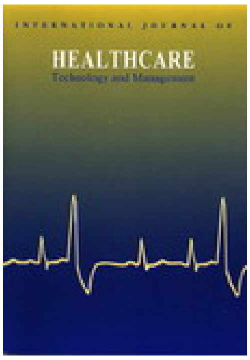

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# Sustainable healthcare information exchanges network design: a scenario-based planning approach

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# Sustainable healthcare information exchanges network design: a scenario-based planning approach

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**Abstract:** As information technology becomes widely embedded in all areas of healthcare operations, healthcare providers have found that patient information sharing is imperative to the sustainability of health organisations. This can be achieved using a healthcare information exchange (HIE). When an agent decides to join the health network, a subscription fee is paid to the HIE for access to services. There are many challenges to creating an effective healthcare information exchange network. This involves understanding the sustainability of the HIE network as well as the dynamic behaviour of healthcare information exchanges. The effect of the uncertainty may increase the infeasibility of the solution. Accordingly, the current study aims to examine the sustainability of the HIE network with uncertain demand. The modelling and solution deal with scenarios-based demand uncertainty, operating costs, and revenues. The computational analyses show the satisfactory performance and the effectiveness of the proposed approach for obtaining a high sustainability level.

**Keywords:** well-established optimisation; HIE; healthcare information exchange; healthcare provider; scenario-based planning approach; robust optimisation; network design.

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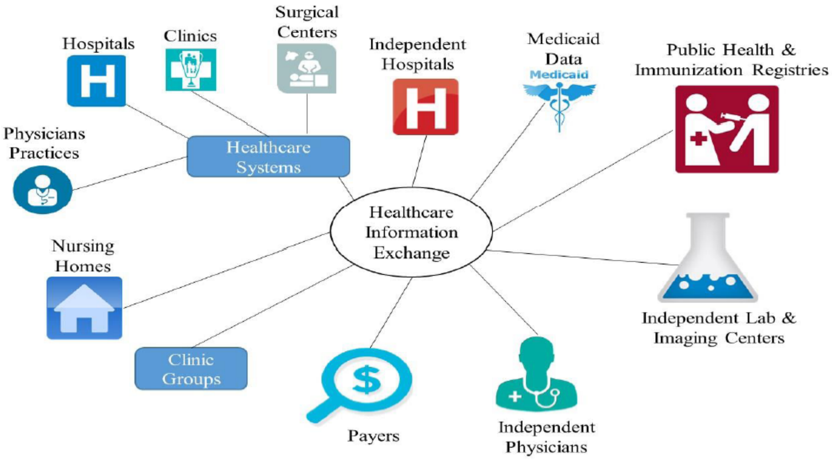
## 1 Introduction

The healthcare information exchange (HIE) is a complex network for sharing patient information in heterogeneous organisations via the electronic health record (EHR) (Fontaine et al., 2010). In general, the HIE network consists of three agents (Sridhar et al., 2012):

1. Healthcare providers (HCP) who are suppliers of healthcare patients, such as hospitals, laboratories, and imaging centers.
2. The HIE owns information and controls the process of information exchange between all agents.
3. Insurance agents who pay insurance contracts (Figure 1). Both insurance agents and HCPs pay the cost of subscribing to the healthcare information exchanges (HIEs).

Today, healthcare systems face several challenges; the hardest one is to reduce the risk of loss of information. Although hospitals have been advancing towards using advanced information technology such as EHR, the risk of losing information cannot still be ignored (Smith et al., 2005). This can lead to issues such as retesting and unnecessary visits to patients (Table 1). Joining the HIE network helps HCPs prevent such topics by integrating EHRs into a database. Therefore, the patient records are available to each of the HCP who are members of the HIE network; e.g., when a patient goes to a healthcare center, and they cannot diagnose correctly, the doctor can use the HIE database to retrieve medical records. As a result, unnecessary healthcare procedure is prevented. In general, HIE can help HCPs by recovering the patient, reducing unnecessary health processes, saving on health costs, and preventing medical errors (Ahmed, 2016).

