Optimized Assignments for Real-World Problems: Insights from E-Hailing and Healthcare

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Abstract

The assignment problem in operations research is a method to assign a set of agents for a set of tasks to minimize cost or maximize profit. The method proves to be beneficial in various industries and has been used extensively, including in the development of e-hailing mobile applications. In this research, a real-life example application of an assignment problem using the Hungarian method was used to solve the assignment of e-hailing drivers to customers and patients to beds in the healthcare industry. The Hungarian method calculation was also checked with Excel Solver to find the objective function, subject to well-defined constraints. The result of this study shows the optimized matchmaking of the shortest distance between the e-hailing driver and the customer. Another example, minimizing the cost of total expense in assigning patients to specific beds in a hospital. This study also highlighted findings by other researchers using the assignment problem method could be used as a foundation to develop a new heuristics-based method, especially in healthcare management.

Keywords: *Operations research, e-hailing mobile application, healthcare industry, Hungarian method*

1. Introduction

In operations research, the assignment problem is a basic optimization problem that focuses on determining the most effective way to distribute a set of tasks among a group of agents. The objective is to minimize the assignment's total cost or time or to maximize its profit. It typically arises in a variety of real-world scenarios, such as allocating employees to jobs, students to projects, or even allocating resources to tasks in manufacturing scenarios. The conventional version of the assignment problem involves n agents and n tasks, with one task assigned to each agent and one agent assigned to each task [1]. The goal is to find an assignment that minimizes the overall cost. The costs involved in assigning each agent to a certain task are shown in a cost matrix. Finding the most cost-effective matching is the goal of this assignment problem, which can be described as a bipartite graph matching problem with one set of vertices representing the agents and the other set representing the tasks.

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Depending on the task and agent relationships, the assignment problem could appear in a variety of forms. The most basic form is called the Linear Assignment Problem (LAP), in which each agent is given a single task, and the costs are added up in a method that is linear. In the Generalized Assignment Problem (GAP) the agents may have different capacities; some may be able to undertake more jobs than others. The Quadratic Assignment Problem (QAP) is another complicated form in which the cost is determined by the interaction between pairs of tasks, such as the distance between facilities and the movement of supplies between them, in addition to the individual assignments. These modifications broaden the assignment problem's applicability and enable it to cope with increasingly complex real-life scenarios.

The assignment problem can be solved in several ways; the most well-known is the Hungarian Algorithm for the linear case. This algorithm effectively determines the appropriate assignment by gradually altering the cost matrix and locating the best solution in polynomial time. This coincides with findings by [2], whereby the Hungarian Algorithm is effective in maximizing operational efficiency in the military. More complicated approaches, such as Branch and Bound algorithms, which methodically analyze possible solutions, or Integer Linear Programming (ILP) techniques, which structure the issue as a series of linear equations with integer constraints, are frequently needed for more complicated variations like GAP or QAP. In the real world, these algorithms assist companies in resolving a variety of assignment difficulties.

Key Characteristics

The key characteristic of the assignment problem is it is usually expressed as a linear programming problem, with the decision variables representing whether a specific task is allocated to a specific agent. In mathematics, a matrix is frequently used to illustrate the problem, with the tasks represented by the columns and the agents (such as employees or machines) represented by the rows. The cost or benefit of allocating a particular assignment to a particular agent is represented by each element in the matrix. With the restriction that each agent can only be allocated to one task and each task can only be assigned to one agent, the objective function is to minimize the total cost (or maximize the total profit) of the assignments [3, 4].

The classical assignment problem's balanced nature is another key characteristic. The most basic version ensures that no agent is left unassigned and that all tasks may be assigned to agents because the number of agents and tasks is equal. Unbalanced assignment problems, however, could occur in real-life scenarios where there are more tasks than agents or fewer tasks than agents. In these situations, additional dummy tasks or agents are added to ensure that the problem can be resolved within the parameters of a balanced assignment.

