A Decision Making Model for Performance Evaluation and Profit Sharing in a Diagnostic Laboratory Network

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Abstract

Rationale, aims and objectives Creating networked business models is one of the innovative approaches that have the ability and potential for meeting market needs. The purpose of this study is to provide a decision making model for a fair profit sharing among the members of a diagnostic laboratory network while providing a distinctive value for the patients. Methods To identify the members of the network of laboratories, a suitable approach to calculate members' efficiency scores is proposed. Then, the network members are classified into three groups based on their performance scores. The three groups help administrators identify eligible members, members who need to improve their performance in order to meet the minimum requirements, and members who do not qualify for admission to the network. Since the performance of the members should play a significant role in the fair profit sharing mechanism, the fair allocation of profits among network members is done by the use of Shapely's value based on the efficiency scores of members. Results The results show that for such a fair mechanism, the efficiency and sample size (the number of samples (blood, urine) taken from the patients by the laboratories), as the two effective factors, have a decisive role in the share of profit of laboratory units of the network. In the Laboratory Services Network, members receive a number of samples according to their performance. As a result, the sample size received has a direct impact on the net income of each member. Conclusion In conclusion, it is evident that the use of Shapely value may help managers in the process of sharing profits among network members in a fair way, thereby improving network performance. In this way, incentive strategies may be created for the members of the network and long-term survival of the network may be achieved.

1. Introduction

In recent years, the trend for the development of small and medium enterprises (SMEs) has increased dramatically. One of the fundamental solutions that has been considered in scientific circles for organizing SMEs is the aggregation of these firms and their organization in the form of networks. In other words, by merging companies that operate in similar or related fields, it may be possible to benefit from synergy effects, modernization and increasing its competitiveness, attracting foreign investment and novel technologies. However, the remarkable point is that many of the new possibilities and advantages for those who take part in such co-operations are derived from synergy effects 1. In this new era, presence and activity in networks has become vital for organizations, as co-operation by sharing resources leads to an increase in the capacity of organizations and this, in turn, boosts the ability of organizations to achieve common objectives and interests. Therefore, operation of organizations and companies in the framework of networked businesses is an important factor in meeting market demands 2. The numerous benefits of presence and activity within networks have led organizations to set up network businesses and we are now witnessing the birth and growth of specialized and public networks in various industries and business domains.

The increase of expenses in the diagnostic services sector and the inability of patients to pay for lab services lead to increased pressure on the government to finance health services. In such a situation, laboratories have no competitive advantage and need fundamental changes. Laboratories should significantly lower their expenses and manage their resources in an efficient way. Therefore, the cooperation of laboratories within the framework of a network provides the possibility of lowering the costs (constant and variable), more efficient use of resources in order to offer optimal services, creating competitive advantage for the members of the lab network, and consequently an increase in the income for the whole network and thus for individual labs. Nowadays, efforts have been made to convert laboratory structures into networks, and in this paper two examples of laboratories that have benefited from a network approach are Quest and Dr. Lal. Quest, which is based in the US and has 2200 branches, is ranked as one of the top companies by Fortune and is ranked in the top 12 companies offering laboratory services 3. The lab network Dr. Lal, a unified lab network with a reference lab in Delhi, has over 190 diagnosis labs in 2017 4. From the standpoint of operational capacity in 2015, the network has gathered and processed 21.8 million samples from 7.7 million patients, which is a key advantage for Dr. Lal among its rivals 5.

The variety in laboratory types makes the profitability and allocation of their resources to face the several challenges that impact the sustainability of the laboratory and ultimately, the provision of services. Currently, one of the challenges facing diagnostic networks is to achieve a collaborative network that allocates fair profit among network members. As such, all members expect to receive a fair share of the profits. Therefore, the mechanism of distribution of profits should be based upon the principle of equality. Each member should be aware that the profit they receive is determined by the amount of their contribution. In cooperation networks made up of various players, profit distribution in the network is often based on factors that build the common infrastructure. An understanding of the factors effecting profit distribution leads to the growth of the network and increasing opportunities for benefit and share-holder satisfaction of network policies. Therefore, the prognosis labs network must identify the factors that are necessary to produce a common infrastructure up to the growth stage. With a fair approach to profit distribution, the profit assigned to each lab unit within the network is determined by the amount of cooperation and contribution made by that member.

Inequality in profit distribution has caused some networks to disintegrate. Thus, the fair, objective, and effective distribution of profits is a growing concern for managers. It has been established by numerous studies that profit distribution is in the interests of partners. Therefore, to the best of our knowledge, modern game theory is the best option to address this concern. In cooperative games, we need a solution concept that gives rise to a unique outcome. This endows our model with predictive power 6. One way of looking for a unique solution is Shapely value 7 that makes sure that a fair distribution of benefits will be achieved in accordance with the contribution of each member, thus encouraging the old-time maxims of hard work and equality.

