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The Disability-Adjusted Life Year (DALY) Definition, Measurement and Potential Use

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The Disability-Adjusted Life Year (DALY)
Definition, Measurement and Potential Use*

by
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Abstract

The 1993 World Development Report (WDR), "Investing in Health," used the Disability Adjusted Life Year (DALY) to measure the state of health of a population and, together with the concept of cost-effectiveness, to judge which interventions to improve health deserve the highest priority for action. The Disability Adjusted Life Year is the only quantitative indicator of burden of disease that reflects the total amount of healthy life lost, to all causes, whether from premature mortality or from some degree of disability during a period of time. This paper describes the methodology used in the WDR to calculate DALYs and how they can be used for setting health service priorities.

Contents

The principal suggestion of the 1993 World Development Report (WDR) "Investing in Health" (World Bank, 1993) is to define a package of essential health services, where everything not specified in the package is considered discretionary. The package should never include a less cost-effective intervention if a more cost-effective one is not financed. The line between the essential and discretionary interventions is drawn primarily on the basis of their cost-effectiveness. Exactly where the line is drawn can not be derived from the methodology, it must depend, among other things, on the country's epidemiological situation and on the willingness and ability to pay for health care.

To measure the state of health of a population and, together with the related concept of cost-effectiveness, to judge which interventions to improve health deserve the highest priority for public action, "Investing in Health" makes extensive use of the concept of the Disability-Adjusted Life Year (DALY). The DALY has emerged as a measure of the burden of disease and it reflects the total amount of healthy life lost, to all causes, whether from premature mortality or from some degree of disability during a period of time. These disabilities can be physical or mental. The intended use of the DALY is to assist (i) in setting health service priorities; (ii) in identifying disadvantaged groups and targeting of health interventions; and (iii) in providing a comparable measure of output for intervention, program and sector evaluation and planning.

The number of DALYs estimated at any moment reflect the amount of health care already being provided to the population, as well as the effects of all other actions which protect or damage health. Where treatment is possible—whether preventive, curative or palliative—the effectiveness of the intervention is the reduction in disease burden which the treatment produces. Effectiveness is measured in the same units (DALYs) as disease burden, and so can be compared across interventions which treat different problems and produce different outcomes. In other words, the DALY can be used to measure the gains in health attributable to different actions and add them up.

The proponents of the DALY use this measure for two purposes: (i) to measure the burden of disease, and (ii) to increase the allocative efficiency of the sector by identifying health interventions that, for a given budget, will purchase the largest improvement in health, as measured by the burden of disease indicator (DALY).

Values Incorporated in the DALY Indicator

The five key social preferences or values that are incorporated into the indicator of burden of disease "DALY" are the following:

- ***Duration of time lost due to a death at each age***, which is used to measure years of life lost due to premature mortality (or the number of years of life gained by averting death). This measurement requires defining the potential limit of life; in the case of DALYs, standard years of life lost are used. The standard has been chosen to match the highest national life expectancy observed, which is that of Japanese women (82 years). For a specific standard, the expectations are based on model life-table West Level 26, which has a life expectancy at birth for females of 82.5. The potential life expectancy at birth for males has been set at 80.[1]

- ***Disability weights*** or degrees of incapacity or suffering associated with different non-fatal conditions, which are necessary to make comparisons across diseases, as well as for comparing time lived with a disability with time lost due to premature mortality. Six disability classes measuring the extent of loss of physical functioning associated with a certain condition were defined. Subsequently, a group of independent experts established a weight, ranging from 0 (perfect health) to 1 (death), for each of the six disability classes.[2]

- ***Age-weights***, which indicate the relative importance of healthy life at different ages. The age weights used in the World Bank report rise from birth until age 25 and decline slowly

1 The average gender differences in life expectancy at birth in low mortality populations is 7.2 years. Not all of this difference is biological; a large share is due to injury deaths among young males and higher levels of risk factors such as smoking. In high income groups in low-mortality population this gap narrows. Projecting this forward, the ultimate gap in the life expectancy at birth between the sexes is likely to approach 2 or 3 years; that is, life expectancy for men would be around 80 years.

