Evaluation and Improvement of Healthcare Systems

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Summary

To evaluate the effectiveness of healthcare systems, we describe metrics in three categories: resources, performance, and inequity. In the Incomplete-Induction Model, we use the Variance Analysis method to evaluate the significance of each metric. The four most important metrics are the percentage of GDP spent on healthcare, the ratio of general government expenditure on health to private expenditure, health-adjusted life expectancy, and health inequity.

We combine the metrics into two integrative metrics, the ratio of resources to performance, and health inequity, using the Analytical Hierarchy Process. The two metrics make up the Evaluation Vector.

To compare the effectiveness of different health systems by means of the Evaluation Vector, we construct two comparison models. In Model 1, we compare based on relative disparity. In Model 2, we introduce a coordinate system in which a vector stands for a healthcare system. The effectiveness of the system is reflected by the length of the vector: A smaller length stands for a better system.

In Task IV and Task V, we choose Brazil for its good healthcare system and India for its poor one. According to the two comparison models, both systems are better than that of the U.S. Then we analyze the relationship between resources and system effectiveness in order to explain why the Indian system is better.

In Task VI, we analyze the U.S. system and put forward suggestions

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to improve it. Then we build a model to investigate the influence of the changes. In addition, we measure the historical change in the system. Generally, its effectiveness is increasing, but the growth rate is slower recently.

We also analyze the strengths and weaknesses of each model.

Solution of Task 1

Description and Analysis

We put forward a method to measure a country's healthcare system. To simplify the problem, we first abstract the system as a simplified input-output system (**Figure 1**).

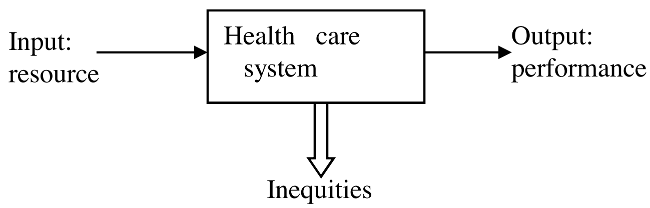

Figure 1. Healthcare as a simplified input-output system.

Sufficient resources should be put in to guarantee that the system functions well. Viewed in isolation, the more resources the system gets, the better it will be. However, linked to output, the better system is not the one with more resources but the one with a low input-output ratio. Later we discuss how to use the metric of resources to measure a healthcare system.

Output reflects the system's performance: The better the system is, the more output it will produce; we define performance later.

How the system operates can't be ignored, since that affects the whole health situation of the country, such as the distribution of resources and the health level in different areas. These factors will be expressed by the metric of Inequities.

Metrics

Resources

A good healthcare system needs adequate resources: human resources, material resources, and financial resources:

- **Human resources** are the population engaged in medical careers, including physicians, nurses, pharmacists, and other health workers.
- **Material resources** are the hardware facilities in the medical system, such as hospitals and hospital beds.

- **Financial resources** include three aspects:
  - The percentage of GDP spent on healthcare.
  - The percentage of total government expenditure spent on healthcare.
  - The ratio of government spending to private spending on health. Apparently, in a good health system this ratio is high.

Performance

- **Health level.** The main objective of a health system is improving health [WHO 2001]. We choose *disability-adjusted life expectancy (DALE)* and infant mortality as criteria, the combination of which can be used to evaluate the level of health.
  - Disability-adjusted life expectancy. DALE is the life expectancy at birth adjusted for disability [WHO 2001]. It is a comprehensive measure of the global burden of disease and the trends of population health level [Mathers et al. 2001].
  - Infant mortality rates. Infant mortality rate is a significant indicator of medical level: High-medical-level countries have a low infant mortality rate.
- **Health-service coverage.** Health-service coverage comprises several factors, such as the immunization coverage of 1-year-olds and the percentage of the population with public insurance. A good health system should provide healthcare for all of its citizens. Usually, developed countries have high rates in the both of those.
- **Responsiveness.** Responsiveness measures how the system performs relative to non-health aspects, meeting or not meeting a population's expectation of how it should be treated [WHO 2001]. The notion of responsiveness is composed of seven elements, including [WHO 2001]:
  - respect for dignity,
  - confidentiality,
  - autonomy to participate in choices about one's own health,
  - prompt attention,
  - amenities of adequate quality,
  - access to social support networks, and
  - freedom to select which individual or organization delivers one's care.

  The seven points above lead to a general metric of responsiveness. In part II we discuss how to combine them.

Inequities

- **Inequities in health.** A healthcare system is not so perfect if the health level varies widely between different categories of the population, even in countries with a rather good health status on average [WHO 2001].To describe inequities in health, we use life expectancy in terms of age, race, gender, socioeconomic class, and so on. If every category has the same life expectancy, the system is fair in terms of health level.