**Figure 1** HIE network (see online version for colours)



*Source*: Adapted from West Virginia Health Information Network (http://www.wvhin.org/services/health-information-exchange/default.aspx)

**Table 1** The effects of missing patient information by HCP

| *Healthcare procedure* | *% raised by Missing Information* |
|---|---|
| Delay in treatment | 25.52% |
| Additional laboratory tests | 22.31% |
| Extra visit | 20.94% |
| Additional imaging studies | 10.92% |
| Medical errors | 18.06% |
| Unnecessary hospitalisation | 13.08% |

*Source*: Witter (2010), Kaelber and Bates (2007) and Sridhar et al. (2012)

All existing modelling approaches are limited to certain conditions for the HIE network problem under study. However, the amount of demand in the network and the amount of time needed to process information vary in different conditions. In other words, in real-world situations, some parameters (e.g., demand, costs of processing information) cannot be determined. Therefore, this study seeks to address various issues of the HIE network in uncertain environments. This paper studies the sustainability of the HIE network in uncertainty conditions, which is modelled using robust scenario-based optimisation.

There are various approaches to estimating uncertainty in mathematical planning, including stochastic programming and robust methods. The stochastic programming method is a viable solution by using a decision tree and evaluation of all scenarios. As the dimension of the program expands exponentially in this method, the solving approach becomes difficult. As such, a robust optimisation approach needs to be undertaken. Robust scenario-based optimisation is not a new method, but recent advances in this method make it easier to solve decision-making problems under uncertainty. In a robust method, one or more parameters are considered uncertain, and the problem is solved in such a way that the solution is feasible and its objective function does not differ significantly from the optimal value.

The remainder of this paper is categorised as follows. The next section contains the literature review. Section 3 includes the problem definition. Section 4 introduces the proposed model and solution. Finally, Section 5 presents some general conclusions and future guides.

## 2 Literature review

Previous HIE studies are divided into quantitative and qualitative research. Qualitative studies address issues of cost, challenges, and benefits of HIE systems based on the experience of experts. Vest and Gamm (2010) discussed the challenge of creating an HIE network. They have described the technologies that have already supported the HIE network. Foldy (2007) stated that creating the HIE network involves external and internal challenges. Lee and Garvin (2003) discuss the challenges of using two-way channels of information movement rather than one-way information movement. These challenges can be social, ethical, or technological. Kaelber and Bates (2007) studied the role of the HIE network in recovering patients. It has been argued that using HIE services in laboratories, pharmacies, imaging centers, hospitals, and clinics will improve patients by reducing the risk of information loss. Herwehe et al. (2012) found that the relationship between clinics and hospitals would allow HCPs to be aware of patients who have had an infection with immunodeficiency and immune deficiency syndrome (AIDS/HIV) and who have not received medication in the last 12 months.

Quantitative studies are divided into descriptive and prescriptive ones. In descriptive studies, simple statistical approaches are applied to analyse HIE networks. Frisse and Holmes (2007) collected 13-month data from the emergency department in Memphis, located in Tennessee, to estimate HIE's profits. Such data consists of laboratory tests, radiological tests, CT scans, and echocardiograms. Bailey et al. (2013) collected emergency department visits from 1 August, 2007, to 31 July, 2009, to specify whether joining the HIE network reduces the number of repetitive tests. They found that 22.4% of tests were unnecessary and thus could be prevented. Adler-Milstein et al. (2008) conducted an evaluation study to consider the activities of the Regional Health Information Organizations (RHIOs), such as data type, type of costs and revenues, and type of agents, and their findings were in line with those mentioned above.

In prescriptive studies, advanced approaches have been used to study the HIE network, such as mathematical modelling and simulation. Berman et al. (Berman et al., 2001) presented a linear programming formulation for estimating HIE network profits from the owner's point of view. Brennan et al. (2005) proposed a MIP approach to model the financial outcomes of joining the network. Merrill et al. (2013) used system dynamics to investigate the implementation of the HIE process for reporting public health at New York Department of Health. The result is that cooperation between the private sector and the governmental sector is the most significant issue that helps to achieve the main objective.