2 Note that the disability weights do not take account of the way in which individual and social resources compensate for the level of disability experienced.

thereafter. According to the World Health Organization (1994), the formula to calculate those weights is:

$$Age\text{-}Weighting\ Function = Cx\,e^{-\beta x}$$

Where:

C = Constant equal to 0.16243.
ß = Constant equal to 0.04.
x = Age.
e = Constant equal to 2.71

- ***Time preference,*** which is the value of health gains today compared to the value attached to health gains in the future (in standard economic theory, the latter is assumed to be lower than the former). It is standard practice in economic appraisal of projects to use the discount rate to discount benefits in the future. The process of discounting future benefits converts them into net present-value terms; these benefits can then be compared with project costs (also discounted if they are spread over more than one year) to determine cost-effectiveness.

The discount rate used in the DALY formula is 3 percent.[3] The formula to discount for time preference is:

$$Discounting\ Function = e^{-r(x-a)}$$

Where:

r = Discount rate, fixed at 0.03
x = Age.
e = Constant equal to 2.71
a = Onset year.

- ***Health is simply added across individuals.*** That is, two people each losing 10 years of disability-free life are treated as the same loss as one person losing 20 years. One could

3 Choices of age distinctions and discount rates express people's feelings about the value of time lived at different ages (age weights) and time periods, that is in the future versus today (discounting). These value weights are as subjective as treating all ages and all future years equally and have been criticised.

also weight duration non-linearly, so as to give priority to fewer people suffering for long intervals over more people suffering for shorter intervals.[4]

In summary, the disability-adjusted life year is an indicator of the time lived with a disability and the time lost due to premature mortality. The duration of time lost due to premature mortality is calculated using standard expected years of life lost with model life-tables. The reduction in physical capacity due to morbidity is measured using disability weights. The value of time lived at different ages has been calculated using an exponential function which reflects the dependence of the young and the elderly on the adults. Streams of time have been discounted at 3 percent. Accordingly the number of DALYs lost due to disability at age "x" can be calculated using the following formula:

$$DALYs(x) = (D)(Cxe^{-\beta x})(e^{-r(x-a)})$$

If the person lives up to the maximum of his life expectancy with disability, we need to add up the total number of DALYs lost from the onset of disability (a) to the age of death (a+L). The following formula can be used:

$$DALY = \_[\frac{Dx0.16243x2.71^{-(0.04xa)}}{(0.04+0.03)^2}]x[(2.71)^{(0.04+0.03)xL}x(1+(0.04+0.03)x(L+a))-(1+(0.03+0.04)xa]$$

Where:

L = Years of life left at age "a"
D = Disability weight (ranging from 1 death to 0 for perfect health).

Procedure to Calculate DALYs

The following examples illustrate how the formula to calculate DALYs is applied. This section is based on the examples presented in the manual "Selecting an Essential Packages of Health Services Using Cost-Effectiveness Analysis" (Data for Decision Making, 1993: pages 16 - 20). Taking into account that each health problem results in four possible outcomes (death, disability before death, permanent disability, or full recovery), we will calculate the number of DALYs lost for each one of these four scenarios.

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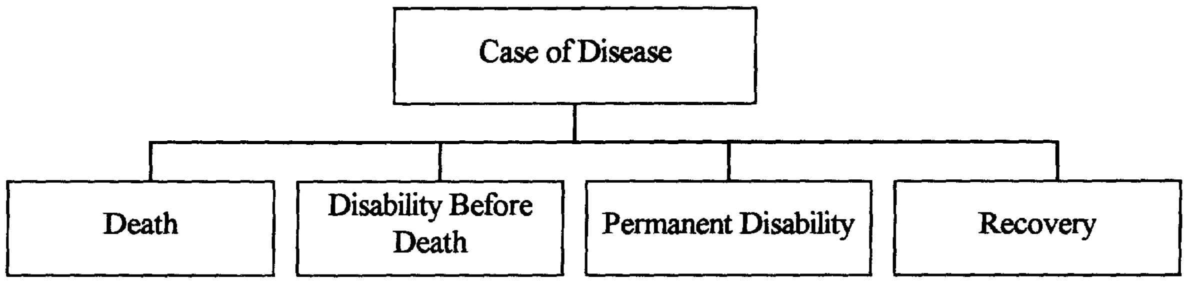
4 This judgement is reflected in the "Oregon plan" for reforming the state's Medicaid system.



