In the one-level population model the number of deaths per year D is expressed as the total number of persons in the population POP divided by the average life expectancy LE. Life expectancy in this simple nondemographic model is equivalent to the time constant of the exponential decline in population that would occur if there were no births. The lower the life expectancy, the larger the fraction of the population dying each year. If the average life expectancy is 50 years, one-fiftieth of the model's population dies each year. Thus in the one-level model the variable LE is simply a rough measure of the general health of the population.* In the age-disaggregated versions of the model, LE takes on its proper demographic meaning as a summary variable calculated from the total age-specific death rate table.

```
CDR.K=1000*D.JK/POP.K                                    18, S
    CDR     - CRUDE DEATH RATE (DEATHS/1000 PERSON-YEARS)
    D       - DEATHS PER YEAR (PERSONS/YEAR)
    POP     - POPULATION (PERSONS)
```

The crude death rate CDR is computed for graphic display, since it is the measure of mortality most often cited in compilations of world population data and the one from which the net population growth rate can be most readily calculated. It does not feed back to any other variable in the model. As we have already mentioned, the crude death rate is determined both by the probability of mortality at each age and by the population's age structure. In the simple one-level model, the age-structure contribution is not taken into account, and the mortality probability is expressed by a single number 1/LE. Since the world population in this century has contained a relatively large proportion of young people with low mortality risk, actual historical crude death rates tend to be somewhat lower than those generated by the one-level population model.

The world average crude death rate in 1970 was about 13 deaths per 1,000 people, or 1.3 percent. In the same year, reported crude death rates for individual nations varied from 29–30 in Angola and Upper Volta to 5–6 in Israel, Taiwan, Hong Kong, and Singapore (USAID 1971, pp. 210–214). The very low rates in the latter countries are due in large part to their young age structures. There is also a strong possibility of bias toward low values in national and global death rate statistics for two reasons: areas that do not record vital statistics tend to be those with the highest death rates, and in some areas that do gather vital statistics infant deaths are imperfectly registered.

Life Expectancy LE   Many different factors interact in the world to influence a population's average level of health, or life expectancy. The relative contributions of these factors have never been quantitatively assessed, in part because their interactions are extremely complex, as the U.N. Population Division has stated:

> It is by no means easy to assess the roles played by the various factors which have been at work in the reduction of mortality. It is not possible on the basis of existing data to measure separately the effects of such diverse causes as the improvements in nutrition, housing, environmental sanitation, personal hygiene, and medical knowledge and services or the increasing health consciousness of people and their desire for a longer life. . . . Indeed, there is reason to believe that the analytical tools available at present for studying this problem are as yet deficient; the application of different methods to the same data results in different estimates of the relative importance of the factors. The problem is further complicated by the absence of reliable data. [U.N. 1953, p. 60]

*The equation (deaths per year = population/life expectancy) is only demographically correct for a theoretical stationary population (Keyfitz 1971b, pp. 658–659).

When one variable of interest (life expectancy) seems to depend on a number of other variables (nutrition, housing, income, sanitation, education, medical services), statistical inference techniques are usually employed to sort out the relative importance of each contributing factor. Few statistical analyses have been carried out on the determinants of human life expectancy (for an example, see Kusukawa 1967), and, as the preceding quotation indicates, the results that have been obtained are generally contradictory and unsatisfactory. We believe the basic reasons are (1) that, as the United Nations suggests, the data base is not yet sufficient for rigorous quantitative analysis, and (2) that the causal relationships behind the data may not meet the basic requirements for statistical analysis. They may be highly nonlinear and mutually interdependent (that is, involved in feedback loops, so that no variable can be considered exogenous to the system or clearly independent of any other variable).

As an illustration of these statements, let us consider the three factors most commonly cited as important determinants of mortality: income or general standard of living, health care, and nutrition. A good case can be made both logically and empirically that the life expectancy of a population will increase as any of these three factors improves.

A preliminary analysis would suggest that income is highly correlated with and probably drives the other two—health care and nutrition. Income per se probably cannot raise life expectancy unless it can be spent on food, doctors, medicine, and housing. Thus rising income may affect life expectancy only through the ability of an industrializing society to provide better food, develop medical and sanitation technologies, and offer more health care facilities. The empirical relationship between income and food per capita is shown in Chapter 4; that between income and health service expenditures is shown in Figure 2-30.* Both relationships are quite regular and show little variation among the nations for which data are available. The mechanisms by which food and services are generated by a growing economy are contained in the agriculture and capital sectors of World3.

The empirical relationships between food per capita, health services, and life expectancy are shown in Figures 2-23 and 2-24 in the form of cross-sectional data from more than seventy nations for the period 1966–1968.* We shall discuss each of these relationships in detail later. It is important here to note just two simple points. First, the curves are nonlinear. As one would expect, when food or health care is

*See Appendix D to this chapter for original data.