However, all studies have been conducted assuming that customer demand has been fixed, while agents may leave the HIE network. It is considered that the environment is static (Ahmed, 2016). Therefore, this study aims to study the sustainability of the HIE network with uncertain demand. At the beginning of each year, HCPs are permitted to leave the network and add new ones to the network. In the following section, a stochastic planning approach is proposed to model the mentioned problem.

## 3 Problem definition

The Health Network plans to establish several HIEs in a set of potential locations ($I$) to serve a set of HCPs ($J$). The cost of establishing a HIE is $c_i$ in place $i \in I$. The demand for any HCP $j \in J$ is equivalent $d_j$ which is met by an HIE, and the cost of each unmet demand unit for the health network is $q$. This cost is because some of the HCPs have not yet joined the HIE network while patients visit them; therefore, HIEs are not able to provide information about these HCPs.

The objective is to locate HIEs before customer demand is known, so that the total cost of creating HIEs, serving patients, and imposing a penalty for unmet demand is minimised.

# 4 Proposed model

## 4.1 Assumptions

1 the studied network includes two agents: HCPs and HIEs

2 after determining the locations of agents in the network, a stochastic planning model is used by providers to estimate the number and size of services

3 the capacity of the HIE is unlimited.

## 4.2 Mathematical notation

### 4.2.1 Sets

$I$ set of the potential locations for the establishment of the HIE

$J$ set of the HCPs

$S$ set of possible uncertain scenarios

### 4.2.2 Parameters

$c_i$: Fixed cost of HIE $i \in I$

$f_i^s$: Variable cost of HIE $i \in I$ and under scenario $s \in S$

$r_j^s$: The amount the HCP $j \in J$ pays for using the HIE under the scenario $s \in S$

$d_j^s$: The demand of any HCP $j \in J$ from the HIE under the scenario $s \in S$

$q$: The unit cost of each demand is not met

$p^s$: The probability of the scenario $s \in S$

### 4.2.3 Decision variables

$$\delta_i^s \begin{cases} 1 & \text{If the HIE } i \in I \text{ is established under the scenario } s \in S \\ 0 & \text{Otherwise} \end{cases}$$

$x_{ij}^s$: Numbers of patients go to the HCP $j \in J$ under the scenario $s \in S$, and the HCP $j \in J$ receives information from the HIE $i \in I$.

$v_j^s$: Numbers of patients go to the HCP $j \in J$ under the scenario $s \in S$, but the HCP $j \in J$ cannot be held accountable.

$g^s$: The bonus calculated for each response to the patient under the scenario $s \in S$.

### *4.3 Mathematical formulation*

The objective function (1) shows the amount of fixed and variable costs, the penalty for not meeting the demand, and the bonus paid by the government. The fixed (base) fee includes the cost of establishing an HIE, and the variable cost or subscription fee includes the cost of maintaining and operating the HIE (Covich et al., 2011). In addition to subscription fees, the HIE network can receive a financial bonus from the government. Part of the bonus depends on the size of the network, which is given by the formula.

Constraint (2) shows that the sum of the number of patients whose demands are met and the number of patients whose demands are not met, is equal to the total patients' demand. Constraint (3) states that in order for sustainability in the health network, the benefit should be greater than zero. Constraint (4) guarantees that if HIE *i* is established, the service is available. *M* is a large positive number and can be equal to all demand. Constraint (5) specifies the maximum amount of governmental bonus, and constraints (6) and (7) present decision variables of the proposed model.