We will represent each outcome in an hypothetical life horizon between the onset of disease and the resulting health outcome. The axis indicates the number of years an individual is expected to live.

The example corresponds to a female child who contracts poliomyelitis at age five. As a result she can die; she can live for a period of 5 years and then die; she can be permanently disabled; or she can recover after a period of disability. Lets assume that the horizon of life (total) is 82.95 years, when she got sick at 5 she still had 77.95 years of life left. We will assume that the disability weight in her case is 0.5.

Case 1: DALYs Lost Due to Immediate Death.

The horizon for this case is:

```
                              Death
|--------|-------------------------------------------------|
0        5                                               77.95
```

We have the following information:

C = 0.16243.
D = 1 (This is because the person dies, in case of disability it is 0.5).
r = 0.03 (Discount rate of 3 percent).
ß = 0.04 (Value fixed by experts, see World Health Organization, 1994).
a = 5 (Year of death).

L = 77.95 (Remaining years of life. It is equal to 82.95 years minus 5 years).
e = 2.71.

Replacing in the DALY formula the above values we have:

$$DALY = \_[\frac{1x0.16243x2.71^{-(0.04x5)}}{(0.04+0.03)^2}]x[(2.71)^{(0.04+0.03)x77.95}x(1+(0.04+0.03)x(77.95+5))-(1+(0.03+0.04)x5]$$

The number of DALYs lost to premature mortality is equal to 35.85.

Case 2: DALYs Lost Due to Death Following Disability.

The horizon for this case is:

```
              Disability                  Death
|--------|----------|------------------------------------------------|
0        5         10                                              72.95
```

In this case we have to calculate the number of DALYs lost due to disability and the number of DALYs lost due to premature mortality. To calculate the number of DALYs lost due to disability we have the following information:

C = 0.16243.
D = 0.5
r = 0.03 (Discount rate of 3 percent).
ß = 0.04
a = 5 (Year when the disability starts).
L = 5 (Years with the disability).
e = 2.71.

$$DALY = \_[\frac{0.5x0.16243x2.71^{-(0.04x5)}}{(0.04+0.03)^2}]x[(2.71)^{(0.04+0.03)x5}x(1+(0.04+0.03)x(5+5))-(1+(0.03+0.04)x5]$$

Then the number DALYs lost due to disability is 2.0.

To account for the number of DALYs lost due to premature death (72.95 yrs.), we have the following information:

C = 0.16243.
D = 1.

r = 0.03
ß = 0.04
a = 10 (Year when the person dies).
L = 72.95 (Potential years of life left at time of death).
e = 2.71.

$$DALY = \_[\frac{1x0.16243x2.71^{(0.04x10)}}{(0.04+0.03)^2}]x[(2.71)^{(0.04+0.03)x72.95}x(1+(0.04+0.03)x(72.95+10))-(1+(0.03+0.04)x10]$$

The number of DALYs lost due to premature death are 36.85 years. Here there is an important point to take into account. Those 36.85 years are the DALYs calculated at the age of 10; to add them up with the DALYs lost due to disability calculated at age of onset (5 years), we have to convert the 36.85 DALYs calculated at age 10 to their value at the age of onset of the disease, that is at age 5. This can be done using the following formula:

$$DALY\ at\ \ age\ of x\ =\ DALY(10)\ \ e^{-rs}$$

The variables in the formula have been defined previously, except for "s" which is the number of years we have to discount (age of 10 minus age of 5). Applying the formula we have:

$$DALY\ at\ the\ age\ of\ 5 =\ 36.85\ x(2.71)^{(-0.03x(10-5))}\ =\ 31.7$$

That is, at the time of the onset of the disease (5), the number of DALYs lost due to premature mortality at age 10 equals the number of DALYs lost at age 10 (36.85) times 0.86, which is 31.7 years.