This paper presents a game theory model called the Shapley Value Model to distribute profits among members of the medical diagnostic labs network. For this purpose, first, the network members are determined by k-means clustering algorithm as one of the most important and most used algorithms in literature. Then, the proposed profit-sharing model calculates the profit of each laboratory and provides decision makers with more reliable information on the profit share of each member of the network.

The remainder of the paper is organized as follows. In Section 2, the research method is explained. Then, in Section 3, a case study is described. In Section 3, first, how to select the network members is described, and then a proposed approach is used to divide the profits among the members of the network. Finally, the analysis of the results is discussed. Section 4, concludes the paper and introduce some future research suggestions.

2. Research method

In this study, the research method is designed in four stages. In the first step, is the clustering of laboratory units using the K-means clustering method based on the performance scores obtained by Ghafari Someh et al. 8. Finally, the second step proposes an approach towards profit sharing for members of the laboratory network using Shapley's value. In Fig. 1, the research methodology is divided into two phases.

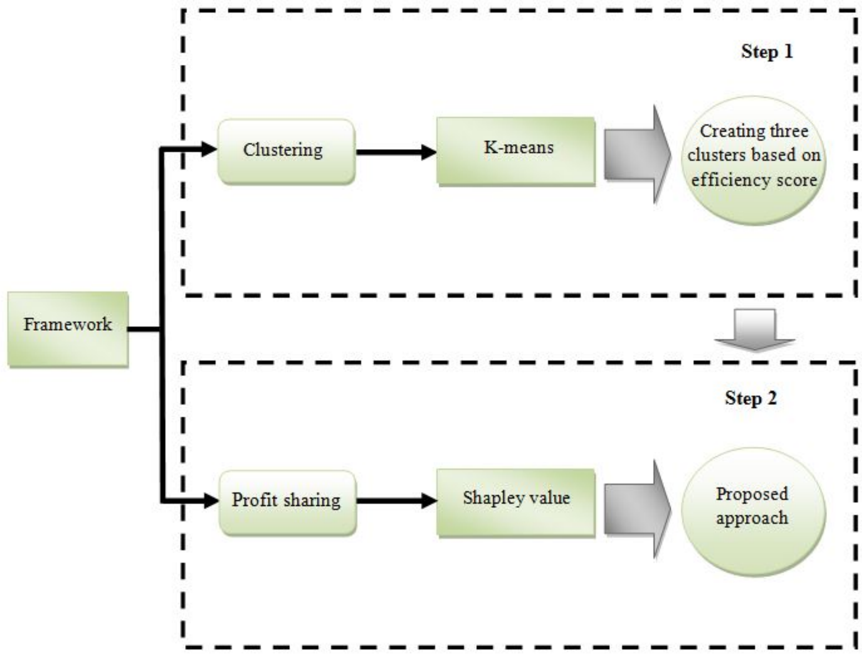

Fig 1. Steps in the research method

2.1 Clustering

Cluster analysis is a classification technique for forming groups in a complex set of data that does not rely on any presuppositions about the number or structure of groups. In cluster analysis, membership in groups is unknown for all observations, and even the number of groups is unclear. The purpose of this technique is to identify homogeneous groups. Groups are determined in such a way that the degree of consistency between members of the same group is strong and the degree of consistency among members of different groups is weak. Therefore, cluster analysis is an effective tool in scientific and management research that groups a set of data into a d-dimensional space so that the similarity in the clusters is maximized and the consistency between the two different clusters is minimized 9. Therefore, clustering can be of great help to managers in selecting units for the diagnostic network. In this study, we performed clustering based on the efficiency score of the labs.

There are various clustering methods that are used in a wide range. Among the clustering algorithms, the K-Means method is a very common method for partitioning. The K-Means method is one of the methods of data clustering in data mining. This method is a unique and flat method. For this algorithm, different forms have been expressed. But all of them have a repetitive process that attempts to obtain central points for clusters in a number of fixed clusters, which are in fact the same as the average of points belonging to each cluster, as well as to assign each data sample to a cluster, in a way that the data sample has the minimum distance to the center of that cluster. In the K-Means algorithm, initially k members (k is the number of clusters) are randomly selected from the n members as cluster centers. Then the n-k remaining members are assigned to the nearest cluster. After assigning all members, the cluster centers are recalculated and the members are assigned to the clusters according to the new centers, and this continues until the centers of each cluster remain constant. The best clustering is one that maximizes the total similarity between the cluster center and all cluster members, and minimizes the overall similarity between cluster centers.