The assignment problem also has a linear cost structure, which means that the cost of assigning an agent a task is fixed and unaffected by other assignments. Assignment problems are distinguished by this aspect from other types of optimization problems, such as scheduling or routing, where costs could change depending on previous or ongoing assignments. Another important characteristic is the use of algorithms to solve the assignment problem. One of the most popular and effective techniques for handling this kind of issue is the Hungarian algorithm.

Furthermore, assignment problems are by their very nature combinatorial. They involve testing with various assignment combinations to determine which of them produces the greatest outcome. Even for huge scenarios, the previously mentioned techniques can effectively solve this combined component despite its mathematical complexity.

Example of Assignment Problem in Real-Life Scenarios

The assignment problem is a significant optimization tool that helps organizations increase resource efficiency, cut expenses, and enhance operational outcomes across a range of industries. Because of its variety of practical uses, the assignment problem is an essential tool in fields including workforce management, production, logistics, and education. For example, in many companies, managers are frequently involved with allocating employees to tasks or projects according to their qualifications and experience. Let's say a software corporation could be given a few new projects to finish in addition to a pool of developers, designers, and project managers. Every project has its own set of requirements, and everyone has varying degrees of competence with technologies or tasks [5]. Here, assigning employees to tasks in a way that maximizes output while lowering costs or guaranteeing deadlines is the assignment problem. The difficulty lies in matching the right individual to the proper assignment based on their skills. Algorithms are frequently used to balance workloads and guarantee that each employee is utilized effectively.

Assignment problems are common in the management of hospitals. For example, Schäfer et al. developed a heuristic in operational planning when assigning patients to beds [6]. In a hospital, the assignment of patients to beds requires consideration of several factors that could be constraints in operations research. To maximize the provision of healthcare services or minimize patient waiting times, the assignment problem by utilizing the Hungarian method proves to be useful in efficient management. Other than that, mathematical models using assignment are also being used in the backend of mobile applications. A real-life example is matchmaking by assigning a driver to the customer in an e-hailing application like Grab [7]. The details of the application backend are explained in the next section.

2. Method

One of the most crucial tasks for ride-hailing services (or Grab) is matching the appropriate passengers with the appropriate drivers [7]. Passengers may take longer to get to their destinations, and drivers may lose money if this is carried out less efficiently. The fact that this is an ongoing process with an ongoing supply of new ride requests and drivers becoming available is possibly the most difficult aspect of it all. The example problem discussed in this paper is a typical assignment problem, in which the goal is to match a group of available drivers with a group of passengers who are looking for rides in a way that minimizes the distance from one driver to one customer. Below is an example of a situation where Grab drivers (Drivers 1, 2, and 3) are available while three passengers (Customers 1, 2, and 3) are asking for rides. The distances (in kilometers) between each driver and each customer are listed in Table 1.

Table 1. Matrix of Distance Between e-Hailing Drivers and Customers

	Customer 1	Customer 2	Customer 3
Driver 1	10 km	5 km	8 km
Driver 2	9 km	7 km	4 km
Driver 3	12 km	6 km	9 km

Each driver is situated at a distinct location throughout the city. The goal is to ensure that every customer has an assigned driver, and that each driver can service a maximum of one customer while minimizing the total distance driven by all drivers. To solve this assignment problem, the Hungarian Method can be used, with the assumption that must be considered:

- m = n, which means passengers and drivers are equal in numbers.
- The number of passengers can be given to more than one driver.
- There is a cost associated with each driver and passenger, in this case is the total distance.