- **Inequities in responsiveness.** The same as health level: If some people are treated with courtesy and others are not, there are inequities in responsiveness.

- **Fairness of financial contribution.** To be fair, the expenditure each household faces should be distributed according to ability to pay rather than by risk of illness [WHO 2001]. That means that a household should not become impoverished to obtain healthcare, and rich households should pay more towards the system than poor households [Gakidou et al. 2000].

The Combination of Metrics

We devise a composite measure of the three metrics: Resources, Performance, and Inequities.

Analytical Hierarchy Process

- **Divide layers.** We divide the metrics into several layers as **Figures 2–5** show.

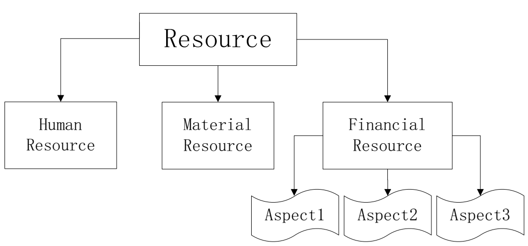

Figure 2. Resources.

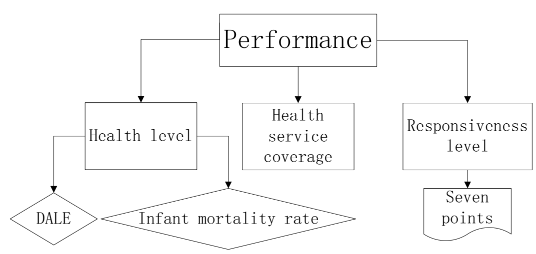

Figure 3. Performance.

- **Evaluation Vector.** A good system should use the least resources possible to produce performance, therefore we use the ratio of Resources to Performance to evaluate the system's effectiveness.

  The other metric is the inequity index. Since the two metrics may not have the same magnitude, it is not appropriate to add or multiply them.

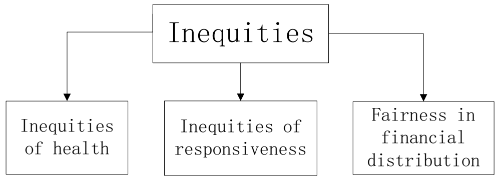

Figure 4. Inequities.

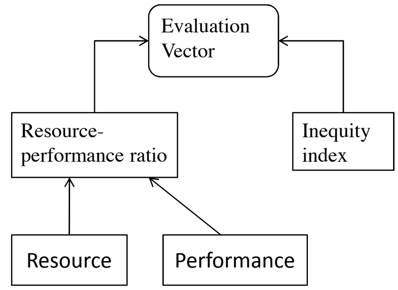

Figure 5. Evaluation.

Hence, we form an evaluation vector (EV) consisting of the two metrics:

$$\text{EV} = \left(\frac{\text{resources}}{\text{performance}}, \ \text{inequities} \right).$$

This is our final composite measure to evaluate the effectiveness of a healthcare system. When both components of the vector are lower, the system is better.

Determine Weights

We specify the calculation of one metric, Resources; the others can be calculated in the same way. After comparing the effect of two criteria in the same layer to the higher layer, we can construct the conjugated-comparative matrix with Saaty's Rule [Jiang 1993]. For example, a_{12} can indicate the difference of the effect on Resources between Human Resources and Financial Resources. Let M_1 be the conjugated-comparative matrix of Resources, while the elements of M_2 are Financial Resources:

$$M_1 = \begin{bmatrix} 1 & 2 & 3 \\ \frac{1}{2} & 1 & 2 \\ \frac{1}{3} & \frac{1}{2} & 1 \end{bmatrix}, \qquad M_2 = \begin{bmatrix} 1 & 1 & 2 \\ 1 & 1 & 1 \\ \frac{1}{2} & 1 & 1 \end{bmatrix}.$$

After calculation of the matrix using the summation method [Jiang 1993], we obtain the weight vectors:

$$w_1 = (.539, \ .297, \ .164), \qquad w_2 = (.41, \ .33, \ .26).$$

So we can form the formulas:

$$\begin{aligned} \text{Resources} &= .539 \times \text{FR} + .297 \times \text{HR} + .164 \times \text{MR}, \\ \text{FinancialResources} &= .41 \times \text{Asp}_1 + .33 \times \text{Asp}_2 + .26 \times \text{Asp}_3, \end{aligned}$$

where our notations are defined in **Table 1**.

Table 1.
Symbols used.