In this research, we use expert opinion to classify laboratory units using the k-means method. It should be noted that the grouping is based on the performance scores of the laboratory units.

2.2 Profit sharing

Profit sharing is one of the essential factors in determining the value of a company. The term profit sharing refers to company's decisions regarding the payment of benefits to shareholders of the company, in other words, the distribution of profits, size and model of cash payments to shareholders 10. Therefore, the decision of the company to decide how much dividends can be distributed to shareholders is a matter of the profit sharing policy. The healthcare industry as one of the active and effective sectors can be a great source for reducing costs and increasing profitability through the implementation of laboratory networks. For profit sharing, factors that are necessary for the network of diagnostic laboratories for joint infrastructure development up to the stage of growth should be identified and an appropriate mechanism should be developed among the members of the network. According to the experts, the criteria used to determine the factors influencing profit sharing are as shown in Fig. 2.

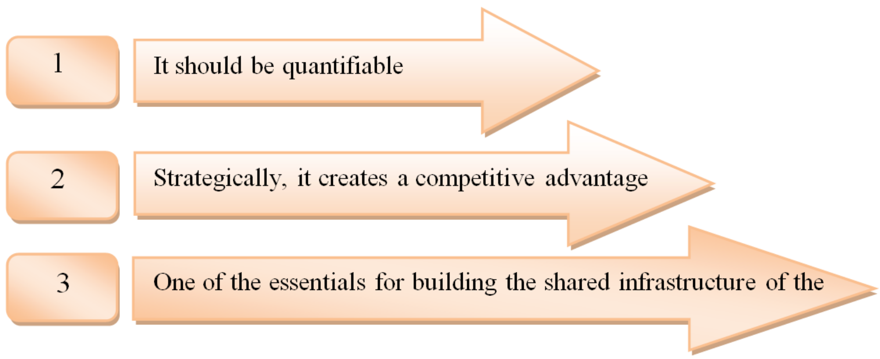

Fig 2. Selection criteria for effective factors for profit sharing Effective factors in the network of laboratories for the development of shared infrastructure are evaluated in accordance with Table 1 to identify those factors among them that have all the proposed criteria for the profit sharing.

Table1. Evaluation of effective factors in the profit sharing

Criterion / Factors	It should be quantifiable	Strategically, it creates a competitive advantage	One of the essentials for building the shared infrastructure of the network
Efficiency	✓	✓	✓
Human resources	✓	✓	
Sample size	✓	✓	✓
Importance of status of partners in the network			✓

According to Table 1, two factors of sample size and performance score are among the factors that have all the criteria considered and are selected for the allocation of profits.

2.2.1 Shapley's value

In this study, labs are considered to be players who work together to obtain maximum value. Therefore, according to the two factors of sample size and the efficiency score, the value of the coalition of laboratories is obtained according to formula 1.

$$v\,(\text{Lab }1) = n_1\ f_1,\ v\,(\text{Lab }2) = n_2\ f_2\ ,\ldots..,v\,(\text{Lab }25) = n_{25}\ f_{25} \qquad (1)$$

$$v\,(Lab1\ \cup Lab\ 2) = f_{12}\,(n_{12})\,,\ v\,(Lab\ 2\ \cup Lab\ 3) = f_{23}\,(n_{23})\ \ ,\ldots,$$
$$v\,(Lab\ 24\ \cup Lab\ 25) = f_{24\ 25}\,(n_{24\ 25})$$
$$\vdots$$
$$v\,(Lab1\ \cup Lab\ 2\ \cup \ldots\ \cup Lab\ 25) = f_{1\ 2\ldots 25}\ (n_{1\ 2\ 3\ldots 25})$$

According to Formula 1, the value of each laboratory is calculated from the product of the efficiency and sample size. For the calculation of binary, triplet and finally twenty-five-tuple values, it is suggested that by aggregating the labs in the form of a reference laboratory, the efficiency of different permutations from the aggregation of laboratories be calculated. For example, by aggregating laboratories 1 and 2 into a reference laboratory, the reference laboratory's efficiency can be calculated as f_{12}. Shapley 11 is a desirable approach that results in a unique result, and hence its predictive power is reasonable. Therefore, the value of each laboratory is obtained as follows:

$$\varphi_i\,(v) = \sum_{S\subset N} \frac{(m-1)!\ (n-m)!}{n!}\ \ [v\,(s) - v\,(s - \{i\})] \qquad (2)$$

Where m is the number of members of the coalition S, n is the number of members of the set N, S- {i} is a coalition that does not belong to i 12.