Mathematical Model for the Grab Driver Assignment Problem

The mathematical model presented below determines which driver must be assigned to a passenger [1]. The model uses a binary decision variable (x_{ij}). To formulate the integer assignment problem, let

i = the drivers (i = 1, 2, 3)
j = the passengers (j = 1, 2, 3)
x_{ij} = a binary variable indicating if driver i is assigned to passenger j
c_{ij} = cost associated with each unit of x_{ij}
Z = minimum total distance traveled by all assigned drivers

Decision Variable

$$x_{ij} = \begin{cases} 1, \text{ if agent } i \text{ is assigned to task } j \\ 0, \text{ otherwise} \end{cases}$$

Objective Function

The objective function of this assignment problem is to minimize the total assignment cost, i.e., the total distance travelled by all assigned drivers.

$$\text{Minimize } Z = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij}\, x_{ij}$$

For this case,

$$Z = 10x_{i1j1} + 5x_{i1j2} + 8x_{i1j3} + 9x_{i2j1} + 7x_{i2j2} + 4x_{i2j3} + 12x_{i3j1} + 6\, x_{i3j2} + 9x_{i3j3}$$

Constraints

1. Each customer is assigned exactly one driver.

$x_{i1j1} + x_{i2j1} + x_{i3j1} = 1$

$x_{i1j2} + x_{i2j2} + x_{i3j2} = 1$

$x_{i1j3} + x_{i2j3} + x_{i3j3} = 1$

2. Each driver is assigned to at most one customer.

$x_{i1j1} + x_{i1j2} + x_{i1j3} = 1$

$x_{i2j1} + x_{i2j2} + x_{i2j3} = 1$

$x_{i3j1} + x_{i3j2} + x_{i3j3} = 1$

3. Binary restriction on the decision variables, either driver *i* is assigned to customer *j*.

$x_{ij} = 1$

$x_{ij} = 0$

3. Results and Discussion

Solve Using the Hungarian Method

This is a balanced assignment problem solved using the Hungarian Method in the following steps. Table 2 illustrates the initial matrix table.

Table 2. Initial Matrix Table of a Balanced Assignment Problem

	Customer		
Driver	**1**	**2**	**3**
1	10	5	8
2	9	7	4
3	12	6	9

Tables 3 to 5 present the steps to determine the driver assignment to the passenger.

1. Subtract the minimum value for all values in the respective rows of Table 2.

   Row 1: -5 for each value
   Row 2: -4 for each value
   Row 3: -6 for each value

   Table 3 shows the value in each cell after the subtraction of the minimum value in each row.

Table 3. Matrix Table After Step 1

	Customer		
Driver	**1**	**2**	**3**
1	5	0	3
2	5	3	0
3	6	0	3

2. Subtract the minimum value for all values in the respective column of Table 3.

   Column 1: -5 for each value
   Column 2: -0 for each value
   Column 3: -0 for each value

Table 4 shows the value in each cell after the subtraction of the minimum value in each column.

Table 4. Matrix Table After Step 2

	Customer		
Driver	**1**	**2**	**3**
1	0	0	3
2	0	3	0
3	1	0	3

3. Draw a minimum number of horizontal and vertical values to cover all zeros. Table 5 shows that most zeros should be covered with lines.

Table 5. Matrix Table After Step 3.

	Customer		
Driver	**1**	**2**	**3**
1	0	0	3
2	0	3	0
3	1	0	3

4. Table 5 shows that the number of lines drawn to cover all zeros (3) is equal to the number of rows (3), and hence the optimal solution is hidden in the covered zeros.

5. To identify the optimal solution:
   i. Begin with rows or columns that have only one zero. Cross out both the row and column involved.
      - Row 3 has only one zero.
      - Cross out both Row 3 and Column 2.

   ii. Move to the rows and columns that are not yet crossed out, with preference given to any such row or column that has only one zero.
      - Column 3 has only one zero.
      - Cross out Column 3 and Row 2.