Abbreviations	Meaning
HR	Human resources
MR	Material resources
FR	Financial resources
HL	Health level
HSC	Health service coverage
RL	Responsiveness level
DALE	Disability-adjusted life expectancy
HALE	Health-adjusted life expectancy
IMR	Infant mortality rate
IH	Inequities of health
IR	Inequities of responsiveness
I	Inequities metric
R	Responsiveness metric
FFD	Fairness in financial distribution
Asp_i	Seven aspects of responsiveness
HL	Health level
RP	Resources/performance ratio
EV	Evaluation vector
L	Length of the evaluation vector
TH	Total expenditure on health as % of GDP
GHtoPH	Ratio of government expenditure on health care to private expenditure
GHtoG	Government expenditure on health as percentage of total government expenditure

Formulas

Using a similar method, we arrive at equations as follows:

$$\begin{aligned}
\text{Performance} &= .49 \times \text{HL} + .31 \times \text{HCS} + .2 \times \text{RL}, \\
\text{HealthLevel} &= .6 \times \text{DALE} + .4 \times (1 - \text{IMR}), \\
\text{Responsiveness} &= \frac{1}{7} \sum_{i=1}^{7} \text{Asp}_i, \\
\text{Inequities} &= .4 \times \text{IH} + .4 \times \text{IR} + .2 \times \text{FFD}.
\end{aligned}$$

With these formulas and our basic criterion, we easily get the evaluation vector to evaluate the effectiveness of a healthcare system.

Strengths and Weaknesses

The Analytical Hierarchy Process method is a good combination of qualitative and quantitative analysis, and it gives the weights conveniently. But it possesses a certain subjectivity.

Solution of Task II

Modify the List of Metrics and Calculate Each

In Task I, we listed three total metrics and several small metrics. But data for some metrics are unavailable, so we need to modify our list of metrics. In this task, we take the U.S. as an example.

Data Disposal

For the sake of consistency, we need to process the original data, which we denote as V_{original}.

Step 1: Find the maximum and minimum values in the whole table, denoted by $V_{\max}$ and $V_{\min}$. The adjusted value is

$$V_{\text{adjusted}} = \frac{V_{\text{original}} - V_{\min}}{V_{\max} - V_{\min}}.$$

Step 2: If the metric has only one factor, we can simply use V_{adjusted}. If the metric consists of several factors, we should give each one the weight as determined in Task 1.

Neglected Metrics

We neglect the metrics of responsiveness inequities and fairness of financial contribution because we lack data.

To quantify responsiveness, WHO surveyed 35 countries, giving scores in seven aspects; but data for the U.S. are absent [WHO 2007]. Thus, we delete this factor. Without the metric of responsiveness, we should adjust the weights in calculating the metric Performance:

$$\text{Performance} = .613 \times \text{HL} + .387 \times \text{HCS},$$

Selected Metrics

- Resources
  - Human resources (**Table 2**):

    $$\text{HR} = .25(\text{physicians} + \text{nurses} + \text{dentists} + \text{pharmacists}),$$

    where the numbers are measured per thousand of population.
  - Material resources (**Table 3**): We choose hospital beds per 10,000 population to reflect the amount of material resources.

Table 2.

Human resources (per thousand of population).

Year: 2000	Physicians	Nurses	Dentists	Pharmacists
U.S.	2.56	9.37	1.63	0.88
Max, 35 countries	5.91	15.2	1.63	3.14
Min, 35 countries	0.02	0.11	0	0
Normalized U.S. value	.43	.61	1	.28

Table 3.

Material resources (hospital beds per 10,000).

Year: 2003	Beds
U.S.	33
Max, 35 countries	1324
Min, 35 countries	2
Normalized U.S. value	.24

– Financial resources (**Table 4**):
  - ∗ TH = Total expenditure on health as % of GDP
  - ∗ GHtoPH = Ratio of government expenditure on health care to private expenditure
  - ∗ GHtoG = Government expenditure on health as percentage of total government expenditure.

$$\text{FR} = \text{Financial resources} = .33\text{TH} + .41\text{GHtoPH} + .26\text{GHtoG}.$$

Since by the usual calculation the normalization result for GHtoPH turns out to be extremely exceptional, we calculate it instead by

$$V_{\text{adjusted}} = \frac{\ln V_{\text{original}} - \ln V_{\min}}{\ln V_{\max} - \ln V_{\min}}.$$

Table 4.

Financial resources as percentage of GDP.