Since each laboratory's share is calculated based on expected cash flows, but these cash flows are uncertain, Shapley's value can support this profit sharing. Thus, the profit of each laboratory is predicted by the weighted average of the value of each laboratory in the laboratory net income according to formula 3.

$$\pi_i = \frac{\varphi_i(\text{Lab i})}{\varphi_1(Lab\ \ 1)+\varphi_2(Lab\ \ 2)+\ldots+\varphi_{25}(Lab25)} * IN \quad , \quad i = 1,2,\ldots,25$$

In formula 3, φ_i (Lab i) is the value of each laboratory and IN is the net income of the laboratory network.

3. Case study

The diversification and expansion of specialized laboratories in Tehran has led to increased activity in this field. According to the statistics released by the Iranian Health Reference Laboratory, the volume of laboratory services market in Tehran is 16.6% of the total share of the country, which represents a significant contribution. The share of medical diagnostic laboratories Tehran in the public and private sectors is 29% and 71%, respectively. Considering the importance of the private sector, the statistical population of this study consists of 25 private medical diagnostic laboratories in Tehran province.

After evaluating the performance of 25 units of laboratory, based on the performance scores by Ghafari Someh et al. 8, the laboratory units were divide into three clusters by using K-means method. The results show that 10 laboratory units belong to the first group, 5 laboratory units belong to the second group and 10 laboratory units belong to the third group. Finally, the 10 laboratory units belonging to the first group make up a laboratory network and 5 laboratory units in the second group use strategic planning to join the network, and the 10 laboratory units in the third group have no chance of joining the network and can be deleted. Table 2 and Figure 3 show clustering of 25 laboratory units using the k-means method.

Table2. Clustering 25 medical diagnostic laboratories

K-means label	Labs
1	1
1	2
1	3
3	4
1	5
2	6
1	7
3	8
3	9
2	10
1	11
3	12
1	13
3	14
2	15
2	16
3	17
3	18
3	19
3	20
2	21
1	22
3	23
1	24
1	25

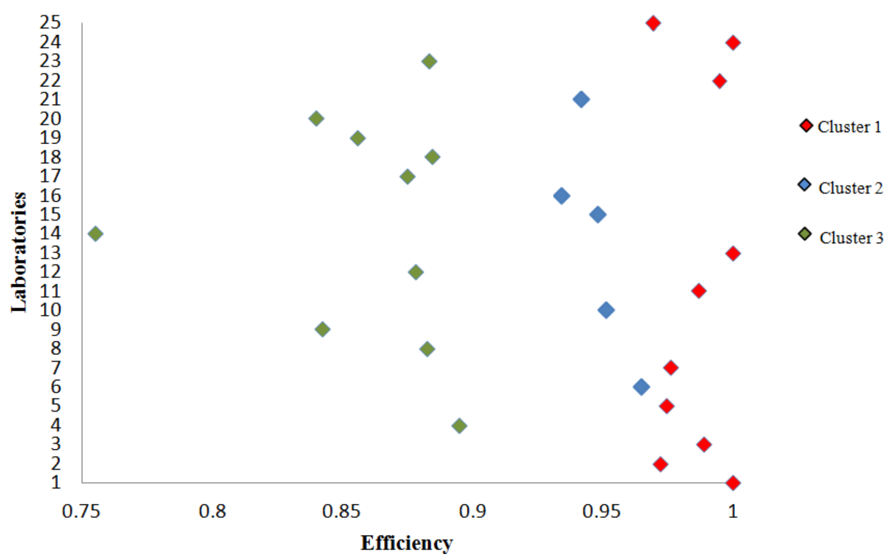

Fig 3. Clustering 25 medical diagnostic laboratories

Fig. 3 shows that the laboratories 22, 24, 25, 1, 2, 3, 5, 7, 11, 13 marked in red are in the first cluster. The laboratory units 21,16,6,10,15 marked in blue are in the second cluster and the laboratories 23,20,18,19,17,12,14,4,8,9 marked in green are in the third cluster.

Given the collaborative mechanism among the members of the laboratory network, an important factor in the continued collaboration of the members in the network is profit sharing based on fair principles among the members. To predict the contribution of each laboratory to the laboratories network, different combinations of coalitions are calculated by two effective factors of the sample size and efficiency, and then, with the help of Shapely's value, the value of each laboratory is obtained. Finally, the profit of each member is calculated by the average weighted value of each laboratory in the income of the network.

To describe the proposed profit sharing approach in the network, let us consider, for simplicity, a set of three laboratories (labs A, B, and C) that constitute a laboratory network.