In summary, the total number of DALYs lost due to a period of disability followed by death equals the number of DALYs lost to disability (ii) plus the number of DALYs lost to premature death (31.7), that is 33.7 DALYs.

Case 3: DALYs Lost Due to Permanent Disability.

The horizon for this case is:

```
                         Disability
|---------|----------------------------------------------|
0         5                                            77.95
```

We have the following information:

C = 0.16243.
D = 0.5
r = 0.03 (Discount rate of 3 percent).
ß = 0.04
a = 5 (Year of onset).
L = 77.95 (Remaining years of life. It is equal to 82.95 years minus 5 years).
e = 2.71.

Replacing in the formula the above values we have:

$$DALY = \_[\frac{0.5x0.16243x2.71^{(0.04x5)}}{(0.04+0.03)^2}]x[(2.71)^{(0.04+0.03)x77.95}x(1+(0.04+0.03)x(77.95+5))-(1+(0.03+0.04)x5]$$

The total number of DALYs lost due to permanent disability equals to 17.92.

Case 4: DALYs Lost Due to Disability Followed by Complete Recovery.

The horizon for this case is:

```
          Disability           Healthy
|---------|--------|------------------------------------------|
0         5       10                                        77.95
```

We have the following data:

C = 0.16243.
D = 0.5
r = 0.03

ß = 0.04
a = 5.
L = 5 (number of years with disability).
e = 2.71.

Replacing the above values in the DALY formula we have:

$$DALY = [\frac{0.5x0.16243x2.71^{-(0.04x5)}}{(0.04+0.03)^2}]x[(2.71)^{(0.04+0.03)x5}x(1+(0.04+0.03)x(5+5)) - (1+(0.03+0.04)x5]$$

The number of DALYs lost to disability equal to 2.0 years.

To calculate the total number of DALYs lost due to poliomyelitis in a community we have to add the number of DALYs lost by each individual. Lets imagine that in a particular community there is a total of 20 female children who contract poliomyelitis, all of them at age 5, and that 4 of them die immediately, 4 die at age 10 after a 5-year period of disability, 4 of them are permanently disabled, and 4 recover completely after a disability period of 5 years. In this case the total number of DALYs lost in that community due to poliomyelitis equals to:

$$Total\ DALYs\ lost = 5x(35.85) + 5x(33.7) + 5x17.92 + 5x2 = 447.4$$

Data Needed to Estimate the Burden of Disease

- ***Cause of death patterns by age and gender*** are needed to calculate the years of life lost to premature death. Worldwide, only about 30-35 percent of all deaths are captured by vital registration. For the remainder, cause of death structure as a function of the level of mortality can provide broad cause-of-death groups. Such methods are generally unreliable for more specific causes.

- To measure the time lived with a disability in a manner that can be meaningfully compared with the time lost due to premature mortality, there is a need for the following data: **(i)** ***age and gender specific information on the incidence of disease, (ii) the proportion of disease incidence leading to a disabling outcome, (iii) the average age of disability***

onset, the duration of disability, and (iv) the distribution of disability across the six classes of disability severity. In most cases this data is unavailable and researchers are forced to rely on estimates, many of which are uncertain. There are two important sources of error: (i) some disabilities might have been omitted, which would give a downward bias to our estimates of the years lived with disability, and (ii) the computations do not take into account comorbidity (an individual experiencing multiple illnesses) and biases the results upwards. The fact that individuals can have more than one disability of the same or different classes at the same time can not be ignored. Presumably, several class 1 disabilities may combine to raise someone's total disability severity to a higher class. However, the effect of three distinct class 1 disability will not be to triple the disability severity weight for the individual.[5] In addition, the magnitude of the overestimation due to comorbidity will be greater if the probabilities of getting different disabilities are dependent on each other (for example, a diabetic has an increased risk of blindness, angina pectoris, amputation, neuropathy and renal failure).

