv preprint arXiv:1203.2295.

[24] Simonis, H. (2005). Sudoku as a constraint problem. Proc. 4th Int. Works. Modelling and Reformulating Constraint Satisfaction Problems, 13-27.

[25] Tang, Y., Wu, Z., & Zhu, C. (2015). An improved strategy for solving Sudoku by sparse optimization methods. arXiv preprint arXiv:1507.05995.

[26] Tang, Y., Wu, Z., & Zhu, C. (2015). An improved strategy for solving Sudoku by sparse optimization methods. arXiv preprint arXiv:1507.05995.

[27] Hölldobler, S. and Schweizer, L. (2014). April. Answer set programming and clasp a tutorial. In Young Scientists' International Workshop on Trends in Information Processing (YSIP) (p. 77).

[28] Simonis, H. (2005). Sudoku as a constraint problem. Proc. 4th Int. Works. Modelling and Reformulating Constraint Satisfaction Problems, 13-27.

[29] Wang, L., Zhang, W., Yan, B., & Cai, A. (2016). Equivalence of L0 and L1 Minimizations in Sudoku Problem. arXiv preprint arXiv:1605.01031.

[30] Soto, R., Crawford, B., Galleguillos, C., Monfroy, E., & Paredes, F. (2014). A prefiltered cuckoo search algorithm with geometric operators for solving Sudoku problems. The Scientific World Journal.

[31] American Society of Health-System Pharmacists. (1993). ASHP guidelines on preventing medication errors in hospitals. American Journal of Health-System Pharmacy, 50(2), 305-314.

[32] Authority, P. P. S. (2005). Problems associated with automated dispensing cabinets. Patient Saf Authority, 2(3), 21-23.

[33] Cheung, K. C., Bouvy, M. L., & De Smet, P. A. (2009). Medication errors: the importance of safe dispensing. British journal of clinical pharmacology, 67(6), 676-680.

[34] Kk

[35] Koopmans, T.C. and Beckmann, M. (1957). Assignment problems and the location of economic activities. Econometrica: journal of the Econometric Society, pp.53-76.

[36] Corry, P. and Kozan, E. (2004). Ant colony optimisation for machine layout problems. Computational optimization and applications, 28(3), pp.287-310.

[37] Azarbonyad, H. and Babazadeh, R. (2014). A genetic algorithm for solving quadratic assignment problem (QAP). arXiv preprint arXiv:1405.5050.

[38] Cimikowski, R. and Mooney, E. (1995). Heuristics for a new model of facility layout. Computers & Industrial Engineering, 29(1-4), pp.273-277.