Table 6. Matrix Table: Show the Identification of Optimum Solution

	Customer		
Driver	**1**	**2**	**3**
1	0	0	3
2	0	3	0
3	1	0	3

Once the optimal solution is obtained in Table 5, the zero will be picked to signify the minimization of the distance between which driver and which customer. Hence, in Table 6, circled zeros are found to be the most suitable assignment of each driver to passenger. Following on from Table 6, Table 7 shows that the assignment of drivers to customers is as follows:

Grab driver assignment to Customer as follows:

- Driver 1 to Customer 1
- Driver 2 to Customer 3
- Driver 3 to Customer 2

Referring to Table 1, the distances between these assigned drivers and to customer are tabulated in the third column of Table 7. The linear model is solved to obtain the objective function.

Table 7. Result of the Balanced Assignment Problem

Driver	Customer	Distance
1	1	10 km
2	3	4 km
3	2	6 km

Objective Function:

To minimize the total distance for the drivers to be assigned to customers

$Z = (10x1) + (4x1) + (6x1)$

$= 10 + 4 + 6$

$Z = 20$

Solve Using Excel Solver

Figure 1 shows the linear model of the assignment problem being solved using Microsoft Excel Solver. The initial matrix was filled in the upper table, and followed by the automation of the Solver to assign which drivers to which customers. Cell in green shows the value of the objective function, which is similar to per result in 3.1 above.

Grab ride-hailing service							
	Customer A	Customer B	Customer C				
Driver 1	10	5	8				
Driver 2	9	7	4				
Driver 3	12	6	9				
	Customer A	Customer B	Customer C			Supply	Minimize Z
Driver 1	1	0	0	1	=	1	20
Driver 2	0	0	1	1	=	1	
Driver 3	0	1	0	1	=	1	
	1	1	1				
	=	=	=				
demand	1	1	1				

Figure 1. Excel Solver for the Assignment Problem of Grab Drivers to Customers

Case Study

For a real-world case study, a review was conducted on findings by Borchani et al. in the article titled Heuristics-based on the Hungarian method for the patient admission scheduling problem [8]. The improvements are needed to cater to the increasing operational expenses and the demand due to the growing number of admissions into hospitals, due to the increasing population. Originally introduced by Demeester, and later improved by researchers with various heuristic models [8].

In this study, the objective function is to minimize all penalties of three grouped constraints, subject to constraints such as room gender, room preference, room specialism, and more. But the most important constraint is room capacity, which needs to be satisfied for the solution to become feasible. At the end of this paper is the authors come out with 2 heuristics based on the Hungarian method in solving the patient admission scheduling problem.

During the development of a heuristic to assign patients based on their medical profile to room specialisation, the author assigns the patient to individual beds first using the Hungarian method. The following example is seven patients to be assigned to seven beds.

Patient: woman 1 (w1), woman 2 (w2), woman 3 (w3), woman 4 (w4), male 5 (m5), woman 6 (w6), male 7 (m7)

Beds: bed 1 (b1), bed 2 (b2), bed 3 (b4), bed 4 (b4), bed 5 (b5), bed 6 (b6), bed 7 (b7)

Cost Matrix

Table 8 shows the initial matrix of the assignment problem regarding the patient admission scheduling. Rows are the patients who will be assigned to beds in columns. The value in every cell signifies the cost of assigning patients to beds. According to Borchani et al., the cost in the patient admission scheduling is not of monetary value but a measure of inefficiency and penalty associated with assigning patients to beds that do not meet medical requirements and personal preferences [8].

Table 8. The Initial Matrix in Assignment of Patients to Hospital Beds

	b1	b2	b3	b4	b5	b6	b7
w1	0	28	28	108	108	108	108
w2	10	18	18	68	68	68	68
w3	10	8	8	58	58	58	58
w4	10	0	0	30	30	30	30
w5	10	0	0	10	10	10	10
w6	10	0	0	50	50	50	50
w7	10	10	10	50	50	50	50

Mathematical Model

i = The patient (i = 1, 2, 3)
j = The bed (j = 1, 2, 3)
x_{ij} = a binary variable indicating if patient i is assigned to bed j
c_{ij} = cost associated with each unit of x_{ij}
Z = to minimize the total cost associated with the measure of inefficiency and penalty concerning patient admission scheduling