Year: 2004	TH %	GHtoPH %/%	GHtoG %
U.S.	15.4	44.7/55.3	18.9
Max, 35 countries	16.6	98.8/1.2	33.4
Min, 35 countries	1.6	12.9/87.1	1.4
Normalized U.S. value	.92	.27	.55

- Performance
  - Health level (**Table 5**):
    - Disability-adjusted life expectancy (DALE): In our data, there is no information about DALE. So we use HALE, health-adjusted life expectancy, to substitute for it.

$$\text{HL} = \text{Health level} = .6\text{HALE} + .4(1 - \text{IMR}).$$

    - Infant mortality.

Table 5.
Health level.

	HALE (2002) Male	Female	Ave.	Infant mortality (2005) per 1000 live births
U.S.	67	71		7
Max, 35 countries	72	78		165
Min, 35 countries	27	30		2
Normalized U.S. value	.89	.85	.87	.031

  - Health service coverage (**Table 6**):
    We choose percentage of immunization coverages to evaluate the level of health service coverage, plus TB treatment success:
    - Measles = immunization coverage among one-year-olds with one dose of measles
    - Diphtheria = immunization coverage among one-year-olds with three doses of diphtheria, tetanus toxoid and pertussis (DTP3)
    - HepB3 = immunization coverage among one-year-olds with three doses of Hepatitis B (HepB3)
    - TB = tuberculosis treatment success (%)

$$\text{Coverage} = .25(\text{Measles} + \text{Diphtheria} + \text{HepB} + \text{TB}).$$

Table 6.
Health service coverage (percentages).

	Measles (2005)	Diphtheria (2005)	HepB3 (2005)	TB (2004)
U.S.	93	96	92	61
Max, 35 countries	99	99	99	100
Min, 35 countries	23	8	20	9
Normalized U.S. value	.92	.97	.91	.61

- Inequities

  We choose probability of dying aged < 5 years per 1,000 live births (under-5 mortality rate) by place (rural or urban). To our disappointment, data are not available or not applicable Africa, the Americas, and Europe. Therefore, to analyze the healthcare system in the U.S., we use "infant mortality by race" to indicate inequity.

Table 7.

Health inequity in the U.S.: Under-5 mortality in 2004.

	Under-5 mortality	Normalized (relative to Black/AA)
White	5.7	.12
Black or African-American	13.2	1
American Indian or Alaska Native	8.4	.44
Asian or Pacific Islander	4.7	.09
Hispanic or Latino	6.5	.67

Table 7 shows high variability, indicating disparity among races and consequent severe health inequity.

Comparison of Healthcare Systems

We construct two models to compare the effectiveness of healthcare systems.

Model 1

Let EV_i be the evaluation vector of system i: $\mathrm{EV}_i = (R_i, I_i)$, where R_i is ratio of Resources to Performance and I_i is the inequity index.

Design of the Model

We construct the comparison function

$$f(\mathrm{EV}_1, \mathrm{EV}_2) = \frac{R_2 - R_1}{\max(R_1, R_2)} + \frac{I_2 - I_1}{\max(I_1, I_2)}.$$

The first term is the relative disparity of resources-performance ratio between two systems. The second term is the relative disparity of inequity index between two systems.

If $f(\mathrm{EV}_1, \mathrm{EV}_2) > 0$, then system 1 is better than system 2.

Model Expansion

In our function, the two metrics—resources/performance ratio and inequity index—have equal weight. They could be weighted otherwise.

Model 2

Basic Assumption and Symbol Definition

As before, EV is the evaluation vector with components R (ratio of Resources to Performance) and I (index of inequity). The length of the vector, $L = \sqrt{R^2 + I^2}$, measures the effectiveness of the healthcare system.

Basic Model

All the points on the same circle have the same length (**Figure 6**); in other words, the systems have the same effectiveness. Consequently, a system could adjust internal resources distribution; it could sacrifice the resources/performance ratio to improve the inequity index, or vice versa.

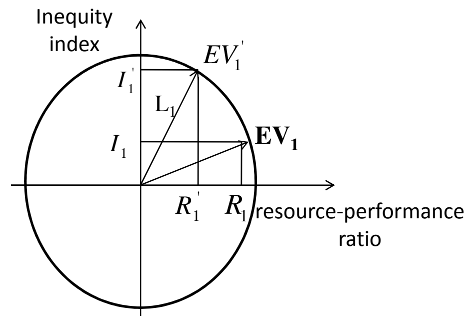

Figure 6. Two healthcare systems of equal effectiveness.

To compare systems, we draw concentric circles according to the evaluation vectors. A system with a smaller circle is better.

Strengths and Weaknesses

Model 1

- The calculation in Model 1 is simple and clear. The model can be easily understood.
- Model 1 could be used to compare any two healthcare systems.
- The weights of resources/performance ratio and inequity index can be adjusted flexibly.