Cost-Effectiveness

Because cost-effectiveness analysis is based on gains associated with health interventions, the next step is to identify appropriate health services and to estimate their effectiveness in reducing disease burden. Cost-effectiveness shifts the focus decisively from individuals, or groups, to interventions. For each disease category, a range of possible interventions needs to be identified. The WDR reported on 26 major health problems and 57 interventions. To select a set of interventions to be evaluated using cost-effectiveness analysis, the following factors need to be considered: (i) standard of best practice; (ii) health care infrastructure and organization; (iii) focus on prevention or treatment; (iv) potential for clustering interventions, some health interventions give rise to multiple health benefits; (v) feasibility and acceptability of interventions; (vi) potential cost of interventions and alternative strategies; and (vii) the effectiveness of the strategy in reducing the disease burden.

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5 Anand and Janson (1995)argue that because of the disease, and not the individual, specific estimation of the disease burden, an individual can turn out to have a cumulative disability weight greater than 1. This would represent a level of functioning even more limited than that associated with death.

Where treatment is possible—whether preventive, curative or palliative—the effectiveness of the intervention is the reduction in disease burden which the treatment produces. An intervention can reduce the burden through any of the following mechanisms: (i) changing the disease incidence, (ii) the probability of developing disabling sequelae; (iii) the duration of the disability, and (iv) the severity of the disability (including death). The first three treatment effects are already included in the formula. Changes in the severity of disability or the distribution of disabilities across the six classes owing to treatment has not so far been captured.

The DALY indicator allows one to measure the effectiveness of different interventions at reducing the disease burden due to a particular condition, as well as permits one to compare the effectiveness across interventions which treat different problems and produce different outcomes. These comparisons show that interventions differ enormously in how much they cost and how much they can improve health. Individual interventions can differ in cost from less than one dollar to more than $10,000. There is little correlation between what an intervention costs and how much additional health it provides. An intervention which saves one person's life and prevents infection of others can gain between ten and 100 years of healthy life, whereas the improvement from some other interventions may amount to only a few hours or days of complete health. The ratio of cost to health gain is the cost-effectiveness of the intervention, expressed as dollars per DALY.

This criterion does not coincide with any of several criteria which are sometimes applied to determine priorities, such as: (i) the incidence or number of people affected; (ii) the individual suffering, or disease burden per person affected; (iii) the amount of total good that an intervention can do, or the reduction in burden possible; (iv) the cost per case of the intervention; or (v) the total cost of helping everyone affected by the problem. It might be the case that only part of the disease burden can be eliminated by the intervention in question, either because only some of the victims are appropriate candidates for the intervention, or because the intervention is only partly effective. The cost-effectiveness of the intervention should be calculated on the basis of the actual health gain (not the total burden, which includes the uncorrectable part) and the actual costs.

Once cost-effectiveness ratios are calculated for each intervention, they can be ranked from the most to the least cost-effective (largest ratios).[6] One additional step is to cluster cost-effective interventions into a package of services. The principal argument for clustering interventions is that it improves cost-effectiveness through at least three mechanisms: (i) synergism between treatment and prevention activities; (ii) joint production costs; and (iii) improved use of specialized resources.

The overall efficiency of a health system, the degree to which it produces value for money, depends greatly on which interventions it delivers. However, it is important to take into account that the inefficiencies in the health sector of most developing countries are not limited to the misallocation of resources (allocative inefficiencies). The combination of inputs used in the delivery of service (technical efficiency) is also very important. Finally, other aspects of sector management such as inappropriate management of human and physical resources, personnel attitudes, absence of quality assurance programs, absence of accreditation systems, inappropriate information systems, etc., have a tremendous impact on sector efficiency.