According to the above description, the model is presented as follows:

$$MaxF_s = -\sum_{i\in I} c_i \delta_i^s + \sum_{i\in I}\sum_{j\in J}(r_j^s - f_i^s)\,\mathrm{x}_{ij}^s - \sum_{s\in S}(p^s \sum_{j\in J} q \times v_j^s) + \sum_{s\in S}(p^s \sum_{j\in J} g^s \times d_j^s)$$
$$\forall s \in S \tag{1}$$

$$\sum_{i\in I} x_{ij}^s + v_j^s = d_j^s \quad \forall j \in J, \forall s \in S \tag{2}$$

$$-\sum_{i\in I} c_i \delta_i^s + \sum_{i\in I}\sum_{j\in J}(r_j^s - f_i^s)\,\mathrm{x}_{ij}^s - \sum_{s\in S}(p^s \sum_{j\in J} q \times v_j^s) + \sum_{s\in S}(p^s \sum_{j\in J} g^s \times d_j^s) \geq 0 \quad \forall s \in S \tag{3}$$

$$\sum_{j\in J} x_{ij}^s \leq M\delta_i^s \quad \forall i \in I, \forall s \in S \tag{4}$$

$$g^s \prec f_i^s \quad \forall i \in I, \forall s \in S \tag{5}$$

$$\delta_i^s \in \{0,1\} \quad \forall i \in I, \forall s \in S \tag{6}$$

$$v_j^s, x_{ij}^s, g^s \geq 0 \quad \forall i \in I, \forall j \in J, \forall s \in S \tag{7}$$

## 5 Solution approach

It is evident from the model presented in Section 4.3 that some of the parameters may follow different scenarios. Therefore, in order to solve this formulation, a robust scenario-based optimisation approach has been applied to cover all possible scenarios to deal with the inherent uncertainty and complexity of the HIE network design.

### *5.1 Robust scenario-based optimisation*

Based on Mulvey and Ruszczynski (1995), a robust solution and a robust model are two critical components of a robust optimisation model. A solution to the optimisation formulation is called a robust solution if it remains close to optimal for all input data scenarios and it is feasible for almost all input scenarios. Given these concepts and definitions, a robust optimisation formulation is being modelled uniquely. As such, two distinct parts of a robust optimisation formulation can be presented as follows:

1 *Structural section*: It is fixed and free of noise in its input data.

2 *Control section*: The function is subjected to volatile and oscillatory data.

The optimisation formulation has the following structure:

$$Min \qquad C^T X + d^T X \tag{8}$$

$$\text{subject to} \qquad AX = b \tag{9}$$

$$BX + CY = e \tag{10}$$

$$X, Y \geq 0 \tag{11}$$

Constraint (8) denotes structural constraints with constant coefficients and no noise or oscillation. Constraint (9) represents control constraints. The coefficients of these constraints are oscillatory. Constraint (10) guarantees that decision variables remain non-negative. To formulate a robust optimisation problem, a set of scenarios is established as follows:

$$\Omega = \{1, 2, \ldots, s\}$$

Proportionate to each scenario $s \in \Omega$ and set $\{d_s, B_s, C_s, e_s\}$ can be related, and the probability of occurrence of each scenario is $P_s$.

$$\sum_{s=1}^{S} P_s = 1 \tag{12}$$

The general form of the robust optimisation formulation of Mulvey and Ruszczynski (1995) is as follows:

$$Min \ \ \sigma\left(X, Y_1, Y_2, \ldots, Y_S\right) + \omega p(Z_1, Z_2, \ldots, Z_3) \tag{13}$$

$$\text{subject to} \qquad AX = b \tag{14}$$

$$B_S X + C_S Y_S + Z_S = e_S \quad \text{for all} \tag{15}$$

$$X, Y \geq 0 \qquad \text{for all } s \in \Omega \tag{16}$$

In the robust model (13), the set $\left\{y_1, y_2, y_3, \ldots, y_S\right\}$ is a set of control variables for each scenario $s \in \Omega$. Also $\{Z_1, Z_2, Z_3, \ldots, Z_S\}$ is a set of error vectors that measure the permitted infeasibility of the control constraints under the scenario*s*. According to multiple scenarios, the objective function $\xi = C^T X + d^T Y$ is a stochastic variable that takes $\xi_s = C^T X + d_s^T Y_s$ with probability $P_s$. The exchange between the robustness of the solution and the robustness of the model is determined by the concept of multi-criteria decision making. The above-mentioned robust optimisation model can measure the amount of this exchange (Talaei et al., 2016).