Model 2

- Compared to Model 1, Model 2 is more visual and intuitive.
- Further development of Model 2 can deal with two indexes not of the same order of magnitude. [EDITOR'S NOTE: We omit this elaboration.]
- In Model 2, the weights of resources/performance ratio and inequity index are equal.

Solution of Task III

The Incomplete-Induction Model

In Task 2, we modified the list of metrics. However, some metrics are not so important. We now use the Incomplete-Induction Model to select them most important metrics.

We select metrics that are applicable to most countries' systems. According to the WHO [2001], the metric Inequities is indispensable in evaluating the effectiveness of health system. So we need to choose other metrics only from among the 14 in the two major factors Resources and Performance.

Design of the Model

Step 1: Choose N countries to analyze.

Step 2: For each country i, obtain the resources/performance ratio RP_i^0 (the first component of the evaluation vector) by the method of Task II.

Step 3: Delete the jth metric and calculate RP_i^j using the other 13 metrics.

Step 4: Let $P_j = \sum_{i=1}^{N} \left(\mathrm{RP}_i^j - \mathrm{RP}_i^0\right)^2$.

Step 5: Choose the metrics associated with the two (or more) largest P_js.

Step 6: Some metrics belong to Resources while others belong to Performance. So we need to adjust the metrics if the metrics we have selected are all from Resources or all from Performance.

Result

We choose for our analysis 10 countries, from different regions of different continents, from different levels of development, and with different healthcare systems. In other words, they are representative in the whole world: Argentina, Egypt, Finland, Ghana, Honduras, Japan, Syria, Thailand, and the U.S.

The three metrics with the highest values of P_j are all submetrics of Resources. Consequently, we go with the first two only and substitute for the third the fourth-ranking metric, which is from Performance. Including the metric for Inequity that we regard as mandatory, the set of four metrics is:

- $M_1 =$ total expenditure on health as percentage of GDP,
- $M_2 =$ ratio of public to private expenditure on health,
- $M_3 =$ HALE, and
- $M_4 =$ Inequities.

Application

The resources/performance ratio R can be expressed in terms of the four selected metrics as

$$R = \frac{.446M_1 + .554M_2}{M_3}.$$

where the weights calculated in Task 2 are adjusted through the following method:

$$\frac{.33}{.33 + .41}, \qquad \frac{.41}{.33 + .41}.$$

In Task IV, we discuss how to calculate the metric for inequities.

Measure the Historical Change

We use the four selected metrics to evaluate a system's historical change; we take the U.S. as our example.

The Change of M_1 and M_2

We show the variation trend of M_1 and M_2 in **Figure 7**. Their values increase, which means that the whole nation (especially the government) has attached increasing importance to medical treatment.

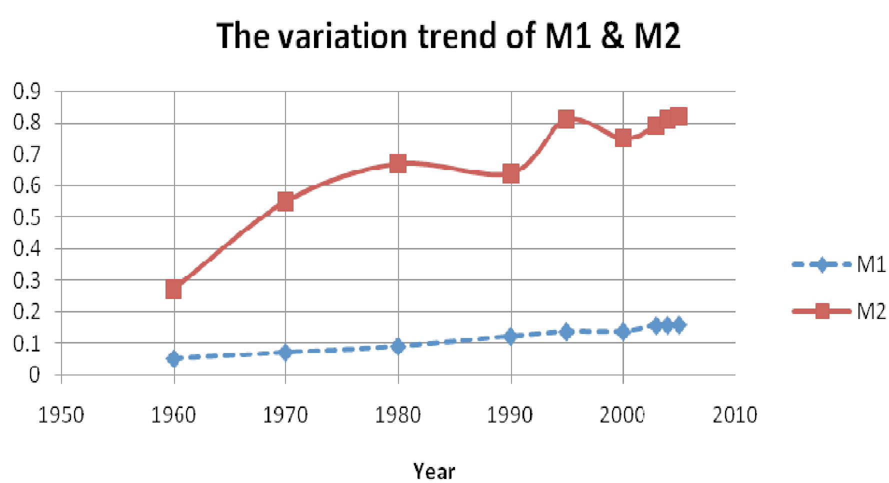

Figure 7. Trends in U.S. total expenditure on health as percentage of GDP (M_1, lower curve) and in the ratio of public to private expenditure on health (M_2, upper curve).

The Change in M_3: HALE

HALE is the most direct and obvious criterion to reveal the health level of the population. Because HALE is a new metric (only since 2000), we can't get enough historical data. Under the circumstances, we use a similar metric, life expectancy, to substitute for HALE. **Figure 8** shows the trend.