Decision Variables

x_{ij} = 1, if all patient i is assigned to *bed j*.
= 0, for otherwise

Objective Function

Minimize $Z = 0x_{w1,b1} + 28x_{w1,b2} + 28x_{w1,b3} + 108x_{w1,b4} + 108x_{w1,b5} + 108x_{w1,b6} + 108x_{w1,b7} + 10x_{w2,b1} + 18x_{w2,b2} + 18x_{w2,b3} + 68x_{w2,b4} + 68x_{w2,b5} + 68x_{w2,b6} + 68x_{w2,b7} + 10x_{w3,b1} + 8x_{w3,b2} + 8x_{w3,b3} + 58x_{w3,b4} + 58x_{w3,b5} + 58x_{w3,b6} + 58x_{w3,b7} + 10x_{w4,b1} + 0x_{w4,b2} + 0x_{w4,b3} + 30x_{w4,b4} + 30x_{w4,b5} + 30x_{w4,b6} + 30x_{w4,b7} + 10x_{m5,b1} + 0x_{m5,b2} + 0x_{m5,b3} + 10x_{m5,b4} + 10x_{m5,b5} + 10x_{m5,b6} + 10x_{m5,b7} + 10x_{w6,b1} + 0x_{w6,b2} + 0x_{w6,b3} + 50x_{w6,b4} + 50x_{w6,b5} + 50x_{w6,b6} + 50x_{w6,b7} + 10x_{m7,b1} + 10x_{m7,b2} + 10x_{m7,b3} + 50x_{m7,b4} + 50x_{m7,b5} + 50x_{m7,b6} + 50x_{m7,b7}$

Constraints

subject to

1. Each patient is assigned to one bed

$$x_{w1,b1} + x_{w2,b1} + x_{w3,b1} + x_{w4,b1} + x_{m5,b1} + x_{w6,b1} + x_{m7,b1} = 1$$
$$x_{w1,b2} + x_{w2,b2} + x_{w3,b2} + x_{w4,b2} + x_{m5,b2} + x_{w6,b2} + x_{m7,b2} = 1$$
$$x_{w1,b3} + x_{w2,b3} + x_{w3,b3} + x_{w4,b3} + x_{m5,b3} + x_{w6,b3} + x_{m7,b3} = 1$$
$$x_{w1,b4} + x_{w2,b4} + x_{w3,b4} + x_{w4,b4} + x_{m5,b4} + x_{w6,b4} + x_{m7,b4} = 1$$
$$x_{w1,b5} + x_{w2,b5} + x_{w3,b5} + x_{w4,b5} + x_{m5,b5} + x_{w6,b5} + x_{m7,b5} = 1$$
$$x_{w1,b6} + x_{w2,b6} + x_{w3,b6} + x_{w4,b6} + x_{m5,b6} + x_{w6,b6} + x_{m7,b6} = 1$$
$$x_{w1,b7} + x_{w2,b7} + x_{w3,b7} + x_{w4,b7} + x_{m5,b7} + x_{w6,b7} + x_{m7,b7} = 1$$