The second term in the objective function, $p\{Z_1, Z_2, \ldots, Z_s\}$ is a penalty function to penalise any violations of the constraints, so that no infeasible solutions are created during the optimisation process. Also, using weight $\omega$, the equilibrium and the exchange between robustness of a answer and robustness of a model can be modelled under a multi-criteria decision-making process.

The expression $\sigma(x, Y_1, Y_2, \ldots, Y_S)$ presented by Mulvey et al. (Mulvey and Ruszczynski, 1995) includes the mean value plus the constant value $\lambda$ multiple variances, as we have:

$$\sigma(X, Y_1, Y_2, ..., Y_S) = \sum_{s=1}^{S} P_s \times \xi_s + \lambda \times \left[ \sum_{s=1}^{S} P_s \times \left( \xi_s - \sum_{s=1}^{S} P_s \times \xi_s \right)^2 \right] \tag{17}$$

The above expression contains a quadratic function. Yu and Li (2000) suggested the following formulation:

$$\sigma(X, Y_1, Y_2, ..., Y_S) = \sum_{s=1}^{S} P_s \times \xi_s + \lambda \times \sum_{s=1}^{S} P_s \times \left| \xi_s - \sum_{s=1}^{S} P_s \times \xi_s \right| \tag{18}$$

This objective function is still nonlinear; therefore, it can be modified to the linear function by adding two non-negative deviations variables. According to Yu and Li's approach, instead of minimising the absolute deviation reference from the mean of the two functions mentioned above, concerning the constraints, the two variables of deviation are minimised. Yu and Li provided an effective solution based on a goal programming approach. It is as follows (equations (19)–(21)):

$$Min = \sum_{s=1}^{S} P_s \times \xi_s + \lambda \times \left[ \sum_{s=1}^{S} P_s \times \left( \left( \xi_s - \sum_{s=1}^{S} P_s \times \xi_s \right) + 2 \times \theta_s \right) \right] \tag{19}$$

subject to

$$\xi_s - \sum_{s'=1}^{S} P_{s'} \times \xi_{s'} + \theta_s \geq 0 \tag{20}$$

$$\theta_s \geq 0 \text{ and integer} \tag{21}$$

The Yu and Li's approach transforms the robust model into a linear model with $m + n$ additional variables ($n$ the number of scenarios and $m$ the number of control constraints), while the proposed model of Mulvey et al. requires $2m + 2n$ decision variables.

## 5.2 Proposed robust model

As stated, the objective function of the HIE network design tends to maximise profits and contains uncertainty parameters and can be written using a robust optimisation method:

$$Max = \sum_{s \in \Omega} Ps.Fs - \lambda \sum_{s \in \Omega} Ps. \left[ \left( Fs - \sum_{s \in \Omega} Ps.Fs \right) + 2\theta_s \right] \tag{22}$$

Constraints (2) to (7)

$$Fs - \sum_{s \in \Omega} Ps.Fs + \theta_s \geq 0 \tag{23}$$

$$\theta_s \geq 0 \text{ and integer} \tag{24}$$

where $P_S$ is the probability of the scenario $s$ and $F_S$ is determined by equation (25). The first term of equation (22) is the expected operating cost. The second term is the variance of the cost, weighted by the parameter $\lambda$. Equations (23) and (24) are used for the linearisation of variance, as stated earlier.

$$Fs = \sum_{i}\sum_{j}(r_j^s - f_i^s)x_{ij}^s + \sum_{j} d_j^s \times g^s - \sum_{i} c_i \times \delta_i^s - \sum_{j} q \times v_j^s \tag{25}$$