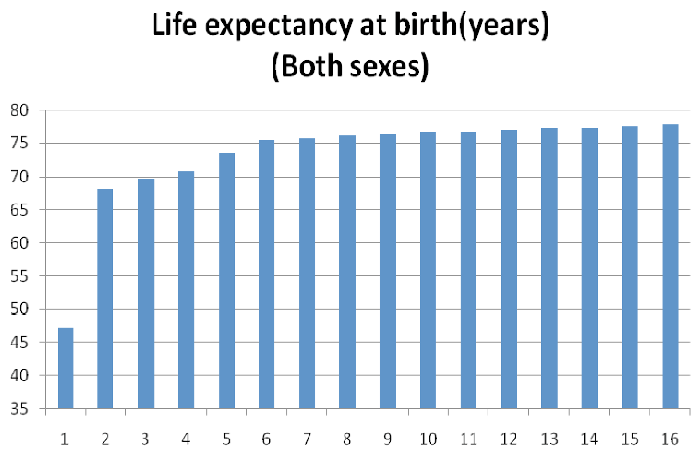

Figure 8. Trend in U.S. life expectancy.

The Change in M_4: Inequities

A good healthcare system aims at not only improvement of the health level but also reduction of health inequity. If the level is reduced or even eliminated, the system is considered to be improved. Recall, we measure inequity in terms of infant deaths per 1,000 live births. **Figure 9** shows improvement in the early 1990s and little change since.

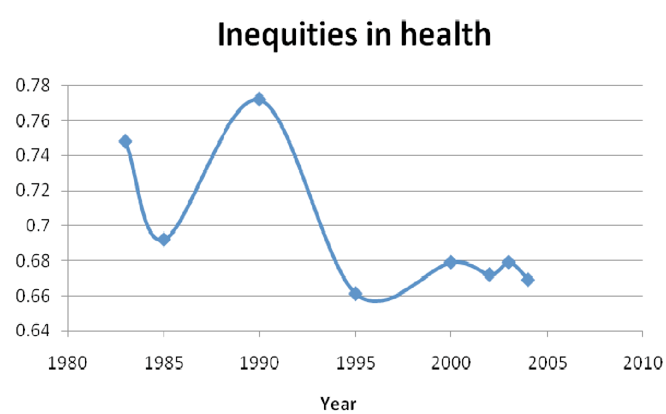

Figure 9. Trend in U.S. healthcare inequity (as measured by infant deaths per thousand live births for different groups).

Solution of Task IV

Brazil's automatic healthcare system is creating enormous value for people there, hence Brazil is considered to have good healthcare.

Calculation of Health Inequities

To measure health inequities in Brazil, we choose three metrics: infant mortality by place (rural and urban), by wealth, and by education level of the mother. In this way, we get three ratios, a_1, a_2, and a_3.

The most equitable situation is if a ratio equals 1; the extent of deviation from 1 shows the unfairness of the system. We use the natural logarithm of original data to normalize the extent of deviation. The bigger the absolute value is, the worse the fairness is:

$$V_{\text{adjusted}} = \frac{|\ln V_{\text{original}}|}{|\ln V_{\max}|}.$$

Adding V_{adjusted} with different weights, we can easily get the index of health inequities of Brazil.

The index of health inequities of India can be calculated in same way.

Comparison

The normalized data for the four metrics for the U.S., Brazil, and India are in **Table 8**.

Table 8.
Comparison of countries.

	% of GDP	Public/Private	HALE	Inequities	EV
U.S.	.92	.27	.82	.67	(.64,.67)
Brazil	.48	.33	.67	.68	(.59,.68)
India	.27	.06	.54	.66	(.24,.66)

The health-adjusted life expectancy in Brazil is shorter than in the U.S., but the U.S. puts more resources into its system in terms of percentage of GDP spent on healthcare. The inequity index in Brazil is a little higher than in the U.S, which means that the distribution of healthcare is more balanced in the U.S.

Using isolated metrics to compare, it's hard to say which system is better. Therefore, we compare using the evaluation vector.

- Compare by Model 1: $f\left(\text{EV}_{\text{U.S.}}, \text{EV}_{\text{Brazil}}\right) = -0.05 < 0$, so by our comparison principle, the system in Brazil is better.
- Compare by Model 2: $L_{\text{U.S.}} = .92$, $L_{\text{Brazil}} = .91$. Smaller is better, hence the system in Brazil is better.

Solution of Task V

Compared to other countries, India ranks very low in percentage of GDP spent on healthcare, while the U.S. ranks high; moreover, the Indian government stakes little of residents' expenditure on healthcare.

The lack of resources leads to low output. The health-adjusted life expectancy in India is shorter than in the U.S. However, we must take into account that India has much smaller medical resources. The ratio of resources to performance in India is much lower than in the U.S., in other words, India's system is better than the U.S.'s.