Data Needed to Estimate Cost-Effectiveness

The cost of an intervention is a function of: (i) the quantity, type, and quality of inputs used;[7] and (ii) the price of those inputs.[8] Because personnel and equipment are frequently shared among health services within the same facility, it is necessary to derive rules-of-thumb for allocating a portion of input cost to specific health interventions. Unfortunately, there is no universally used framework to evaluate the costs of health services.

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6 The decision rule which needs to be employed for selecting the essential package of services is based on the marginal cost per DALY gained.

7 The type and amount of inputs needed for an intervention can be gathered from a survey in a sample of facilities which provide a model for best possible practice of the intervention in a region. Another alternative is to use information from neighbouring countries. Using expert opinions tends to be very imprecise. Since the quality of inputs may be related to prices, it is important to ensure that a constant level of quality is compared across interventions.

8 The price of the inputs has to be based on market prices. Market prices can be based on the original purchase price (historical value) or the replacement price based on market surveys. The latter alternative is preferred.

As mentioned earlier, in order to calculate the number of DALYs gained from health interventions, the impact of each intervention in reducing disease burden must be estimated. The effectiveness of a health intervention depends on: (i) efficacy of the technology used; (ii) diagnostic accuracy; (iii) compliance of health care providers; and, (iv) compliance of patients. Since few empirical studies have evaluated the effectiveness of interventions in various settings, this aspect of the cost-effectiveness exercise is very subjective, most effectiveness estimates are based on opinions and judgments of health professionals.

Conclusion

Estimating the costs and impact, in terms of reducing the burden of disease, of health interventions has a tremendous potential for amplifying and diversifying the health policy debate, and can advance thinking on how to maximize the use of available health resources.

Burden of disease and cost-effectiveness can assist governments in deciding (i) which interventions to finance, priority to cheap DALYs; (ii) how much to subsidize different interventions (full versus partial subsidy); and (iii) whom to buy the interventions for (never finance interventions for the non-poor if they are not being financed for the poor). Another major role for government is to assist private purchasers (whether individuals, medical professionals or insurers) in improving allocative decisions, even where no public funds are involved.

However, it is important to recognize that the methods currently available to conduct cost-effectiveness studies are far from perfect, they require large amounts of resources, and incorporate value choices that have political, economical and ethical implications. Another aspect worth mentioning is that while cost-effectiveness is a criterion for allocating resources, it is not a complete system for enforcing allocative efficiency. Both health professionals and consumers should remain free to spend their own resources to purchase non cost-effective interventions.

The problems that researchers have identified with the WRD methodology, some of which are being addressed, include:

- The need to expand and improve the list of diseases included in the burden of disease exercises.
- The need to improve and validate the method to measure the time lived with disabilities of different severity's.
- The lack of methods to adjust for both dependent and independent comorbidity.
- The inability to quantify the contribution of risk factors in total burden of disease.
- The lack of unit cost production functions to be used widely by researchers doing cost-effectiveness studies.
- The need for more accurate monitoring systems to be able to generate real estimates of mortality and disability by cause.
- The need of projection methods that incorporate known levels and trends of major risk factors such as smoking and trends in other diseases.

The criticisms that have been made to the methodology include the following:

- Requires a lot of data that is not readily available;
- It is an expensive exercise;
- Decisions are made by a group of experts with little involvement of health care providers, interest groups or beneficiaries;
- The methodology is very complicated and does not add much information to what public health specialists already know;
- It discriminates against the elderly;
- The manner in which the information is manipulated is subjective;
- It is difficult to create demand for services that are cost-effective;
- The value choices that underlie the definition of the DALY are not universally accepted;

- Political resistance to reallocation of resources is greater when the package is explicit and published;
- The DALY does not reflect individuals' differential abilities to cope with their functional limitations;
- The maximization of the number of DALYS gained might not be the goal of the health sector;
- Health interventions alone are not capable of raising the life expectancy of developing countries to the level used in the DALY calculations; and
- Cost-effectiveness might not be the criteria to guide the type of services provided.

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