## 6 Case study

This paper examines the proposed model due to selecting a 10-member set of potential locations to establish a HIEs network in Iran. These places are located in Tehran, Isfahan, Shiraz, Mashhad, Yazd, Kerman, Kish, Rasht, Sari, and Tabriz, which are the most populated in Iran (Figure 2). Also, in this model, it was assumed that the number of HCPs for admitting patients is a group of 10 members, including the pharmacy of 13th Aban in Tehran, Isfahan University of Medical Sciences clinic, Bu-Ali Shiraz Hospital, Mashhad Pathobiology Lab, Emergency Department of Shahid Sadoughi Hospital in Yazd, Shahid Bahonar Hospital in Kerman, Clinic Imam Ali Kish, Al-Zahra Maternity Hospital in Rasht, Sari Social Security Clinic and Paraclinika Tabriz Social Security. Each customer's demand depends on the local economic conditions (Abdolazimi et al., 2020; Abdolazimi et al., 2020). According to the data of annual inflation rate derived by sanction effect and politician strategies, for the future, three types of economic scenarios are defined: bad, moderate, and good, with a probability of occurrence of 0.5, 0.3, and 0.2, respectively, as predetermined by decision-makers. Table 2 demonstrates HCP demands for each of the scenarios.

**Figure 2** Location of HCPs (see online version for colours)

Remark:

There are no standards for rendering Persian provincial names into English. These change from one map to the other, including the Iranian ones, which use various improvised French phonetic spelling and Tehrani pronunciation. Here, the names most commonly and traditionally used in English language have been adopted.

The values of uniformly needed parameters are as follows:

$$d_j^s = uniform(40000, 70000)$$

$$f_i^s = uniform(12000, 14000)$$

$$r_j^s = uniform(100000, 140000)$$

**Table 2** The demand of any HCP from the HIE

| $d_j^s$ | *1=bad* | *2=moderate* | *3=good* |
|---|---|---|---|
| $d_1^s$ | 40000 | 45000 | 50000 |
| $d_2^s$ | 54000 | 58000 | 62000 |
| $d_3^s$ | 39000 | 42000 | 45000 |
| $d_4^s$ | 32000 | 40000 | 48000 |
| $d_5^s$ | 49000 | 52000 | 55000 |
| $d_6^s$ | 50000 | 55000 | 60000 |
| $d_7^s$ | 55000 | 60000 | 65000 |
| $d_8^s$ | 45000 | 50000 | 55000 |
| $d_9^s$ | 60000 | 65000 | 70000 |
| $d_{10}^s$ | 55000 | 60000 | 65000 |

The government approves the same budgets for all cities because of justice. So, the variable cost of all HIEs, variable $f_i$, regardless of location, the number of participants, and the number of transactions, is a uniform distribution between 12,000, to 14,000. The amount the HCP pays for using the HIE is 10000, 12000 and 14000 for good, moderate, and bad scenarios, respectively, for any HCP. As well as the fixed cost of establishing information exchange centers (see Table 3).

**Table 3** Fixed cost for establishment of HIE (in a million units of currency)

| *Information exchange centers* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* |
|---|---|---|---|---|---|---|---|---|---|---|
| Construction cost | 12 | 11.5 | 10 | 11 | 10.5 | 10 | 13 | 12.5 | 12.8 | 11.8 |

In order to solve the proposed model in this study, GAMS software version 24.7.3 and CPLEX solver have been used. The values of zero and one are shown in Table 4.

**Table 4** Zero and one variable values

| *Variable* | *Scenario* | | |
|---|---|---|---|
| $\delta_i^s$ | *1=bad* | *2=moderate* | *3=good* |
| $\delta_1^s$ | 0 | 0 | 0 |
| $\delta_2^s$ | 0 | 0 | 0 |
| $\delta_3^s$ | 0 | 1 | 0 |
| $\delta_4^s$ | 0 | 0 | 1 |
| $\delta_5^s$ | 0 | 0 | 1 |
| $\delta_6^s$ | 1 | 1 | 1 |
| $\delta_7^s$ | 0 | 0 | 1 |
| $\delta_8^s$ | 0 | 0 | 0 |
| $\delta_9^s$ | 0 | 0 | 1 |
| $\delta_{10}^s$ | 0 | 0 | 0 |

Table 5 shows the values of positive variables. The government bonus for each scenario is given at the beginning of Table 5.