In terms of inequities, the two countries are almost at the same level.

Even with increasing resources, the effectiveness of a system won't improve without limit. When the amount of resources is lower than the critical point, the effectiveness of the system will increase sharply as of resources grow. But when the resources are above the critical point, as they increase, the effectiveness of the system grows much more slowly.

Figure 10 shows India at point A and the U.S. at point B. Therefore, India's system has broad prospects for development. To improve the effectiveness of system, India should put more resources into the system, such as increasing the percentage of GDP spent on healthcare, building more hospitals, and adding healthcare workers.

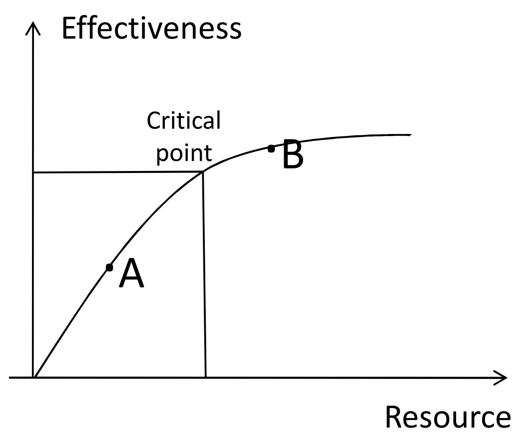

Figure 10. Relative status of the healthcare systems of the U.S. (A) and India (B).

For the U.S., more resources can't bring higher effectiveness. The way to improve the system is to make some change in policy. We discuss detailed measures next.

Solution of Task VI

We choose the U.S. healthcare system to do further study.

Introduction

For the U.S., both criteria R and I are at a high level. But high input doesn't return corresponding high output. "The reasons for the especially high cost of healthcare in the U.S. can be attributed to a number of factors, ranging from the rising costs of medical technology and prescription drugs to the high administrative costs resulting from the complex multiple payer system in the U.S." [Bureau of Labor Education 2001]. So we need to restructure the system based on our four metrics.

Restructuring the System

Modeling: With the four metrics, we can simplify the healthcare system as in **Figure 11**.

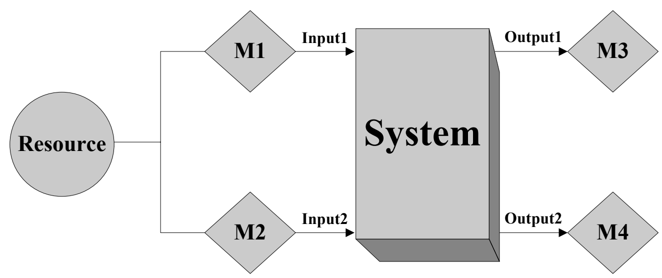

Figure 11. Simplified U.S. healthcare system.

Suppose the initial evaluation vector is

$$\mathrm{EV}_0 = \left(\frac{\mathrm{res}_0}{\mathrm{per}_0}, I_0 \right).$$

The quantity res_0 is determined by M_1 and M_2, while M_3 and M_4 reflect the levels of per_0 and I_0, respectively.

Since M_1 and M_2 are inputs of the system while M_3 and M_4 are outputs, we can describe the system with two functions:

$$M_3 = f(M_1, M_2), \qquad M_4 = g(M_1, M_2).$$

Simplifying the Model

Important considerations are:

- Life expectancy (M_3) is more sensitive to change in total expenditure on health (M_1) than inequities (M_4) is.
- Altering ratio of public expenditures to private (M_2) produces a more sudden response in inequities (M_4) than in life expectancy (M_3).

Thus, the model can be simplified to two single-variable functions:

$$M_3 = f(M_1), \qquad M_4 = g(M_2).$$

Constructing the Functions

M_3, Life Expectancy.
The U.S. spends 15.4% of GDP on health, which is the highest percentage in the world. The input and output of its health system have reached saturation. Despite putting more resources into the system, we get little more output, which doesn't match the high input.

For a health system, the growth rate is low when the input (expenditure) is too small or too large but high when the input is appropriate. So we choose the logistic model to describe the function for M_3:

$$M_3 = \frac{ab}{b + (a - b)\exp(-cM_1)}.$$

The value of the function is b when the independent variable is 0, which stands for the HALE when a country spends none of its GDP on health. We use the HALE of year 1900 for the U.S., so we take $b = 47.3$. The value of the function is a when the independent variable goes to infinity, which stands for the saturation of HALE. The highest expectancy life now is about 78, thus we take $a = 80$. We use data from 2004 and get $c = 0.201$. Therefore,

$$M_3 = \frac{80 \times 47.3}{47.3 + (80 - 47.3)\exp(-0.201 M_1)}.$$

M_4, Inequities.
In our opinion, M_4 will decrease as M_2 (ratio of public to private expenditure) increases. For the sake of convenience, we select an inversely proportional function:

$$M_4 = \frac{k}{M_2}.$$

We use data from 2004 and get $k = 0.548$. Therefore,

$$M_4 = \frac{0.548}{M_2}.$$

Putting Forward Measures

We consider several measures that alter one of the two inputs or both. Accordingly, the two outputs vary.