Table 3 shows the values of different combinations of coalitions. These coalitions are based on two factors (sample size and performance score) that play a decisive role in predicting the contribution of each lab to the network.

Table3. Coalition values

Coalition quantity	Coalition
914	V(A)
15740	V(B)
10182	V(C)
17749	V(AB)
18662	V(AC)
21273	V(BC)
30305	V(ABC)

Table 4 shows the value of each laboratory according to the different combinations of coalitions calculated by Shapley's value function. Note that each of Shapley values represents the amount of that member's cooperation in the network.

Table4. Shapley's value of each laboratory

Lab C	Lab B	Lab A	
0.439	0.390	0.172	Percentage of profit per of laboratory
438531739	389876445	171591816	Profit per of laboratory

If we assume the net income to be ten billion rials (Iranian currency) in the next year, the profit share of each laboratory is predictable by multiplying the weighted average value of each laboratory unit in the network income according to Table 5.

Table5. Profit of each laboratory

According to section 2.2.1, using Shapely's value method, profit sharing was done among members of the diagnostic laboratory network. Table 5 shows the results of profit sharing in a numerical example. In Table 5, the profit of each laboratory is equal to the weighted average of the Shapely's values of laboratories (Table 4). In Table 5, the profit sharing is represented by both percentages and earnings. We assume that if the income of this diagnostic network is ten billion Rials throughout the next year, then it would be possible to predict the profits of laboratories using the percentage of each laboratory's profit.

The profit sharing results show that the better the performance of the labs, the greater the level of satisfaction of patients, because the accuracy of the test results is an effective factor in the selection of laboratories by patients. In this case, by increasing the level of performance of laboratories, the number of samples of these centers has increased, which has a direct impact on the amount of network income. Therefore, the collaboration between the laboratories will increase their efficiency by sharing resources, thus increasing the quality of the results of the tests of these centers, the number of patients and, eventually, the sample size of these centers. Table 3 shows the increasing utility of coalitions with the arrival of a laboratory in each coalition.

In collaborative networks of various actors, a mechanism based on equality is often used to profit profit sharing in the network. In cooperative games, Shapley's value has the nature of fair profit sharing. Since the network of medical diagnostics laboratories, through promotion of cooperation among members, has the properties of a cooperation network, the Shapely approach helps to predict the fair profit sharing among network members. The results show that for such a fair mechanism, the efficiency and sample size, as the two effective factors, have a decisive role in the share of profit of laboratory units of the network because in the laboratory services network, members receive a number of samples according to their performance, which has a direct impact on net income. In this case, trying to make more money by network members should be in such a way as to meet the needs of the network for its lifecycle. Hence, to set up and maintain a diagnostic network, managers are advised to consider the following: (1) Selected criteria for profit sharing must be quantitative in nature in order to be measurable. Therefore, the number of samples and the efficiency, as two effective factors, can have an effective role in the profit sharing of network members. (2) Given the lifecycle of the network of the diagnosis laboratories and the requirements for the network formation stage, the resources used to share profits should be the requirements for the establishment of a shared network of diagnostic laboratories. Therefore, performance evaluation in identifying requirements for network infrastructure will help to create appropriate infrastructure for demand and ultimately increase sample size. (3) Since profit sharing has a strategic property, profit sharing in the network life cycle should create competitive advantage and provide an incentive for attracting and investing members from a strategic perspective, which is also effective in improving member performance and ultimately in accepting more sample numbers.

4. Discussion

In this study, 25 laboratories were nominated to form a laboratory network. The initial condition for determining the members of the network is to calculate the efficiency values of the laboratory units. For this reason, we used the efficiency values calculated by Ghafari Someh et al. 8. Then, by assigning the performance scores to the three clusters by the k-means algorithm, we determine the network members. In the first cluster we put members who can form a network, the second cluster includes members who need to have a strategy for improvement in order to be accepted in the network, and the third cluster includes members who have no chance of joining the network. Since the network depends on the cooperation of the members, we use a cooperative game called Shapley's value which has the advantage of fair profit sharing, and we propose a method for dividing profit. The results show that managers can improve network performance by sharing fair profits among network members, and in addition to network survival, they can create incentive strategies for members of the network.

A limitation exists in this research. In a real-world situation, we are faced with risk and uncertainty in healthcare systems. Therefore, labs efficiency score might not correspond to actual values in this study. Therefore, several interesting directions can be further studied. The network of collaboration in an uncertain environment should be considered and the use of uncertain DEA methods, such as Fuzzy DEA, interval DEA, and robust DEA, may also be investigated and compared.

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