2. Each bed is assigned to one patient

$$x_{w1,b1} + x_{w1,b2} + x_{w1,b3} + x_{w1,b4} + x_{w1,b5} + x_{w1,b6} + x_{w1,b7} = 1$$
$$x_{w2,b1} + x_{w2,b2} + x_{w2,b3} + x_{w2,b4} + x_{w2,b5} + x_{w2,b6} + x_{w2,b7} = 1$$
$$x_{w3,b1} + x_{w3,b2} + x_{w3,b3} + x_{w3,b4} + x_{w3,b5} + x_{w3,b6} + x_{w3,b7} = 1$$
$$x_{w4,b1} + x_{w4,b2} + x_{w4,b3} + x_{w4,b4} + x_{w4,b5} + x_{w4,b6} + x_{w4,b7} = 1$$
$$x_{m5,b1} + x_{m5,b2} + x_{m5,b3} + x_{m5,b4} + x_{m5,b5} + x_{m5,b6} + x_{m5,b7} = 1$$
$$x_{w6,b1} + x_{w6,b2} + x_{w6,b3} + x_{w6,b4} + x_{w6,b5} + x_{w6,b6} + x_{w6,b7} = 1$$
$$x_{m7,b1} + x_{m7,b2} + x_{m7,b3} + x_{m7,b4} + x_{m7,b5} + x_{m7,b6} + x_{m7,b7} = 1$$

3. Non-negativity, each decision variable is binary $x_{ij} \in \{0,1\}$.

Solve Using Excel Solver

Figure 2 shows the linear model of the patient admission scheduling assignment problem in the study by Borchani et al. being solved using Microsoft Excel Solver [8]. The initial matrix of the total cost associated with the measure of inefficiency and penalty concerning patient admission scheduling was filled in the upper table. Followed by the lower table shows the result of the Solver to assign patients to beds. The cell in green shows the value of the objective function after the linear model was solved.

Patient Assignment Scheduling

	b1	b2	b3	b4	b5	b6	b7
w1	0	28	28	108	108	108	108
w2	10	18	18	68	68	68	68
w3	10	8	8	58	58	58	58
w4	10	0	0	30	30	30	30
m5	10	0	0	10	10	10	10
w6	10	0	0	50	50	50	50
m7	10	10	10	50	50	50	50

	b1	b2	b3	b4	b5	b6	b7			Supply	Minimize Z
w1	**1**	0	0	0	0	0	0	1	=	1	166
w2	0	**1**	0	0	0	0	0	1	=	1	
w3	0	0	**1**	0	0	0	0	1	=	1	
w4	0	0	0	**1**	0	0	0	1	=	1	
m5	0	0	0	0	**1**	0	0	1	=	1	
w6	0	0	0	0	0	**1**	0	1	=	1	
m7	0	0	0	0	0	0	**1**	1	=	1	
	1	1	1	1	1	1	1				
	=	=	=	=	=	=	=				
demand	1	1	1	1	1	1	1				

Figure 2. Excel Solver for Assignment of Patients to Beds

The minimum cost associated with the measure of inefficiency and penalty concerning patient admission scheduling is as follows:

Z=(0x1) + (18x1) + (8x1) + (30x1) + (10x1) + (50x1) + (50x1)

Z=166

Patient assignment to bed is as follows:

- w1 to b1
- w2 to b2
- w3 to b3
- w4 to b4
- m5 to b5
- w6 to b6
- m7 to b7

The benefit of applying the operation research technique, specifically the Hungarian method, to the patient admission scheduling problem is that it helps a lot in minimizing the total cost associated with the measure of inefficiency and penalty concerning patient admission scheduling when assigning patients to specific beds. As a result, the problem developed by Demeester, available online, helped other researchers to develop heuristics based on the Hungarian method for optimum management of patient admission while controlling the cost [9].

5. Conclusion

In this study, it is proved that an assignment problem could be utilized to solve a real-world situation, such as in e-hailing and healthcare industries. By using the Hungarian method, an optimal solution obtained and can assign the drivers to passengers for an e-hailing company and the matching of patients and hospitals to their bed allocation. The assignment problem could be used for future research to develop advanced heuristic-based methods in health, since increasing operational demands require solutions for sustainable management. Due to the features and applications of the assignment problem, it is an excellent tool to improve operational efficiency by minimizing costs and improving service delivery through the optimization of total distances for e-hailing drivers and effective flow management of patient admissions. These contributions put in perspective how operations research technique, such as the assignment problem, might be of help in solving complex problems in many industries.

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