1. Altering the ratio of government expenditure on health to private expenditure. In the U.S. system, the main use of government expenditure on

health is to improve the health level of low-income people. Altering this can change the level of inequity.

2. Limiting the rise of total expenditure on health as percentage of GDP to make it constant at an acceptable level. Though there is a sharp increase of total expenditure on health as percentage of GDP, the health level doesn't improve much. That is to say, it has reached a saturation point.
3. Limiting the items and the extension of public insurance. In the existing system, public insurance covers a lot of items, some of which may be unnecessary.
4. Increasing the coverage of public insurance.
5. Limiting strictly the use of new medicine, medical equipment, facilities, and medical technology. Research on these has cost too much, and some outcomes are not so important in improving the overall health level.
6. Regulating the cost of medicine.
7. Reducing excessive medical treatment.
8. Promoting positive competition between different hospitals to reduce the patient's cost on medicine and medical treatment.

All these measures can be divided into three groups by their different effect on the inputs:

- Group A (affect only M_1): Measures 2, 3, 5, 6, 7, 8
- Group B (affect only M_2): Measure 1
- Group C (affect both M_1 and M_2): Measure 4

Testing Various Changes

Maybe some measures can improve the healthcare system while others have the opposite effect. Therefore, we have to quantify how each kind of measure affects the system.

In Task 4, we got the evaluation vector for the U.S. In this Task, we take M_1 and M_2 as the inputs of the system and M_3 and M_4 as the outputs. Because we are analyzing only one country without comparing it to another, we can't normalize the original data. If we calculate the vector as same as Task 4, it may lead to abnormal data. So it is necessary for us to modify the calculation method.

$$\mathrm{EV} = (R, I): \qquad R = \frac{M_1}{M_3}, \qquad I = \frac{1}{M_2}.$$

So the initial evaluation vector of the U.S. is:

$$\mathrm{EV}_0 = (R_0, I_0) = (.206, .67).$$

- Measures in Group A can affect only the total expenditure on health as percentage of GDP (M_1). Suppose that its initial value changes by 5%. Calculating M_3 gives:
  - If $+5\%$: $\text{EV}_1 = (.214, .67)$.
  - If -5%: $\text{EV}_1 = (.196, .67)$.

  Hence, decreasing the total expenditure on health as percentage of GDP reasonably can improve the healthcare system of the U.S.

- The measure in Group B affects only the ratio of public expenditure to private (M_2). Suppose that its initial value changes by 5%. Calculating M_4 gives:
  - If $+5\%$: $\text{EV}_1 = (.206, .638)$.
  - If -5%: $\text{EV}_1 = (.206, .705)$.

  Hence, increasing the ratio of public expenditure to private can improve the healthcare system of the U.S.

- The measure in Group C affects both M_1 and M_2. Suppose that the initial values change by 5%. Calculating M_3 and M_4 gives:
  - Case a: If $M_1 + 5\%$ and $M_2 + 5\%$: $\text{EV}_1 = (.214, .638)$.
  - Case b: If $M_1 + 5\%$ and $M_2 - 5\%$: $\text{EV}_1 = (.214, .705)$.
  - Case c: If $M_1 - 5\%$ and $M_2 + 5\%$: $\text{EV}_1 = (.196, .638)$.
  - Case d: If $M_1 - 5\%$ and $M_2 - 5\%$: $\text{EV}_1 = (.196, .705)$.

  Evidently Case c is the best and Case b is the worst.

  The measure in Group C is coverage of public medical insurance. Increasing it on the one hand increases total expenditure of GDP but on the other hand also increases the ratio of public expenditure to private. So such an increase is similar to Case a.

Strengths and Weaknesses

We have built a model that reveal how the system works based on the four metrics that we created in Task 3. Its parts combine well. Also, it is easy and convenient to test the measures with the model. But there are some weakness when simplifying the model. A single-independent-variable function is not the best to describe a healthcare system.

Suggestion: Major Change

From the results above, we find two major changes that can improve the system:

- Decrease total expenditure on health as percentage of GDP.
- Increase the ratio of government expenditure on health to private expenditure.

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