**Table 5** Positive variable value

| | | | | | | | *Scenario* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *1* | | | *2* | | | *3* | |
| $g^s$ | | | | *12000* | | | *2127* | | | *0* | |
| *Scenario 1* | | | | | | | *J* | | | | |
| $x_{ij}^s$ | | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* |
| *İ* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 50000 | 62000 | 45000 | 48000 | 0 | 60000 | 65000 | 55000 | 70000 | 65000 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 5** Positive variable value (continued)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *Scenario* | | | | | | | |
| | | | *1* | | | *2* | | | *3* | | |
| $g^s$ | | | *12000* | | | *2127* | | | *0* | | |
| *Scenario 2* | | | | | | *J* | | | | | |
| $x_{ij}^s$ | | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* |
| *İ* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 52000 | 55000 | 0 | 0 | 0 | 60000 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 45000 | 58000 | 42000 | 40000 | 0 | 0 | 60000 | 50000 | 65000 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Scenario 3* | | | | | | *j* | | | | | |
| $x_{ij}^s$ | | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* |
| *i* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 39000 | 0 | 0 | 0 | 0 | 45000 | 0 | 0 |
| | 5 | 0 | 54000 | 0 | 0 | 49000 | 50000 | 0 | 0 | 60000 | 0 |
| | 6 | 27580 | 58000 | 0 | 32000 | 0 | 0 | 0 | 0 | 0 | 55000 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 55000 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Variable* | | | | | | *Scenario* | | | | | |
| $v_j^s$ | | | 1 | | | | 2 | | | 3 | |
| $v_1^s$ | | | 0 | | | | 0 | | | 12419 | |
| $v_2^s$ | | | 0 | | | | 0 | | | 0 | |
| $v_3^s$ | | | 0 | | | | 0 | | | 0 | |
| $v_4^s$ | | | 0 | | | | 0 | | | 0 | |
| $v_5^s$ | | | 0 | | | | 0 | | | 0 | |
| $v_6^s$ | | | 0 | | | | 0 | | | 0 | |
| $v_7^s$ | | | 0 | | | | 0 | | | 0 | |
| $v_8^s$ | | | 0 | | | | 0 | | | 0 | |
| $v_9^s$ | | | 0 | | | | 0 | | | 0 | |
| $v_{10}^s$ | | | 0 | | | | 0 | | | 0 | |

Furthermore, the cost and revenue of each scenario can be separately shown, which indicates the particular importance of each scenario. From the difference in costs and revenues, the profit from each scenario will be achieved, as shown in Table 6. Given the probability of occurrence of each scenario and the new objective function defined in Section 5.2, the objective function value is 57,490,000,000 (Monetary Unit (MU)). By comparing the profit from each scenario and the objective function value, we conclude that the model has a high sustainability level.

**Table 6** Results from each scenario

| *Scenario* | *1* | *2* | *3* |
|---|---|---|---|
| Revenue | 57,500,000,000 | 57,510,000,000 | 58,790,000,000 |
| Cost | 10,000,000 | 20,000,000 | 1,292,200,000 |
| Profit | 57,490,000,000 | 57,490,000,000 | 57,490,800,000 |

## 7 Conclusion

The HIE is formed by a group of contributors from a specific area or region. An HIE includes electronic information flows among HCPs such as clinics, hospitals, and laboratories. In addition, health information exchanges provide HCPs with accurate information and this information is available at the right time. As a result, medical information is available to doctors and nurses to make informed decisions. In addition, costs are significantly reduced because of the elimination of retesting, paper, ink, prescription, repeated phone, and follow-up of labs.

When network demand is unknown, the environment is stochastic, and sustainability in such an environment is one of the challenges of creating a robust HIE. In this paper, we tried to determine which health information exchanges are located in one of the candidate areas to maximise the profitability and sustainability of the HIE network by using a robust scenario-based optimisation based on three types of good, medium, and bad scenarios.

For further research, the cost of repairing and maintaining equipment for HIE can be considered in the model. Also, the proposed model does not include inaccurate diagnostic costs and incomplete information, which can be added as an extension to the model. Finally, providers can include cross-country hospitals and clinics, and other types of treatment centers, and can distinguish between them in terms of the type and amount of demand.

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## Compliance with ethical standards

Authors declare that they have no conflict of interest.

## Ethical approval

This paper does not contain any studies with human participants performed by any authors.

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